EVALUATION OF SOLAR COMBISYSTEMS – RECOMMENDATIONS FOR IMPROVING THE THERMAL PERFORMANCE

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1. Introduction

Increasing market development of solar combisystems (SCS) can help to reduce the primary energy demand of buildings and hence the emission of green house gases. To support this market development it is important to strengthen consumer confidence in solar combisystems. An important aspect for achieving this goal is to ensure the performance and quality of the systems under real operating conditions. During the three year project "CombiSol – Standardisation & Promotion of Solar Combisystems" (2007 to 2010) which was supported by Intelligent Energy Europe, 45 solar combisystems installed in 4 European countries (Germany, France, Austria and Sweden) were evaluated in terms of qualitative inspection and quantitative in-situ monitoring according to Jähnig et al. (2008) and Letz et al. (2010a). The objective was to gather information on the installation quality and the thermal performance of solar combisystems under real operating conditions and to compare the results to the ones from laboratory testing.

The large variety of SCS offered on the market and the deviation in installation quality makes it difficult to predict the energy savings that will be achieved by the SCS under real operating conditions. In general it can be stated that the performance of the prefabricated components has improved, but the installation quality is still an important factor influencing the thermal performance of SCS. In this context, the term **installation quality** includes all aspects of installation such as the interconnection of different system components, thermal insulation quality and controller settings. The results of the here applied holistic evaluation approach combining qualitative data from inspection and quantitative data from in-situ monitoring shows potentials for the improvement of the thermal performance of SCS as demonstrated in Ullmann et al. (2010). From the comparison of qualitative data with the corresponding quantitative data, installation aspects were identified as the largest impact factors on the thermal performance.

In this paper the evaluation results gathered within the CombiSol project will be presented. Recommendations concerning the improvement of the installation quality of SCS will be described on the basis of the thermal performance of the evaluated systems.

2. Evaluation of SCS

One of the important goals of the project was the elaboration of recommendations for the installation of solar combisystems. For this, within the CombiSol project a holistic evaluation procedure was applied on 45 SCS within 4 different countries in Europe (France, Austria, Sweden and Germany). The complete evaluation procedure comprises a qualitative and quantitative evaluation (see Fig. 1). The qualitative evaluation gives information on the installation characteristics (e.g. the quality of the thermal insulation) of one specific SCS. The quantitative evaluation provides information on the thermal performance of the combisystems by means of measurement data taken under real operating conditions (in-situ measurements) as well as under laboratory conditions. This holistic approach of qualitative and quantitative evaluation allows the correlation between the thermal performance of combisystems under laboratory and under real operating conditions by comparing the differences in the thermal performance indicators (e.g. the fractional energy savings) and hence shows the influence of the installation quality.

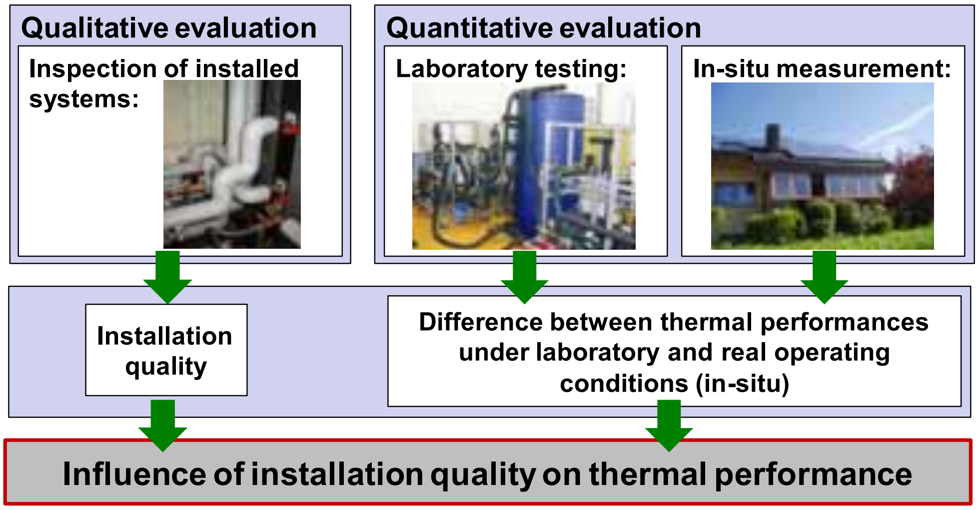

Fig. 1: Overview of evaluation procedures applied within the CombiSol project

In the following, the different evaluation procedures and the corresponding results from the CombiSol project are presented, divided into the different parts: inspection of installed systems, in-situ measurements and laboratory testing.

2.1 Inspection of installed systems (qualitative evaluation)

Despite the fact that the level of prefabrication has increased strongly, installers still have to interconnect a lot of different components when installing a SCS at the construction site. The qualitative evaluation of SCS can help to identify key hurdles that may cause lower thermal performance of the system than possible. The results can be used for improving the prefabrication of components for SCS as well as the installation manual and help to avoid mistakes during installation of SCS. The quality of installation is determined during on-site inspections of SCS where the combisystems are examined using standardized checklists elaborated within the CombiSol project (www.combisol.eu).

The qualitative evaluation comprises the collection of data specific for the location, like the number of persons living in the house, or the heated floor area and the specific data of the combisystems. The specific data of the combisystems characterise the main components such as the solar collector, solar circuit including solar heat exchanger, heat store, auxiliary boiler, domestic hot water (DHW) preparation and space heating as well as the piping, the thermal insulation and controller settings.

The qualitative inspection has shown that missing or none complete thermal insulation is one of the key factors for a reduced thermal performance of SCS. But also other aspects like the controller settings can have a significant impact as well, provided the system is installed hydraulically correct. The components are mostly prefabricated, hence the biggest potential for improvement concerning the thermal insulation is the piping and the interconnections of the components.

Fig. 2 shows an example of a well insulated (left) and a not insulated connection at the heat store (right). The not insulated heat store connection is at the top of the heat store where the backup volume for domestic hot water preparation is located. Due to natural convection within the connecting pipe and the high thermal conductivity of copper used as piping material the pipes have nearly the same temperature as the set temperature of the backup volume for DHW preparation. This fact implicates constant high heat losses throughout the whole year, causing a direct increase in energy demand and hence a decrease in thermal performance of the complete system.

Fig. 2: Good (left) and bad (right) example for the thermal insulation at heat store connections

2.2 In-situ monitoring results (quantitative evaluation)

In the project CombiSol 45 installed combisystems were assessed by in-situ measurements. The aim was to perform the measurements at least over a time span of one year. If monitoring results were not available for a complete year an extrapolation of the measured data was performed according to Letz et al. (2010b). One important aspect to be kept in mind concerning the analysis of the measurement data is the fact, that SCS are only one part of the complete heating system in a building including also i.e. the heat distribution system. It is therefore important to take the complete heating system of a building into account for the assessment of the data. Hence corresponding guidelines (including i.e. the definition of measured entities and measurement positions) were elaborated for in-situ measurements and data assessment of SCS within the framework of the CombiSol project. Due to the fact that measurement data were collected every minute, potentials for improvement can be derived not only from the overall energy balances but also from the investigation of the dynamic system behaviour in detail.

In Fig. 3 the thermal fractional energy savings of monitored SCS within CombiSol are plotted against the fractional solar consumption (FSC). Depicted here are systems for which almost a complete year of measurement data was available at the end of the project.

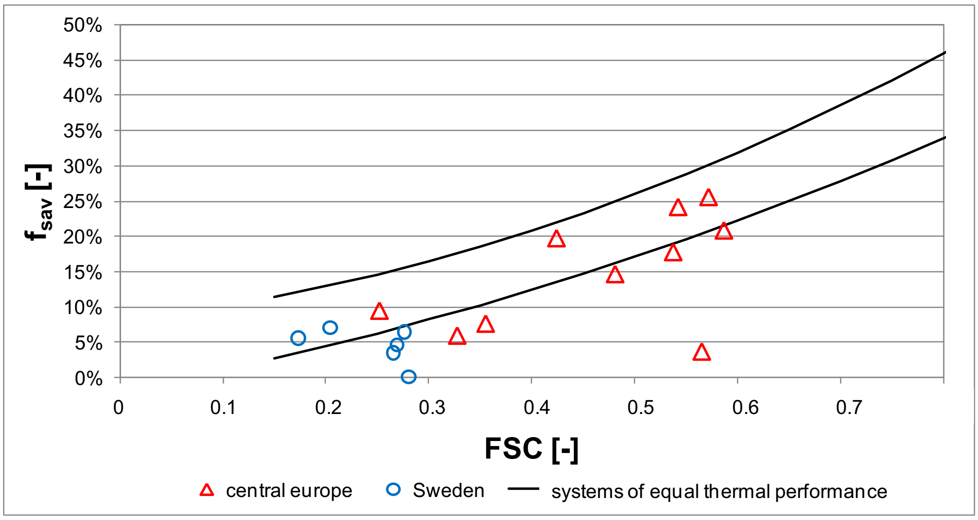

Fig. 3: Fractional energy savings (f_{sav}) over the fractional solar consumption (FSC) for monitored solar thermal combisystems monitored within the CombiSol project

The FSC value is an indicator describing the theoretically achievable fractional energy savings and is defined as the ratio of the theoretically usable solar energy and the energy demand of a conventional non-solar reference system. The solid lines represent systems of equal thermal performance. Herein it is taken into account that a system with i.e. a smaller collector area or lower irradiation has potentially smaller fractional energy savings. The lines delimit the region of good thermal performance (between them). Most of the monitored systems are in the region of good or acceptable thermal performance. But some systems are working badly and one even shows no thermal energy savings at all. The monitored Swedish systems showed the lowest fractional energy savings (f_{sav}) due to smaller collector areas installed. These relative small collector areas are combined with relative large store volumes which are used because of the pellet or wood log boiler widely used in Sweden.

Heat losses were identified to be the major influence on the thermal performance factors (i.e. the fractional energy savings) within the CombiSol project. Heat losses directly increase the auxiliary energy demand and can reduce the thermal performance significantly even if solar gains were quite high for most monitored systems.

This implies on the other hand that consequent reductions of thermal losses are a suitable measure to increase the fractional energy savings and hence to decrease the primary energy demand. Fig. 4 shows the different energies splitted into the demand (DHW, DHW circulation, space heating (SH), thermal losses of store and the supply (auxiliary energy and solar gains). Here only results of systems are depicted for which measurement data are available for one complete year. The data shows a large variety concerning the different heat demands. Especially the DHW circulation ranges from 0 to more than the actual DHW load. In order to keep the heat demand for DHW circulation as low as possible, the hot water piping should be well insulated and adjusted to the actual needs e.g. by means of an on-demand operation. Space heating demand is the largest amount of energy for all systems. Solar gains are quite high for most systems, but thermal losses can negate this positive effect. For AT2 the thermal losses even exceed the solar gains, implying negative energy savings. On the other hand GE2 is a good example showing how small the heat losses can be.

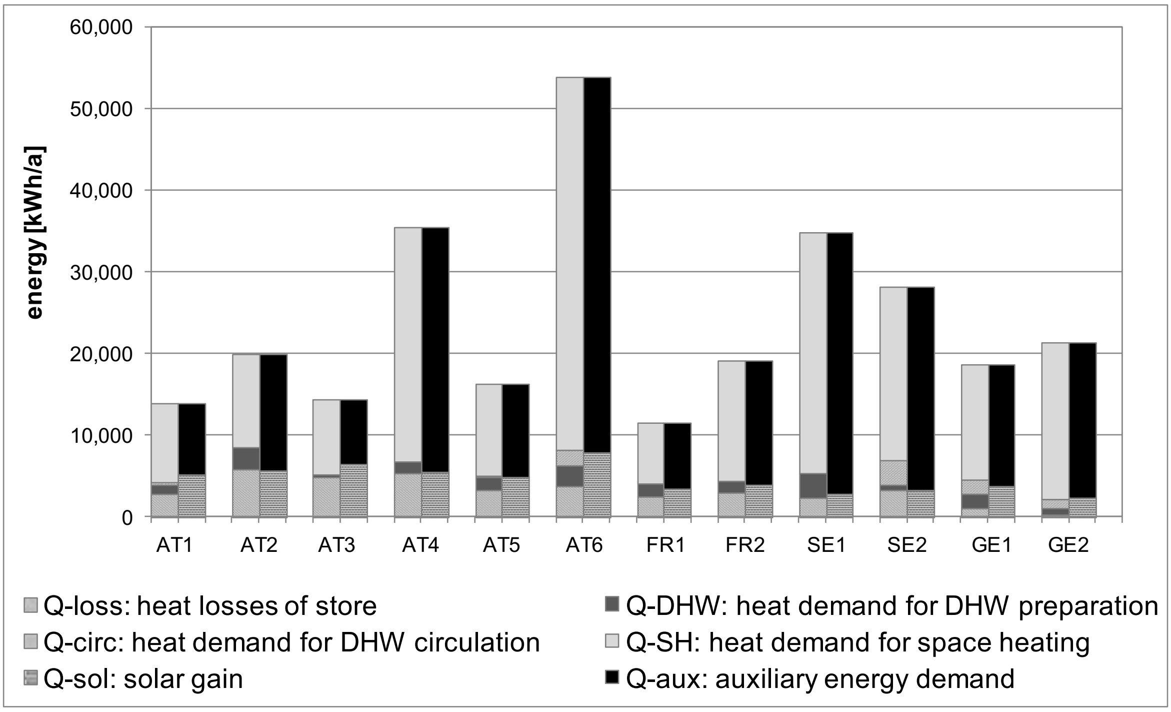

Fig. 4: Results from solar combisystems monitored within the CombiSol project

2.3 Results from laboratory testing (quantitative evaluation)

As a reliable prediction of the thermal performance of solar combisystems is one of the major aspects for a stronger market development, the further development of performance test methods for SCS was a second major work package of the CombiSol project. In order to determine the influence of the installation quality, different combisystems were evaluated both by in-situ measurement and laboratory testing. Two different test methods were applied during the CombiSol project in order to predict the thermal performance of different solar combisystem concepts.

With the component based **CTSS method** (Component Testing - System Simulation), according to CEN/TS 12977-2, originally developed at ITW the thermal performance of SCS is predicted on the basis of physical short term tests performed for the main system components (Drück et al., 2002). Based on the parameters determined for the different components from those tests, the annual thermal performance of the complete system is predicted for defined reference conditions (e.g. meteorological data, load profiles) by using a component-based simulation program such as TRNSYS (Drück et al., 2004).

By the black box approach based on the **CCT method** (concise cycle test) method, which was originally developed by SPF (Solartechnik, Prüfung Forschung) and further developed by INES (Institute National de l´Énergie Solaire) the complete SCS is physically tested (except collector) under laboratory conditions (Albaric et al., 2008). In order to determine the annual thermal performance of a combisystem without a test sequence lasting one complete year, 12 characteristic test days were defined. The annual thermal performance is extrapolated based on the 12 day test results. This black-box test method based on the CCT method and applied here is called SCSPT method (Short Cycle System Performance Test).

For both test methods the parameters determined for performance assessment are e.g. the fractional energy savings (f_{sav}).

The results from laboratory testing (Fig. 5) show quite good agreement between predicted and actual achieved thermal performances. Since the boundary conditions during monitoring and during laboratory testing are different, the figures obtained for fractional energy savings f_{sav} cannot be compared directly. Therefore the comparison has to be performed assessing the thermal performance of the systems in a graph showing the fractional energy savings f_{sav} versus the fractional solar consumption (FSC). The dashed lines in Fig. 5 as well characterise systems of equal thermal performance. Concerning all 4 manufacturers the systems show identical thermal performance during field test monitoring and during laboratory testing according to the CTSS and SCSPT test methods.

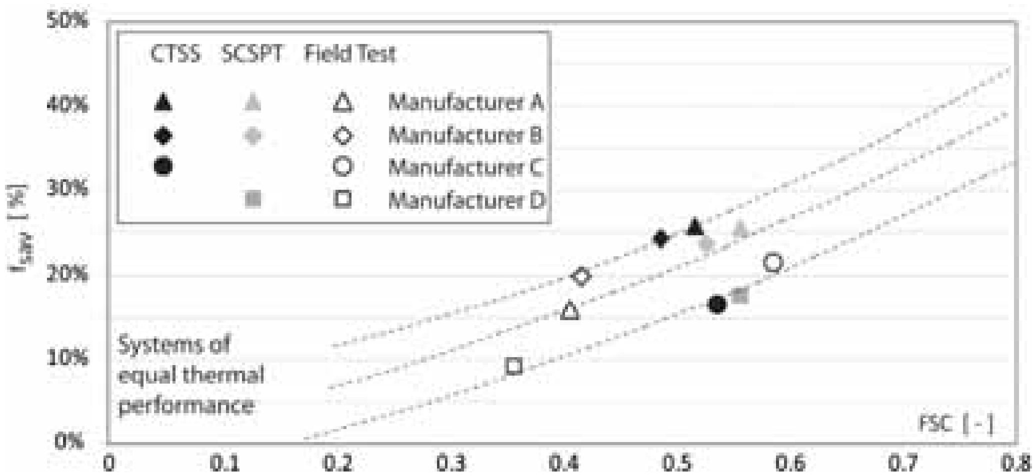

Fig. 5: Comparison between laboratory testing (SCSPT and CTSS method) and measurement (in-situ monitoring); (Mette et al., 2011)

3. Influence of installation quality on thermal performances

In the following a few examples from monitoring are given showing potentials to save primary energy and hence improve the thermal performance of the entire system. Furthermore the major outcomes of the overall system evaluation from the CombiSol project will be presented.

3.1 Thermal insulation

Unintended high inside room temperatures at the heat store or heat distribution system location indicate high heat losses of the system. As an example in Fig. 6 (left side) the room temperature and the space heating load are depicted over one day. The result of the qualitative evaluation shows bad thermal insulation at the heat distribution system for space heating (right side). An improved thermal insulation would reduce the heat losses during the operation of the space heating and directly improve the energy savings.

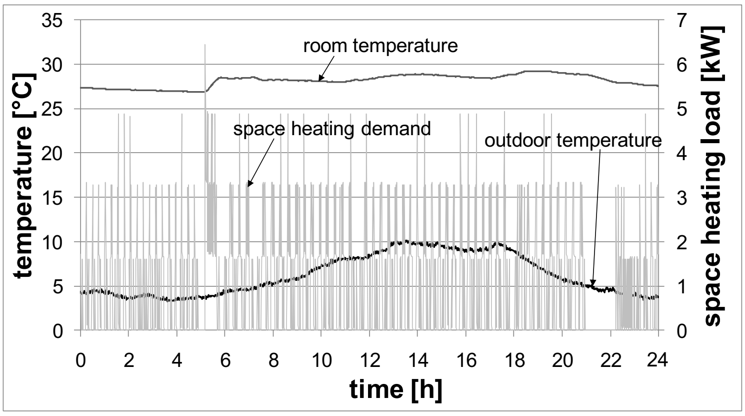

Fig. 6: Influence of thermal insulation on heat losses and surrounding temperature by means of bad thermal insulation (left side) and corresponding room temperature (right side)

The measurements (right side) show a significantly increasing room temperature during times of high space heating demand (2.5 K). This effect indicates the thermal insulation at the space heating distribution to be improvable which was determined during the inspection as well.

3.2 Natural convection inside pipes

Besides the lack of thermal insulation, microcirculation generates heat losses as well. If no thermosiphon breaks or back-pressure valves are installed cold water can sink inside pipes and draw hot water from the top of the heat store into the pipes and thus induce an unintended flow of hot water inside a pipe. An example is depicted in Fig. 7.

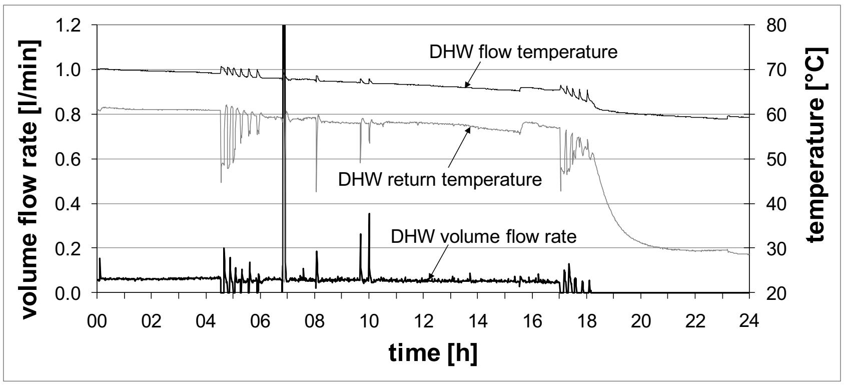

Fig. 7: Missing back-pressure valve and thermal insulation (left side) and microcirculation occurring in DHW/circulation loop (right side)

A missing thermosiphon break or back-pressure valve and insufficient thermal insulation (as shown e.g. on the right side of Fig. 7) can induce microcirculation within pipes causing thermal losses in the range of up to several kWh per day. In Fig. 7 (left side) the microcirculation results in a low and constant volume flow rate from midnight until 6 pm in the evening. The flow temperature is approx. 10 K higher than the return temperature which drops approx. by 30 K towards the cold water temperature after the microcirculation stopped.

3.3 Other aspects

Overall outcomes of SCS monitoring within the CombiSol project show a few more important aspects that are crucial for ensuring a good thermal performance (Papillon et al., 2010). The large data basis gathered within the project is able to supply those aspects with figures and hence demonstrate their importance. The aspects are:

- The main influence on the yearly energy savings are the thermal losses of the whole system. If the thermal insulation is not performed with the appropriate priority, thermal losses might even exceed the yearly solar gains and therefore increase overall primary energy demand. In order to reduce these heat losses several points have to be met:
  - Use one heat store rather than two heat stores to install the same heat capacity. If two heat stores are used adjust the auxiliary volume for DHW and backup volume for space heating to the actual demands and thermally insulate the piping between the heat stores.
  - Reduce the size of interconnecting piping between the components. Concerning piping and hydraulic components compact prefabricated system and sub-components such as e.g. hydraulic stations are better than several units connected on site.
  - In case of installation of separate components on site, the location of the components should be chosen in such a way that the length of the piping is minimised. Also the piping should be carefully insulated without any gaps (including insulation of valves etc.). Especially the hydraulic connections (used or unused) at the heat store should be insulated well – especially at the upper part of the heat store.
- The auxiliary heater is an important part of the combisystem and should be high efficient such as a condensing boiler or ground coupled heat pump. In case SCS are installed in existing buildings and the auxiliary boiler is not a high efficiency one it should be renewed.
- Low temperature heating systems have a positive effect on the performance of the solar combisystem since the solar collector can work at lower temperature levels resulting in increasing its performance.
- Parasitic electrical energy consumption varies in a large band down from less than 500 kWh per year up to three times this value for systems which are not well adjusted.

All of the above aspects should be met carefully in order to ensure a good performance of the complete system. Every aspect not treated in an appropriate way is well able to reduce the primary energy savings, some aspects even significantly.

4. Recommendations for the installation of SCS

Within the CombiSol project the main outcome concerning the thermal performance of SCS is that the reduction of thermal losses should be in the focus even more than increasing of solar gains. Especially due to the fact that conventional (non-solar) systems often do not integrate a heat store for space heating but solar thermal systems are dependent on them, SCS have the disadvantage of potentially higher thermal losses. Furthermore, in order to reach best possible performances of SCS the two main parts - solar thermal system and auxiliary heater - have to be integrated well into the complete system in both hydraulic and control aspects. The detailed recommendations elaborated within the CombiSol project are divided into different aspects, summarized below (Papillon et al., 2010):

- Overall system concept
- Single or multi store concepts
- Heat store
- Auxiliary heater
- Space heating
- Solar collector circuit
- General aspects

4.1 Overall system concept

Solar thermal combisystems can be categorized into 6 different system categories by differentiating the systems by their two major components DHW preparation and integration of the auxiliary heater:

- DHW type A: tank-in-tank (DHW store inside space heating store)
- DHW type B: immersed heat exchanger (internal DHW heat exchanger inside space heating store)
- DHW type C: fresh water unit (DHW preparation via external plate heat exchanger)
- Auxiliary integration 1: as return flow increase
- Auxiliary integration 2: only charging heat store (heat store as buffer store for space heating)

The different types of DHW preparation can here be combined with any type of auxiliary integration.
Auxiliary integration 1 implies potentially lower heat losses and is best suited for boilers which are able to modulate well in wider power ranges and still operate with high efficiency such as i.e. natural gas or small oil boilers. Solar thermal systems planned for smaller solar fractions are well suited for auxiliary integration 1 as times when solar energy is able to supply space heating completely are rare. Therefore times with hot fluid running through the shut off auxiliary boiler causing heat losses are few.
Auxiliary heating 2 has potentially larger heat losses and is more suited for boilers which operate more efficiently with longer running times such as i.e. standard heat pumps or pellet boilers. This type of auxiliary integration is more suited for medium to large solar fraction combisystems where the space heating demand can be covered by solar heat over longer periods of time and the boiler would only increase heat losses being located within the heat distribution piping.
The auxiliary volume for DHW causes constant heat losses at the upper part of the heat store and should therefore be adjusted to the actual demand. Since the DHW comfort can mostly not be adjusted via the size of the auxiliary volume for DHW (heat store connections are fixed) the temperature sensor heights as well as the set temperature for DHW auxiliary heating should be adjustable.
DHW type A and B are best suited for biomass boilers having high flow temperatures, whereas DHW type C is better suited for modulating boilers with sufficient power such as natural gas boilers. By keeping the auxiliary volume small using sufficiently large powered boilers integrated as return flow increase, thermal losses can be kept at a minimum and the thermal capacity of the heat store can be used most effectively for storing solar heat.

4.2 Single or multi store concepts

The qualitative evaluation within the CombiSol project showed the average of heat store volume and collector area to be between 50 and 100 l/m^2. About one third of the systems consist of more than one heat store.
Multi store systems have some strong disadvantages implying higher thermal losses compared to one store systems. For storing the same volume the ratio of heat store surface area to volume is roughly one third larger for two stores compared to one single store implying significantly higher thermal losses. Furthermore the interconnections between the heat stores increase potential heat losses especially if not insulated. One further aspect is the difficulty to adjust the auxiliary volume for DHW when using two stores instead of just one. It is therefore recommended to check carefully if the advantage of easier handling during installation or larger heat store capacity outweighs the above mentioned disadvantages.

4.3 Heat store

As the above presented monitoring results from the CombiSol project show, thermal losses within a lot of SCS were quite high. The qualitative inspections showed quite good agreement between high thermal losses measured and large lacks of thermal insulation at the heat store(s) and piping as well.
Even though the insulation of the heat store is mostly prefabricated, it was not always installed correctly. At only one third of the systems investigated the unused pipe connections were insulated. This leads to high thermal losses especially if the connections are located at the upper part of the heat store. The length of uninsulated piping can easily add up to a surface area of half a square meter or more. Thermosiphon breaks were only used in very rare cases. It is recommended to use a tank concept which has no connections at the top of the heat store but at the side or the bottom of the heat store. This prevents heat losses at the top of the heat store. As already mentioned above the usage of two heat stores is not recommended if it is possible to

install the same or a slightly lower volume by only using one store. Fig. 8 shows good and bad examples of heat store insulation with potentials for improvement.

Fig. 8: Thermal insulation of heat store and connected piping, bad (left side) and good (middle) respectively well insulated with improvement by using thermosiphon breaks (right side); (Papillon et al., 2010)

The return flow for space heating should be connected to the heat store depending on its average return flow temperature. If the return flow temperature is expected to be low (i.e. in case of floor heating, wall heating or low-temperature radiators) the return flow should be connected near the bottom of the heat store. If the return temperature is expected to be higher, the return flow should be connected at a higher part of the heat store (i.e. at the height of the auxiliary return flow).

4.4 Auxiliary Heater

There is a large variety of different boilers available on the market and it is not possible to recommend a certain type of boiler since it has to fit to the respective combisystem and the specific boundary conditions (i.e. DHW load and space heating flow and return temperatures). A condensing natural gas boiler for example requires low return temperatures in order to use the condensing effect properly.

Concerning the dimensioning of the auxiliary boiler, it has to be kept in mind that the heat store of a solar combisystem comprises a domestic hot water auxiliary volume. The average power demand for DHW is only 0.5 kW (assuming a 4 person household with a hot water demand of 200 litres per day with 10/60°C). Hence, provided the DHW auxiliary volume is large enough to meet the peak load the maximum boiler power can be reduced to the maximum space heating demand.

4.5 Space Heating

The space heating demand within the monitored systems represent around 70 to 90 % of the total heat demand and the DHW preparation (including circulation) between 10 to 30 %. Not only the total heat demand but also the reason that space heating is mainly required during times with lower solar gains (lower radiation and lower ambient temperatures) results in the fact that the space heating demand dominates the thermal behaviour of the solar combisystem.

In general low temperature heating systems have a number of advantages. They lead, for example, to higher solar collector efficiencies due to lower mean operating temperatures, lower heat losses, better efficiencies of condensing boilers due to lower return temperatures or larger usable heat store capacities. Low temperature systems can be achieved e.g. by appropriate dimensioning of the heat emitting elements or radiators respectively, proper hydraulic adjustment of each emitting element, low flow systems and a good thermal insulation of the piping.

4.6 Solar Collector Circuit

The solar collectors within the evaluated systems were mostly on roof mounted. Qualitative evaluation showed that the thermal insulation especially outside the building is exposed to several negative impacts and therefore should be water resistant, high temperature resistant and protected against animal bites.

Measures against stagnation of the solar collector field should be passive if possible and security aspects should be met carefully. This involves for example the connection of the expansion vessel to the collector circuit from above or the placement of the safety valve as well as the collection vessel behind it (i.e. temperature resistance).

4.7 General Aspects

As mentioned above a lot of different aspects can lower the efficiency of a combisystem and can add up to a significant reduction in the thermal performance. Therefore all recommendations should be met equally in order to reach the maximum performance of the SCS. The design of an optimised combisystem should start with the planning defining the placement of the different components in such a way that the length of the piping is minimised. This potentially reduces the heat losses and will save installation costs. Thermosiphon breaks should be used in order to avoid microcirculation in the piping. The requirements related to the heat and comfort demands (i.e. DHW load and circulation) should be met exactly, since the appropriate adjustment directly saves primary energy and hence improves the thermal performance of the system. Concerning the hydraulic interconnection of components they should be placed minimizing the length of piping operated at high temperatures (i.e. on primary side of heat exchanger or before mixing valve). The heat distribution piping showed to have potentially high heat losses and therefore should be insulated properly including all components such as valves etc. for which in some cases already prefabricated insulation material is available.

5. Summary

In the course of the CombiSol project 45 solar thermal combisystems (SCS) installed in 4 European countries were evaluated using a holistic approach including qualitative evaluation in terms of system inspections, in-situ measurement and standard testing procedures.

The in-situ measurement of 45 SCS showed overall satisfying thermal performances represented by the (fractional) thermal energy savings that were achieved. The performances were well in the range predicted by laboratory testing. This is showing that the two test methods are able to predict the thermal performance of SCS in a reliably way. The test methods can hence be considered as well suited tools for the determination of the thermal performance of SCS.

The performed in-situ monitoring showed good and bad examples and revealed potentials for improvement. The recommendations elaborated within the CombiSol project are related to the complete SCS including all components. One of the most relevant aspects was the thermal insulation of the system including the heat store including its connections and the piping. Large heat losses caused by missing thermal insulation reduce the benefit of even high solar gains to a minimum in the overall thermal performance and hence increases the primary energy demand. But also other aspects such as controller settings showed to be very important for an optimal operation of the system. A higher level of prefabrication and workshops for installers might be able to improve the SCS performance even more.

Besides the evaluation of the installed systems, two different test procedures were investigated within the CombiSol project, the SCSPT (Short Cycle System Performance Test) and the CTSS (Component Testing – System Simulation) procedure. The comparison of the two test methods showed that in principle both test procedures are well able to predict comparable thermal performances of SCS. Achieving similar results requires the usage of the same boundary conditions not only for global data (as weather and load conditions) but also for hydraulic and control aspects. Especially with regard to the SCSPT method the control aspects showed to be crucially importance.

By supplying a wide range of qualitative, quantitative and comparative data, the CombiSol project supports significantly the consumer confidence in solar thermal combisystems and additionally gives feedback to the solar thermal industry. This will potentially increase the market development of these systems and help to develop better performing and more installer-friendly systems. The recommendations given within the project are one of the major aspects in order to achieve these aims and are therefore of crucial importance. Hence the further dissemination of the results from the CombiSol project will be ongoing.

6. Acknowledgement

The work described in this paper is partly funded by European Commission within the Program "Intelligent Energy Europe" under grant number EIE/07/295. The authors gratefully thank for this support and carry the full responsibility of the content of this publication.

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