OPTIMIZATION OF SOLAR THERMAL COMBI-SYSTEMS FOR DOMESTIC HOT WATER AND SPACE HEATING

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1. Introduction

The aim of this paper is to give an overview on solar thermal combi-systems, which are typically used in Germany, based on a benchmark test of these systems carried out in 2010. In the second part the potential and need to optimize these systems to further increase their acceptance in the market are described.

Solar thermal systems for domestic hot water heating and space heating support, so called combi-systems, are very common in Germany, Austria, and other central European countries. In Germany, about 50% of the newly installed solar thermal systems are combi-systems, which typically cover 20% to 30% of the domestic hot water and heating demand of a well-insulated one-family home. However, though their large market share, for customers as well as for installers it is almost impossible to compare the performance and quality of the different types of combi-systems offered on the market. A minimum quality of the components is usually given by the guarantee that must be legally offered by the producers. In addition, solar thermal collectors must have a Solar Keymark to receive a subsidy in Germany, with this their quality and performance is certified according the EN 12975 standard. But information about the performance and the expected solar gains of the delivered system as a whole is usually not provided. It could be measured according to the component based system test method described in EN 12977. Since the manufacturers offer a large number of system combinations they are afraid about the high costs for testing each variation and only a few systems are tested yet.

In 2010, the German consumer magazine ÖKO-TEST asked Fraunhofer ISE to conduct a benchmark test of 17 combi-systems in order to support their readers with making choices. For the benchmark test, a new methodology was developed. The results were published in October 2010 (Ökotest, 2010). In March 2011, another market overview of 60 combi-systems was published by the solar magazine Sonne, Wind & Wärme (2011). Both publications showed the huge variety of systems available. The systems mainly differ regarding to the type of components used - in particular the water storage tank, the system concept applied - especially the way of integrating the space heating system, and their control concept.

The diversity and the spread in the types of the systems as well as the results of the benchmark test indicate clearly, that there is great room for optimization of the solar thermal combi-systems regarding the performance and the costs.

2. Current combi-system technology

Combi-systems offered in Germany with the aim to cover 20% to 30% of the overall heat demand with solar thermal energy in a well-insulated one-family home have typically an aperture collector area between 9 and 15 m^2 in the case that flat plate collectors or between 7 and 10 m^2 in the case that evacuated tube collectors are used. The combined hot water storage tank for domestic hot water and buffer tank for space heating, the so called combi-tank, has usually a volume between 500 and 1000 litre. In Austria the combi-systems are typically bigger, sometimes up to 30 m^2 collector area, however in this paper we are focusing on the German market.

The solar thermal combi-systems can be principally distinguished according to the way they are integrated into the space heating system of the building. In figure 1 the two most common principles are shown. On the left the hot water storage tank is used as buffer for all central provided heat used in the building. The combi-tank is heated up by the solar collectors or the auxiliary heater, e.g. a gas boiler, and the domestic hot water and the space heating circuits take the heat out of the storage tank when needed.

The system on the right uses the return-flow riser principle in the space heating circuit. The water of the space heating circuit only flows through the storage tank if there is sufficient solar thermal energy available, this is the case when the available storage temperature in the relevant region of the storage tank is higher than that of the return-flow of the space heating circuit. If the available temperature in the storage tank is below the temperature of the space heating return, the space heating return flows directly to the auxiliary heater where it is reheated for use in the space heating circuit, by passing the storage tank. If the temperature of the solar heated return-flow after flowing through the storage tank is below the desired temperature the auxiliary heater will close the remaining gap.

By using the return-flow riser principle only the part of thermal energy for the space heating which is provided by the solar collectors is stored and flowing through the storage tank. This is reducing the standing heat losses by the tank and could increase the efficiency of the solar collectors due to possibly lower temperatures in the storage tank. However, the auxiliary boiler must be able to regulate its power to top up the preheated water temperature of the space heating circuit and do this efficiently.

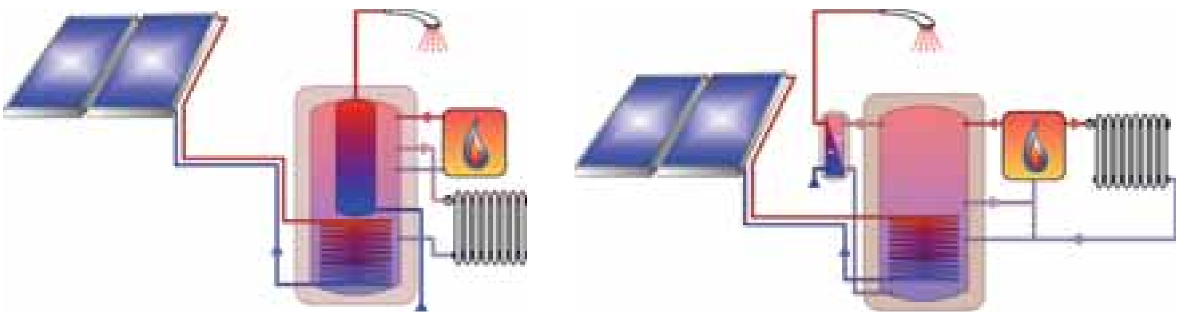

Fig. 1: Two ways to integrate a solar thermal combi-system into the space heating system: Using the hot water storage tank as buffer storage (left) and heating circuit return flow raising (right)

In figure 1 two principles for heating up the domestic hot water are shown as well. On the left side the “tank-in-tank” concept is used, where a smaller inner tank with domestic hot water is mounted within the buffer storage tank. The buffer storage tank is heated by the solar collector or by the auxiliary heater. The domestic hot water in the inner tank is heated by conduction through the stainless steel inner tank wall. This is similar to when a long winding, corrugated tube is used instead of the inner tank (see also figure 2).

On the right hand side the domestic hot water is prepared in a so called “fresh-water station”. This is a heat exchanger outside the tank, which heats up the domestic hot water at the time of usage using the hot water from the buffer store. The domestic hot water heating principles can be freely combined with the principles of connection the heating circuit.

The collector field of combi-systems is usually composed of a number of solar thermal flat plate collectors with a typical size of about 2 m^2 per collector. Some manufacturers are producing large collectors with a size of 5 to 12 m^2, however, these collectors are usually used for much larger systems. Sometimes evacuated tube collectors are used, but their share is only about 15% on the German solar market.

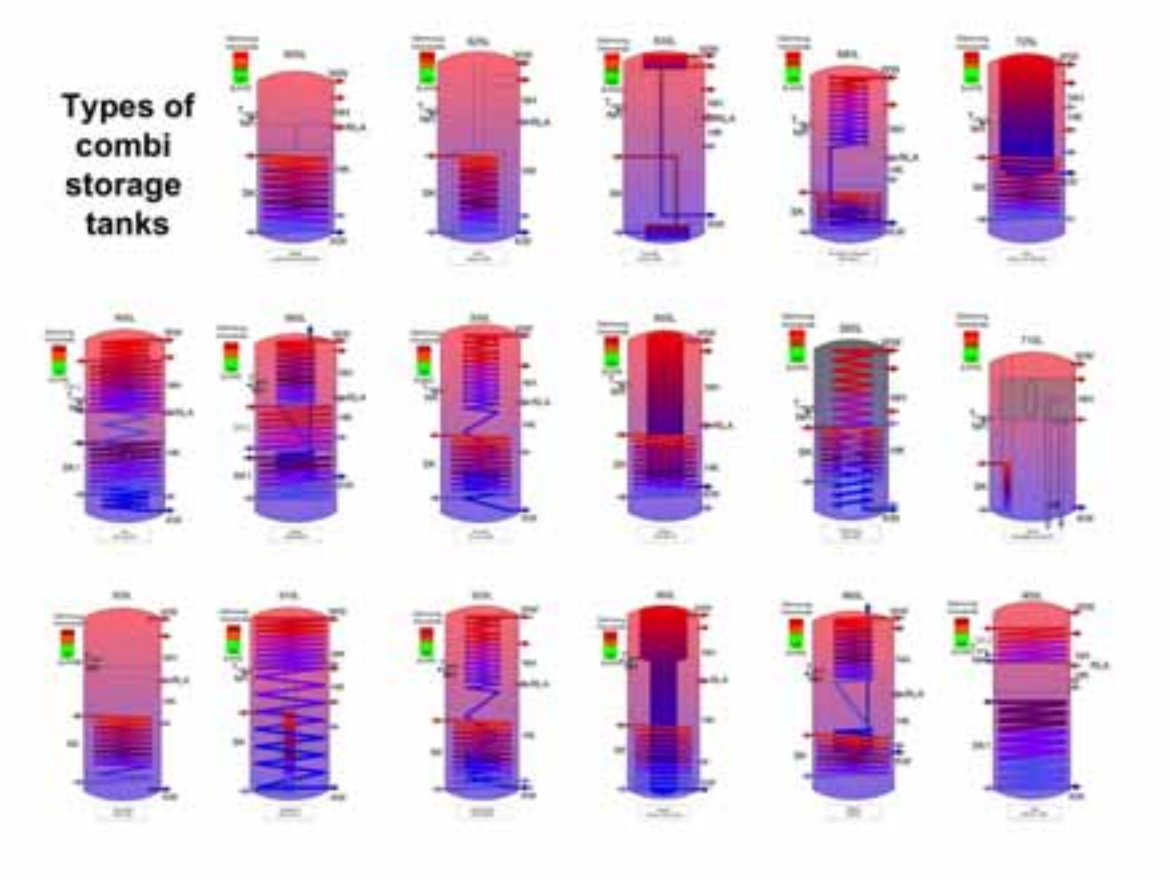

Fig. 2: Drawings of the 17 combi storage tanks covered by the benchmark test, every storage has a different design

The key component of a combi-system is the combi-tank. All manufacturers are offering own types of combi-tanks with their own design. Figure 2 shows the 17 combi-tanks, which were offered by the manufacturers for the Ökotest benchmark test. Five of them are heating the domestic hot water with an external fresh-water station, three are using a tank-in-tank-concept and nine are using an internal corrugated tube. Seven of the combi-tanks are using specific constructive measures inside the tank to improve the temperature stratification for the solar and/or the space heating loop.

3. Benchmark test and market overview

3.1 Methodology of the benchmark test

In the past, for benchmark tests carried out by the consumer tests organization Stiftung Warentest, all systems were physically tested with the component oriented test method according EN 12977 (Stiftung Warentest, 2009). However, this benchmark test is very expensive and needs almost 2 years from planning to publication. The new benchmark test had to break with this timeframe and with the high costs. The options were either to create a simplified benchmark test or to waive the benchmark test based on a physical test according EN 12977. Since the authors believe, that the availability of benchmarks is necessary to further develop the market, a new concept for a benchmark test was developed.

The principle of the new benchmark test was to compare combi-systems, which are specified by the suppliers based on a desired solar fraction under given framework conditions. The test was executed without additional physical testing of the combi-system, by simulating the system performance based on the data provided by the suppliers, which are either certified e.g. the collector data by the Solar Keymark, or are easily verifiable from documentation. In addition, the assessment is strongly oriented towards relevant criteria for the consumer.

The solar thermal manufacturers and suppliers were asked to propose combi-systems which cover at least 20% of the heating demand in a one family home in the city of Passau and in the city of Essen. Table 1 describes the boundary conditions for the test. A diverse group of 17 manufacturers and system houses, together covering more than 50% of the solar thermal market, participated in the test. Therefore, the results are considered representative for the market.

Tab. 1: Boundary conditions for the TNRSYS simulation of the combi-systems

Required solar fraction and main simulation conditions	Solar fraction of at least 20% of the overall heating demand with a domestic hot water demand of 175 litres per day with 45°C and a space heating demand of a one family home with 140 m^2 living area with a specific space heating demand of 51.9 kWh m^{-2} a^{-1} in Essen and of 62.7 kWh m^{-2} a^{-1} in Passau. The solar collectors are mounted oriented south with a tilt angle of 45°, with no shadow on the collectors.
System requirements	The combi-system must be offered as a unit on the market, which must contain at least the solar collectors, the combi-tank, the solar station and the controller. The solar collectors must have a Solar Keymark.
Documents	The suppliers must deliver: Description and data sheets of the system and the components, the Solar Keymark certificate of the collector, a drawing with dimensions of the combi-tank and the documentation for the installer and the customers.

The overall performance of each system was simulated with the program TRNSYS for both cities, Passau and Essen. The TRNSYS simulation of the storage tank was based on the parameter set of a real tested combi-tank and was adapted by using the available real data of the combi-tanks: volume and height, the positions of the inlets and outlets, the type of heat exchangers and their positions, and possible stratification supports specified by the supplier. In addition the U-value of the insulation of the storage tank was calculated and used in the simulation. The orientation of the collectors, the length and insulation of the collector circuit pipes, the control strategy and the auxiliary heater were defined equal for each system.

To do a fair assessment of solar thermal systems, which differ on many aspects is not simple. The solar yield of the collector alone is not a practical criterion, since the larger the collector area is, the higher the total solar yield. Therefore the solar fraction was used, which is a measure of the conventional energy avoided, and depends stronger on the storage tank features. The solar fraction is defined as:

$f_{save} = 1 - \frac{Q_{aux}}{Q_{ref}}$ (eq. 1)

with the thermal energy provided by the auxiliary heater (Q_{aux}) and the thermal energy that would have been needed by a reference system without the use of solar energy (Q_{ref}).

However, also the solar fraction is not a reasonable criterion alone since systems with the biggest collector areas would be automatically assessed good. On the other side, if the solar fraction per collector area is used, the system with the highest collector efficiency would be advantaged and this would be not right either.

Therefore, it is important to realize what the relevant criteria for the customer are. Three main criteria were identified for the benchmark test: the solar combi-system should replace a relative high share of fossil fuels, it should have a good performance to cost ratio and the installation should be of good quality.

As a result, following three criteria were used equally to assess the combi-systems in the benchmark test:

1. The solar fraction, because the customers want to replace as much as possible fossil energy.
2. The economics represented by the ratio of the money saved over the lifetime of 20 years due to the energy savings and the investment costs.
3. The quality of the operating instructions for the installers as well as for the customers, as an indicator of the quality of the installed systems.

3.2 The combi-systems tested and the results of the benchmark test

As already described, the 17 combi-systems varied a lot regarding design and concept used. But also the size of the selected collector area, the storage tank volume, as well as the system price varied a lot. This was astonishing, since the same goal - to deliver a solar fraction of at least 20%, was given. Obviously, the companies pursue different strategies in their combi-systems offerings in general. It may also be presumed that the companies, which were offering rather big systems expected to compensate higher costs with a good performance-cost relation, or they were not sure how they could achieve the required solar fraction under the boundary conditions provided.

Tab. 2: Ranges of data of the 17 combi-systems participating in the benchmark test

System data	
Collectors	3 evacuated tube collectors with 7.4 – 9.6 m^2 and 14 flat plate collectors with 9.1 – 14.2 m^2 aperture area Collector parameters of the flat plate collectors: η_0: 74,7% - 84,8%, a_1: 3,09 – 4,34 W m^{-2} K, a_2: 0.004 – 0.026 W m^{-2} K^{-2}
Combi-tanks	Total volume: 600 – 1000 litre Standby volume for domestic hot water: 200 – 323 litre Thickness of the storage insulation: 75 – 125 mm UA-value of the insulation: 7.2 – 14.3 kJ h^{-1} K^{-1}
System price	7500 – 14100 € incl .installation

The ranges in the most important parameters of the combi-systems tested are presented in Tab. 2 while Tab. 3 shows a summary of the main results.

In general, the results of the benchmark test according the assessment criteria defined were very positive with two “Very Good” and 15 “Good”. The results in each of the three criteria varied between “Very Good” and “Satisfying”.

Tab. 3: Ranges of data of the 17 combi-systems participating in the benchmark test

Test results	
Solar fraction	22% - 30% for Essen and for Passau Assessment: 5 x “Very Good”, 11 x “Good”, 1 x “Satisfying”
Economics	Energy cost savings over 20 years in relation to investment costs: 124% - 202% Assessment: 1 x “Very good”, 12 x “Good”, 4 x “Satisfying”
Documentation	Assessment: 1 x “Very good”, 14 x “Good”, 2 x “Satisfying”
Overall	Assessment: 2 x “Very Good”, 15 x “Good”

3.2 Critical consideration of the test methodology

The authors are aware that the methodology of the benchmark test regarding the system performance simulation is a compromise between the cost and time to carry out the test and the accuracy of the results. It is well known, that e.g. the type of storage tank insulation and the way, how it is mounted, internal construction features and the heat losses at its connections can influence the performance of the storage tank significantly. However, the influences of these effects cannot be known without physically testing the storage tank according EN 12977.

With the method chosen, the performance of the “idealize” storage tank is considered, taken into account its design and insulation and not the possible parasitic effects describe. This “idealized” performance is representing its general ability to contribute to a good performance of the system. In reality, the storage could perform worse if e.g. the stratification is destroyed by the construction of the connection pipes, but it could not perform better. Therefore the ranking of the test is regarded as reasonable. To consider the design and insulation of the storage in the simulation is a significant improvement in comparison to only considering the parameters of the collector.

The authors consider the benchmark test results reasonable and the ranking as fair. However, it is recommended to further investigate the accuracy of this simplification in order to develop the methodology further and identify the best compromise of testing effort and accuracy of the results.

4. Optimization of the combi-systems

The German solar thermal market dropped in 2009 and 2010 by about 25% each year and is stagnating in 2011. There are several reasons for this very disappointing market development, which are often cannot be influenced by the solar thermal sector like the overall economic situation. However, it is also true that the competition within renewable heating technologies like solar thermal energy, pellets boiler, heat pumps, combined heat and power units and even photovoltaics with heat pumps is growing and the competitiveness of the solar thermal technology must be improved to significantly increase the solar thermal market in future again. Today the customers are much more price-sensitive, since they know that it is not only the renewable heating system they have to invest in, in the coming years they must as well invest in the insulation of their building, perhaps in a more efficient or electric vehicle and probably they have to pay more for energy in general.

Therefore the solar thermal investment must become economically more attractive. In the benchmark test the calculated overall energy cost savings are a factor of 1.25 up to 2 higher than the investment costs, which indicates the profitability of the combi-systems in general. This calculation is based on an average annual energy price increase of 8%, as it was the case over the last 10 years. However, the customers often compare only the annual savings at the current energy price with the result that the combi-system investment is not profitable and the return on the investment will not be achieved within the lifetime of the system.

Therefore, there is a strong need to optimize the combi-systems with two goals, first to increase the solar fraction in order to increase the savings and second to reduce the price of the combi-systems.

4.2 Optimizing the combination of parameter values

The results of the benchmark test could give some hints for this optimization. Most of the parameter values of the combi-systems tested varying by a factor of two, however, the solar fraction is only varying by a factor of 1.36. The fact, that the system with the highest solar fraction of 30% has also one of the best values for economics with 195% shows, that high solar fraction and good economics is possible at the same time. These are clear indicators for a great room for system improvements for most of the systems.

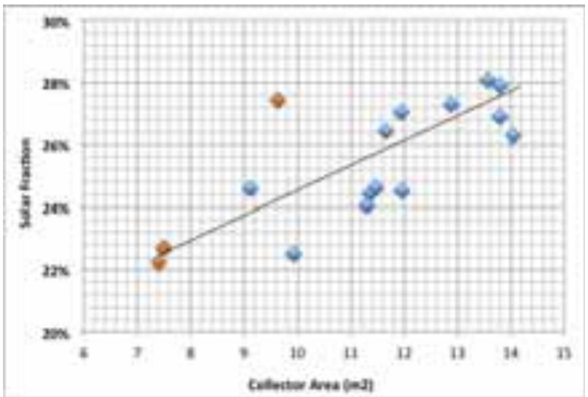

Fig. 3: Dependency of the solar fraction on collector area (orange dots: evacuated tube collectors)

For the finding of the ideal combination of the size of the collector area and its parameters, the combi-tank volume and its parameters as well as the design of the tank, figure 3 and 4 could be helpful. They show for the 17 combi-systems the dependency of the solar fraction on the collector area, on the storage volume and on the heat loss value UA, which is reflecting the quality of the insulation.

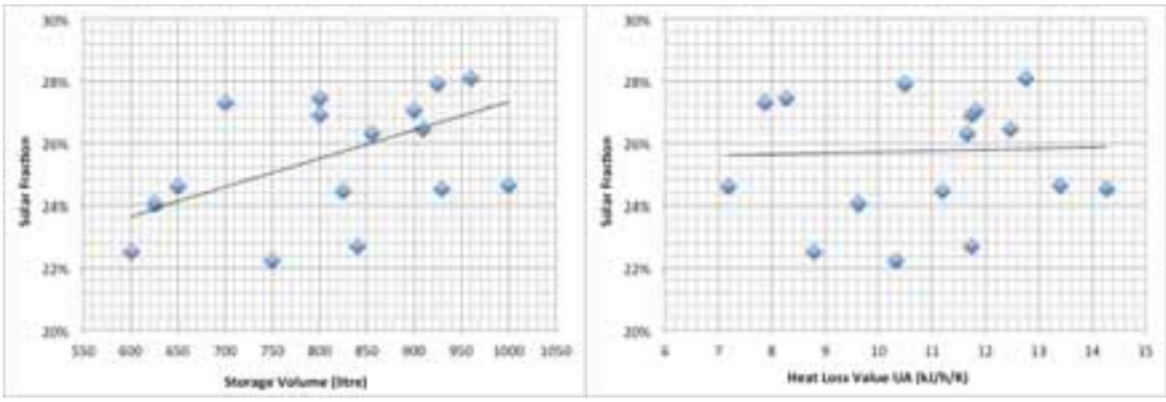

Fig. 4: Dependency of the solar fraction on the storage volume and the heat loss value of the storage (quality of insulation)

There is a clear tendency to higher solar fractions with larger collector area and larger combi-tank volume, however there are several examples where the same solar fraction was achieved e.g. with a collector area of 11.5 and of 14 m^2, with a 650 and a 1000 litre storage volume and with a heat loss value of 7 and of 14.2 kJ h^{-1} K^{-1}. This analysis must be made more in detail and the interdependency of the parameters shown in the separate graphs must be taken into account, however the figures already give a clear idea of the spread of the results.

To improve the overall performance of the combi-system effectively, the parameter must be identified, which shows the highest effect by improving its value. Therefore a parameter study was carried out to identify the influence of the change in each parameter on the solar fraction. Outgoing from the reference system which was defined by the average values of the systems tested (collector: 12 m^2, $\eta_0 = 80\%$, $a_1 = 3{,}6\, W\, m^{-2} K^{-1}, a_2 = 0.015\, Wm^{-2} K^{-2}$, combi-tank: $V = 800\, ltr$, $UA = 11 kJh^{-1} K^{-1}$), the solar fraction was simulated for increasing and decreasing values of the parameters in 4 steps, covering approximately the range of each specific parameter within the test.

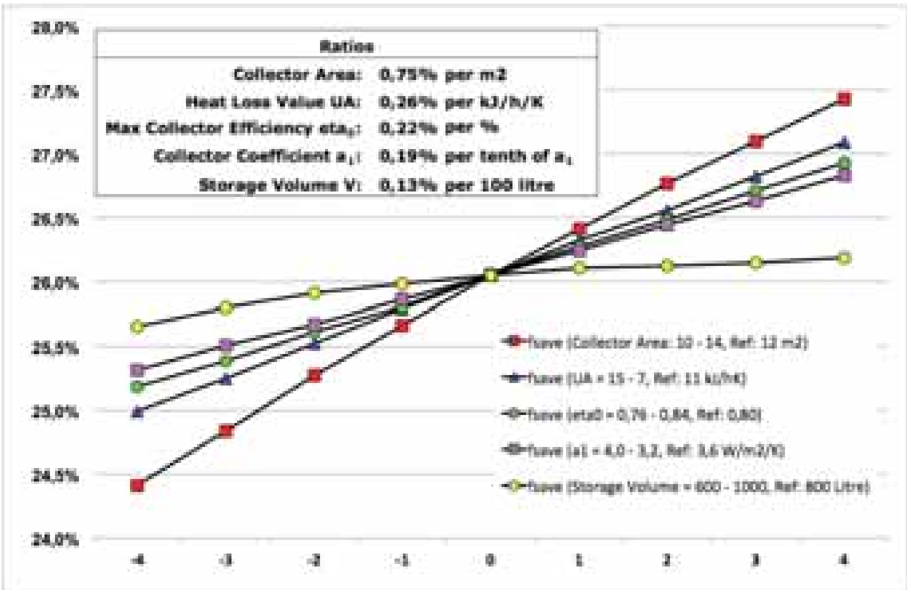

Fig. 5: Comparison of influence of different parameters varied in the dimensions of the test

The results are shown in figure 5. The variation of the collector area has the highest impact on the solar fraction, followed by the UA-Value of the combi-tank and the collector parameters. The variation of the storage volume shows the lowest impact on the solar fraction.

For manufacturers aiming to optimize their combi-systems, the most cost-effective way to improve their combi-system is from interest. Therefore the sensitivity identified in figure 5 of each parameter must be weighted with the additional or saved costs by changing this parameter in order to find the most cost-effective way to optimize the combi-systems. If, for example, the improvement of the of the UA-value (the storage insulation) would have a medium effect on the solar fraction, but is reachable with much lower costs than the increase of the collector size with the same result, the improvement of the UA-value would be the best option to go.

In general, this kind of analysis is not new. However, in this case the simulation is based on a representative sample of combi-systems offered on the market and can be combined with real investment costs for these systems. In addition, the methodology of the benchmark test can be used for the assessment the results of the system improvements.

4.2 Optimizing the system concept and hot water storage tanks

The optimization work should additionally focus on the design of the combi-systems, which is mainly defined by the design of the combi-tanks. In the benchmark test it could not found a significant advantage of one of the concepts to integrate the space heating circuit into the storage tank or to heat up the domestic hot water. Figure 6 shows the solar fraction of the reference system by only varying the design of the combi-tank. So the influence of varying the type of integration of the heating circuit, the heat exchangers and the stratification support is shown. The other storage tank parameters were normalized and equal for all simulations. The simulation shows that the design is influencing the solar fraction by 2% for the combi-tank designs of the benchmark test.

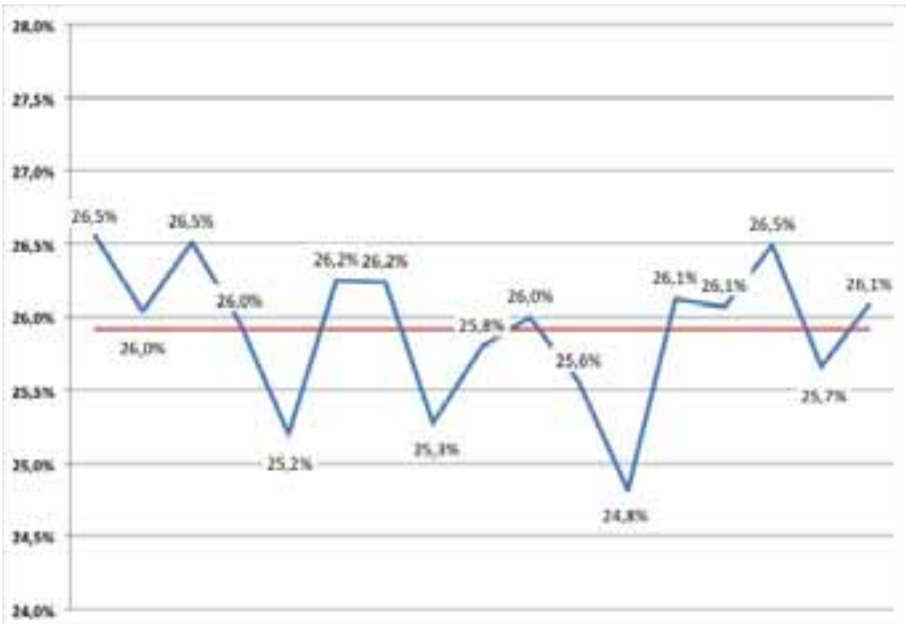

Fig. 6: Solar fraction of the reference combi-system with different combi-tank designs, result of the simulation study with the design of the 17 combi-tanks of the benchmark test

Presumably the variation of the performance differences related to the combi-tank design as presented in figure 6 is not directly linked to the cost of the combi-tank. Therefore, it is expected that the performance-cost ratio can be significantly increased by a detailed analysis of the combi-tank designs and the related costs followed by optimizing the combination of the performance-improving and cost-reducing factors.

A further optimization step could be done by to the manufacturers. Taken into account that according figure 6 the resulting performance differences doesn't justify the high number of different combi-tank designs, groups of manufacturers could work together to optimize one combi-tank and develop it to a common platform, which can be produce in higher numbers. As in the automotive industry the specific product can look different and can have some additional features but is being built on the same platform. This would reduce costs and increase the security of the combi-tank functionality since more R&D effort would be focused on the development and the probability of failures would be reduced by a reduced variety of combi-tank designs.

4.3 Innovative system designs

Recently several manufacturers introduced innovative solar combi-system designs to the market. For example the company Schüco presented a combi-tank in 2011, which separates different parts of the volume of the storage tank strongly by two plastic sheets. The exchange of thermal energy between the different parts of the tank is strongly reduced and happens only under specific conditions. The companies Junkers and Bosch-Buderus introduced in 2010/2011 a new solar system concept, where only solar thermal energy is stored in the hot water storage tank and the preheated hot water as well as the preheated space heating circuit is heated up with the condensing boiler with the through-flow-principle. According the advertisement of the companies, the same solar fraction can be achieved with a 30% smaller collector area due to reduced heat losses of the storage. Further new system designs are on the market, especially in combination with heat pumps.

Since it is not simple to compare the systems and justify if the improvements can be considered as significant and reliable in comparison to the existing system types it is necessary to intensify the work on the test methods, the performance simulation and the definition of assessment criteria to make all combi-systems comparable and support the innovations in this sector.

5. Summary and outlook

Solar thermal combi-systems for domestic hot water heating and space heating support are very common in central Europe and a broad variety of combi-systems is available on the market. Though this is a competitive market, customers as well as installers usually are not informed on the system performance of a specific combi-system. The system performance could be tested with the component oriented performance test according EN 12977, but the manufacturers are afraid that they must test every possible combination of components, which would lead to high testing costs. On that background the Fraunhofer ISE carried out a benchmark test for combi-systems on behalf of the consumer magazine Ökotest based on a simplified performance test. The system performance was simulated based on certified and easily verifiable component data. In addition a customer oriented assessment concept was developed.

The size and design of the combi-systems represented in the test were proposed by the companies which were asked to provide systems with a solar fraction of at least 20% of the overall heat demand in a one-family home in Essen and in Passau. 17 combi-systems participated in the benchmark test and all of them received the final assessment "very good" or "good". The participating combi-systems varied a lot in all parameters of the collectors, the combi-tanks and in the system design. Every combi-tank differs from the others. The investment costs varied up to a factor of 2, however the system performance varied only up to a factor of 1.36. This shows that there is a great room to optimize the combi-systems regarding the optimal combination of components and their parameters as well as the design of the systems in order to increase the solar fraction and to reduce the costs. An analysis how the different parameters of the components are influencing the solar fraction was presented which can be used for optimizing the combi-systems by the manufacturers.

The benchmark test gives a very good overview on the market of combi-systems. However it makes clear that it is necessary to further work on a simple, but reliable and accurate performance test for combi-systems. The results of the benchmark test demonstrate, that there is a great room for the optimization of the combi-systems. A detailed analysis of the test results could be helpful by doing that. One idea presented is to develop a common platform for an optimized combi-tank, which could be used by several manufacturers. There is a strong need for the further optimization of the combi-systems in order to increase the acceptance in the market. Some ideas and possible methodologies are presented in the paper.

6. References

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