Solar Combisystems Promotion and Standardisation

Final report

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Symbol list

Symbol	Definition	Unit
alt	altitude	10^3 m
C	consumption	kWh
Conc	concentration	%
Cf	specific heat capacity	kWh/kg.K
Cv	calorific volumetric value	kWh/m^3.K
I_{sol}	solar irradiation	kWh/m^2.d
P	pressure	Pa
Q	energy quantity, load, loss	kWh
Q_c	energy delivered by the solar collector	kWh
T	temperature	K
v	volume	m^3
$\dot{V}$	volumetric flow rate	m^3/s
W	electric consumption	kWh
θ	temperature	°C
Δt	time step	h
ρ	density	kg/m^3
Suffixes		
aux	auxiliary	
c	solar collector	
co	cold	
cor	correction	
e	external	
el	electrical	
g	gas	
H	space heating	
i	internal (temperature)	
l	loop	
ls	loss	
me	mean	
n	normal	
nd	need	
sol	solar	
wa	warm	
W	Domestic Hot Water	
*	used when a definition is slightly modified	
Fonts		
normal	calculated values	
bold	**identified or estimated values**	
italic	*measured values*	

Annual and monthly values:

In general, energy balances can be calculated on a yearly or monthly period, with same formula. If the annual formulas are ambiguous, the symbol Σ is placed before the concerned figure.

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Introduction

Solar combisystems (SCS) are solar heating installations providing both space heating and domestic hot water in buildings. The main objective of Combisol project was to encourage an accelerated market deployment of SCS – hence a higher share of heat produced by solar energy - and to promote an improved quality of the systems installed.

In particular, Combisol project wants to:

- promote best practices for solar combisystems in new and existing buildings,
- promote standardised systems and cost-effective solutions,
- propose recommendations to manufacturers with regard to combisystems design,
- train installers,
- develop specific dimensioning tools in order to facilitate the recommendation for solar combisystems based on the EPBD methodology,
- increase consumers confidence, providing information on energy efficiency of solar combisystems, based on in-situ monitoring and test labs.

In this report, lessons learned and results of the project are presented.

After evaluating the potential of solar combisystems in terms of market and energy savings, a review presents the different technologies available on the market and trends.

Then the results of a qualitative assessment carried out in Germany, Austria, France and Sweden on 70 systems are reported. Thanks to a detailed questionnaire and inspection on site, key points for progress, but also good examples are presented, and some conclusion provided to improve the quality.

Out of the 70 systems qualitatively evaluated, 45 were selected in-situ monitoring based on the same methodology in the 4 participating countries. The results after several months of measurement are presented with valuable lessons about optimizing performance.

Measuring the thermal performance thanks to in-situ monitoring is the best option to evaluate both design of the system and installation of the system. But this option is expensive and the end-user is only informed about the thermal performance of the system only after buying and measuring it. To provide end-user with valuable information on the thermal performance before purchasing such systems, lab test methods are required. Two test methods will be presented based on a component approach and on a system approach. Inter-comparisons of system performance in labs have been done with promising results but further development is still required. More, a relative good correlation between in-situ monitoring and lab tests has been checked.

Based mainly on the qualitative and quantitative evaluation, main recommendations for efficient solar combi-systems have been elaborated. These recommendations addressed to manufacturers, installers and planners are the results of intensive work, and should be taken into account in the future for quality improvement of solar combisystems.

Finally, quality of systems relies also on efficient tools for dimensioning, and qualifications of installers. The last sections of this report will present tools that have been developed within this project as well as training materials focusing on the main lessons learned in this project.

Once quality of systems is achieved, the last section provides recommendations related for the promotion of solar combi-systems in the form of “carrots” (incentives), “sticks” (regulation) and “guidance” (education) policies.

1 Potential of solar combisystems

Main authors : Alexander Thür and Gabriele Kuhness

According to the goals of the energy policy in Europe to reduce CO2 emissions it is necessary to find and to use all possible sources for renewable energy in a proper way. Thermal heat is a main part of energy consumption in Europe and again space heating and domestic hot water for residential buildings is a significant part of low temperature heat consumption in Europe.
In order to estimate possible contribution of overall solar thermal energy for all types of demand in Europe the study "POTENTIAL OF SOLARTHERMAL IN EUROPE" was prepared for the European Solar Thermal Industry Federation (ESTIF) within the 6th framework program by the Vienna University of Technology – Energy Economics Group (EEG), Peter Biermayr, and the AEE – Institute for Sustainable Technologies (AEE INTEC), Werner Weiss [17].
Within the CombiSol project based on this study and also based on the actual statistic data from IEA-SHC report "Solar Heat Worldwide 2008" [1] the possible contribution of solar combisystems for space heating and domestic hot water preparation mainly in single family houses was derived based on estimations from national experts of the participating institutions. Therefore, these numbers specifically related to solar combisystems shall be interpreted as a good guess but not as the result of detailed statistical calculations.

The determination of the potential of solar thermal in the European Union (EU 27) in this report is based on detailed country studies done within the ESTIF study concerning the solar thermal potential in the five reference countries Austria, Denmark, Germany, Poland and Spain representing a good mix of all climate zones in Europe, varied subsidy models and different solar thermal market developments.
The potential study is based on a model, which accounts for many factors like e.g. share of new buildings, energy index of buildings, the quality of retrofits, economic state, subsidy structure and also limited factors like availability of space for solar collectors. The model delivers the potential of the solar thermal market for 2020, 2030 and 2050.
This potential results in three differently ambitious scenarios - „BAU-" (Business As Usual), „AMD-" (Advanced Market Deployment) and „RDP-scenario" (Full Research Development and Policy). First it was detailed evaluated for the five countries Austria, Germany, Denmark, Poland and Spain and based on that derived for the EU 27.

Because of missing results within this study for France and Sweden, the potential for these countries were derived from other countries with similar structures. The French potential is based on Spain, the Swedish potential is based on Denmark. The result of the potential study for solar thermal in general and for solar combisystems especially can be summarized for EU 27 and the CombiSol partner countries as following.

The overall solar thermal short-term potential of the **EU 27** for 2020 results in a specific collector area between 0.2 m² (BAU) and 0.8 m² per inhabitant (RDP), which corresponds to 97 million m² (BAU) and 388 million m² (RDP).

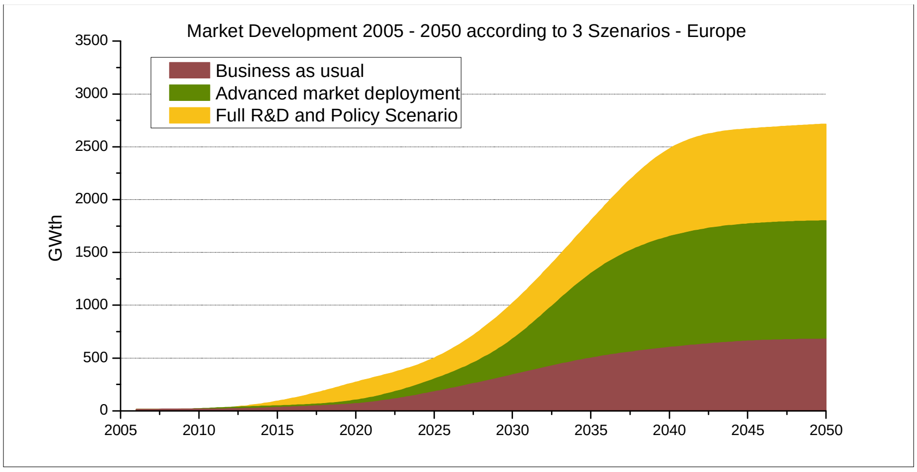


Figure 1: Solar thermal potential in EU 27 based on the three scenarios; Source: [17]

[1] Source : Solar Heat Worldwide Edition of 2005 to 2008 [Werner Weiss, Gerhard Faninger, Irene Bergmann, Roman Stelzer, Franz Mauthner, 2007-2010]

The overall solar thermal medium-term potential of the EU 27 for 2030 results in a specific collector area between 1 m² (BAU) and 3 m² per inhabitant (RDP), which corresponds to 485 million m² (BAU) and 1,455 million m² (RDP).
The overall solar thermal long-term potential of the EU 27 for 2050 results in a specific collector area between 2 m² (BAU) and 8 m² per inhabitant (RDP), which corresponds to 970 million m² (BAU) and 3,880 million m² (RDP). This collector area corresponds to an energy saving of 1,552 TWh and would reduce the CO_2 emission to 687 million tons per year.

The overall solar thermal short-term potential of **Austria** for 2020 results in a specific collector area between 1 m² (BAU) and 3 m² per inhabitant (RDP), which corresponds to 8.2 million m² (BAU) and 24.7 million m² (RDP).
The overall solar thermal medium-term potential of Austria for 2030 results in a specific collector area between 1.7 m² (BAU) and 5 m² per inhabitant (RDP), which corresponds to 14 million m² (BAU) and 41 million m² (RDP).
The overall solar thermal long-term potential of Austria for 2050 results in a specific collector area between 2 m² (BAU) and 8 m² per inhabitant (RDP), which corresponds to 16 million m² (BAU) and 66 million m² (RDP).
For solar combisystems 20.46 million m² are expected to be used as part of the overall collector area (RDP). This collector area corresponds to an energy production of 6.4 TWh which equals 2.0 million tons CO_2 emissions (oil equivalent) per year.

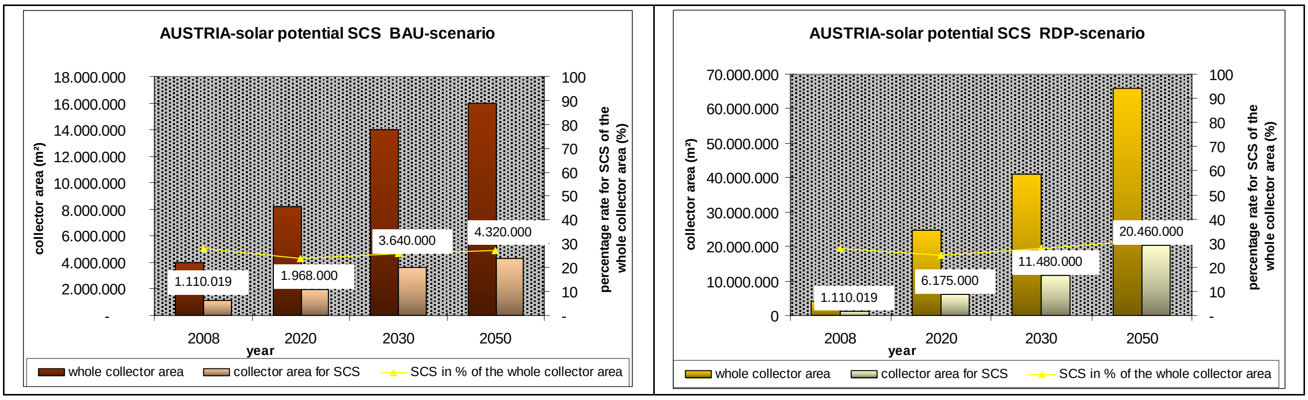


Figure 2: Overall solar thermal potential and potential for SCS in Austria: once the BAU-scenario (left), once the RDP-scenario (right)

The overall solar thermal short-term potential of **Denmark** for 2020 results in a specific collector area between 0.2 m² (BAU) and 0.6 m² per inhabitant (RDP), which corresponds to 1.1 million m² (BAU) and 3.3 million m² (RDP).
The overall solar thermal medium-term potential of Denmark for 2030 results in a specific collector area between 0.8 m² (BAU) and 2.5 m² per inhabitant (RDP), which corresponds to 4.5 million m² (BAU) and 13.6 million m² (RDP).
The overall solar thermal long-term potential of Denmark for 2050 results in a specific collector area between 2 m² (BAU) and 8 m² per inhabitant (RDP), which corresponds to 10.9 million m² (BAU) and 43.4 million m² (RDP)

For solar combisystems 4.34 million m² are expected to be used as part of the overall collector area (RDP). This collector area corresponds to an energy production of 1,328 GWh which equals 423,000 tons CO_2 emissions (oil equivalent) per year.

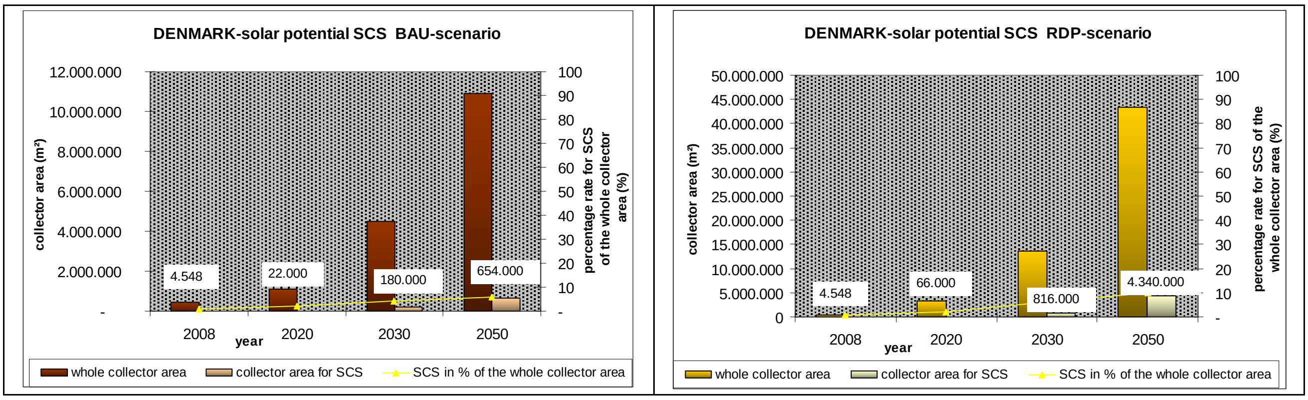


Figure 3: Overall solar thermal potential and potential for SCS in Denmark: once the BAU-scenario (left), once the RDP-scenario (right)

The short-term potential of **Germany** for 2020 results in a specific collector area between 0.5 m² (BAU) and 1.5 m² per inhabitant (RDP), which corresponds to 41 million m² (BAU) and 124 million m² (RDP).
The medium-term potential of Germany for 2030 results in a specific collector area between 1.3 m² (BAU) and 4 m² per inhabitant (RDP), which corresponds to 107 million m² (BAU) and 331 million m² (RDP).
The long-term potential of Germany for 2050 results in a specific collector area between 2 m² (BAU) and 8 m² per inhabitant (RDP), which corresponds to 165 million m² (BAU) and 662 million m² (RDP).

For solar combisystems 152.26 million m² are expected to be used as part of the overall collector area (RDP). This collector area corresponds to an energy production of 47.2 TWh which equals 15.0 million tons CO_2 emissions (oil equivalent) per year.

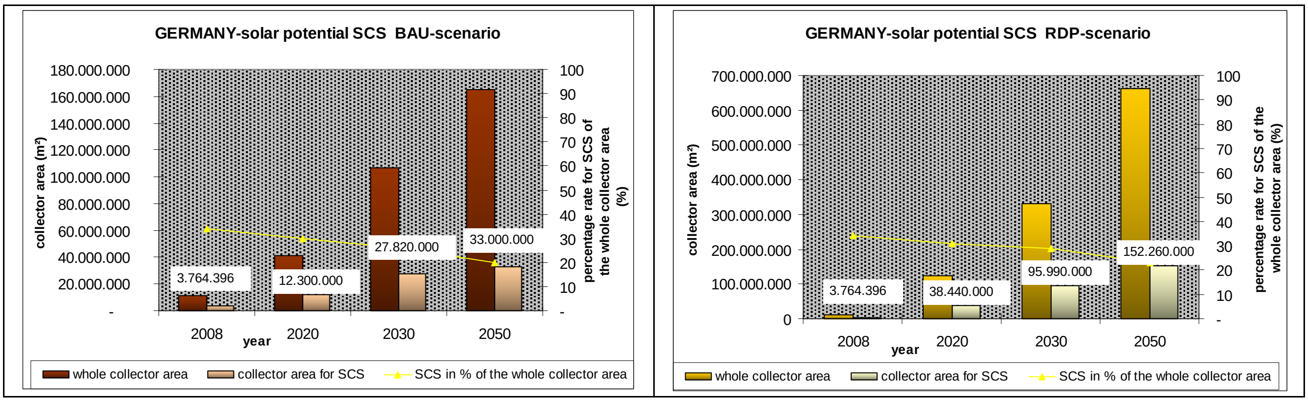


Figure 4: Overall solar thermal potential and potential for SCS in Germany: once the BAU-scenario (left), once the RDP-scenario (right)

The short-term potential of **France** for 2020 results in a specific collector area between 0.2 m² (BAU) and 0.5 m² per inhabitant (RDP), which corresponds to 12.3 million m² (BAU) and 30.1 million m² (RDP).
The medium-term potential of France for 2030 results in a specific collector area between 1.2 m² (BAU) and 2.8 m² per inhabitant (RDP), which corresponds to 76 million m² (BAU) and 181 million m² (RDP).
The long-term potential of France for 2050 results in a specific collector area between 1.8 m² (BAU) and 5.5 m² per inhabitant (RDP), which corresponds to 115 million m² (BAU) and 363 million m² (RDP).

For solar combisystems 65.34 million m² are expected to be used as part of the overall collector area (RDP). This collector area corresponds to an energy production of 20.1 TWh which equals 6.4 million tons CO_2 emissions (oil equivalent) per year.

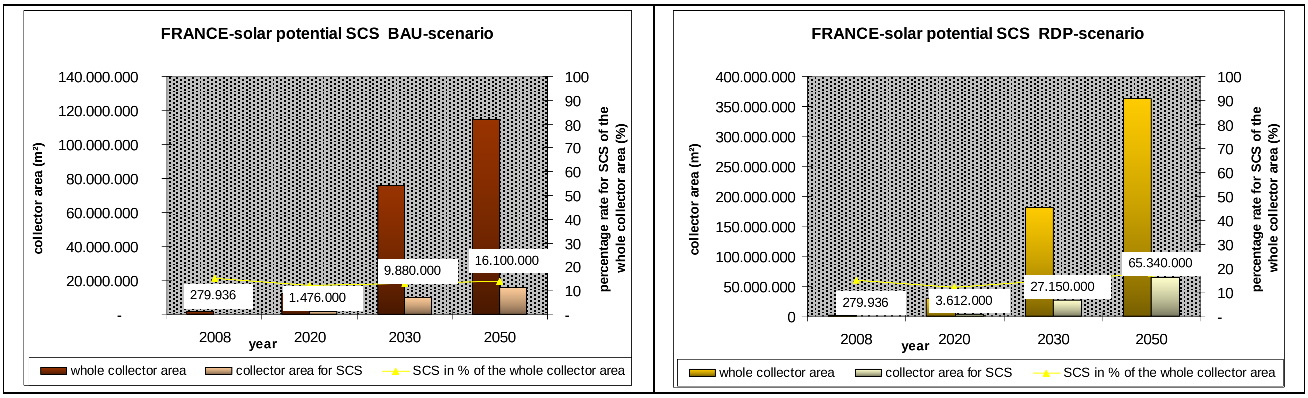


Figure 5: Overall solar thermal potential and potential for SCS in France: once the BAU-scenario (left), once the RDP-scenario (right)

The short-term potential of **Sweden** for 2020 results in a specific collector area between 0.1 m² (BAU) and 0.3 m² per inhabitant (RDP), which corresponds to 1.3 million m² (BAU) and 3.2 million m² (RDP).
The medium-term potential of Sweden for 2030 results in a specific collector area between 0.6 m² (BAU) and 1.4 m² per inhabitant (RDP), which corresponds to 5.8 million m² (BAU) and 13.4 million m² (RDP).
The long-term potential of Sweden for 2050 results in a specific collector area between 1.5 m² (BAU) and 4.6 m² per inhabitant (RDP), which corresponds to 14 million m² (BAU) and 43 million m² (RDP).

For solar combisystems 26.72 million m² are expected to be used as part of the overall collector area (RDP). This collector area corresponds to an energy production of 8.3 TWh which equals 2.6 million tons CO_2 emissions (oil equivalent) per year.

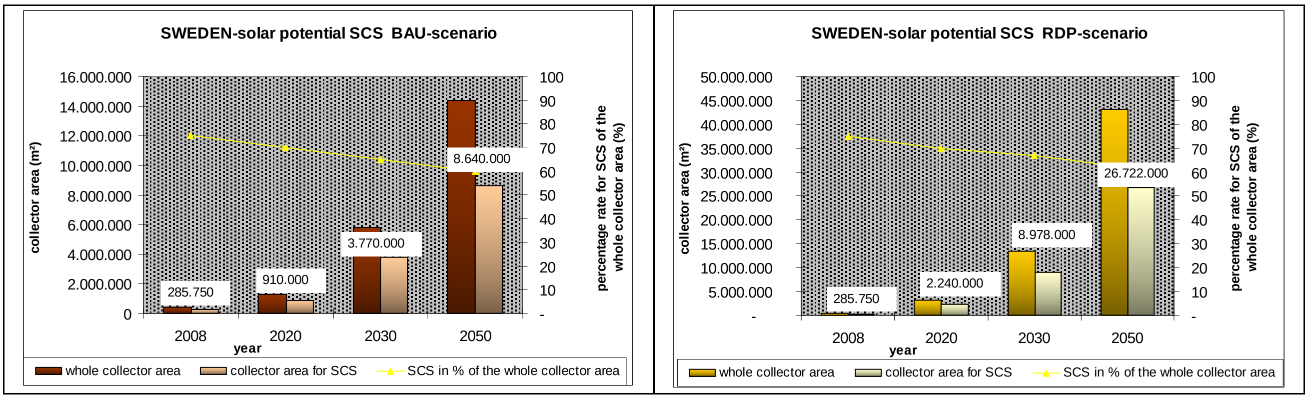


Figure 6: Overall solar thermal potential and potential for SCS in Sweden: once the BAU-scenario (left), once the RDP-scenario (right)

2 Typical solar combisystem

Main Authors : Alexander Thür, Philippe Papillon

Within CombiSol project, a survey has been done regarding typical solar combisystems available on the market. The main results of this survey are:
A standardization of hydraulic schemes has been observed since the end of the 90's, leading to 6 main categories,
More and more complete packages are available on the market, leading to more prefabricated systems that offer the potential to increase the compactness, the level of quality and to reduce the man-power required for installation on site, and thus reducing the risks of misfunctionning.

The following section will address first the main layouts of typical solar combisystems, and then present some products available on the market as well as tendencies for the future.

2.1 Different hydraulic schemes

As already mentioned, 6 main categories of solar combisystems have been identified within the CombiSol survey. These categories differ by:

- Domestic Hot Water preparation : this preparation can be made by:
  - Tank in Tank (option A)
  - Immersed DHW Heat Exchanger (option B)
  - External DHW Unit (option C)
- Integration of auxiliary energy
  - Auxiliary as Return Flow Increase (Option 1)
  - Auxiliary Charging Heat Storage (Option 2)

Thanks to this typology, the various configurations can be classified according to the previous nomenclature, leading to the basic following layouts illustrated in Figure 7, Figure 8 and Figure 9.

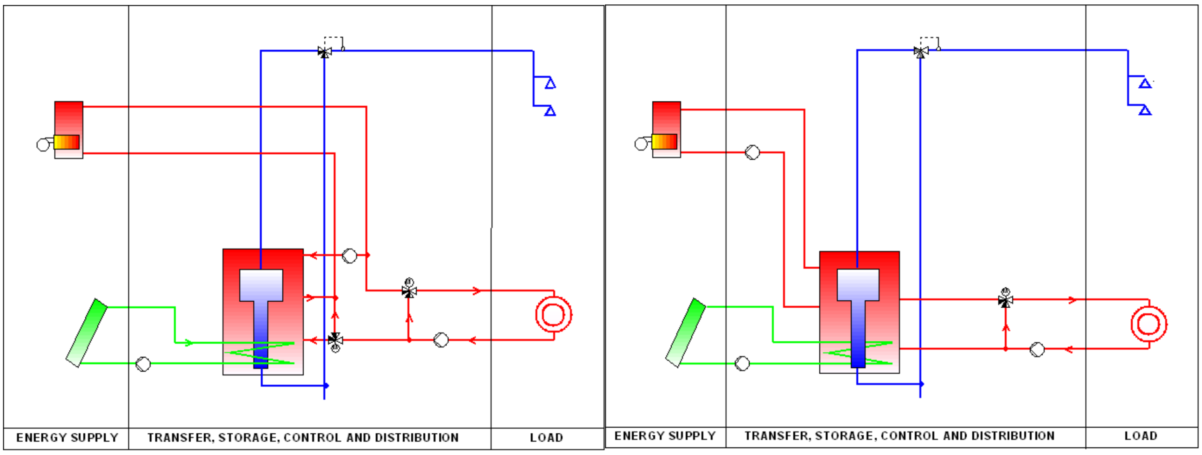


Figure 7: Hydraulic scheme of a tank-in-tank system –
auxiliary boiler is integrated as return flow increase (left) or is charging the heat storage tank (right)

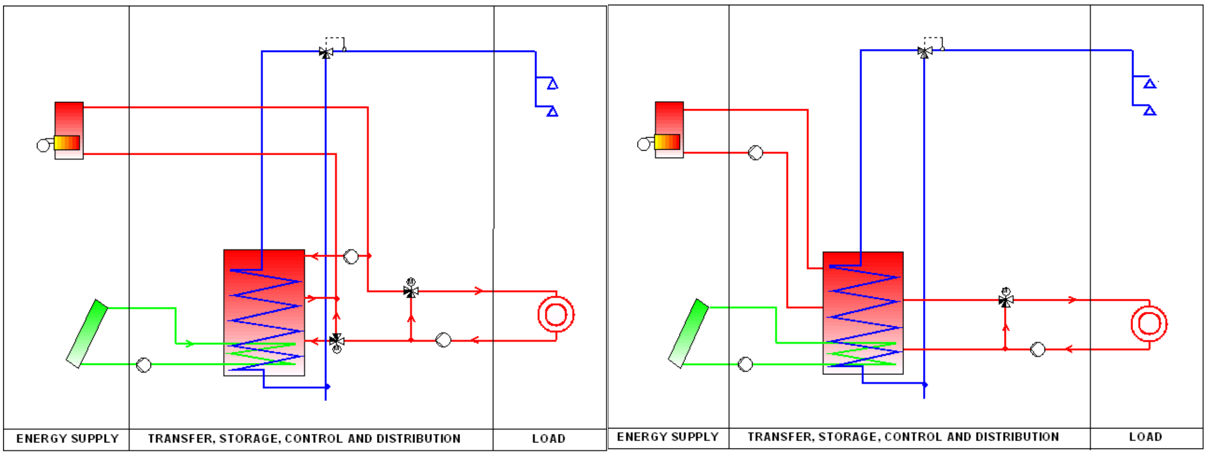


Figure 8: Hydraulic scheme of a heat storage system with an immersed heat exchanger – auxiliary boiler is integrated as return flow increase (left) or is charging the heat storage tank (right)

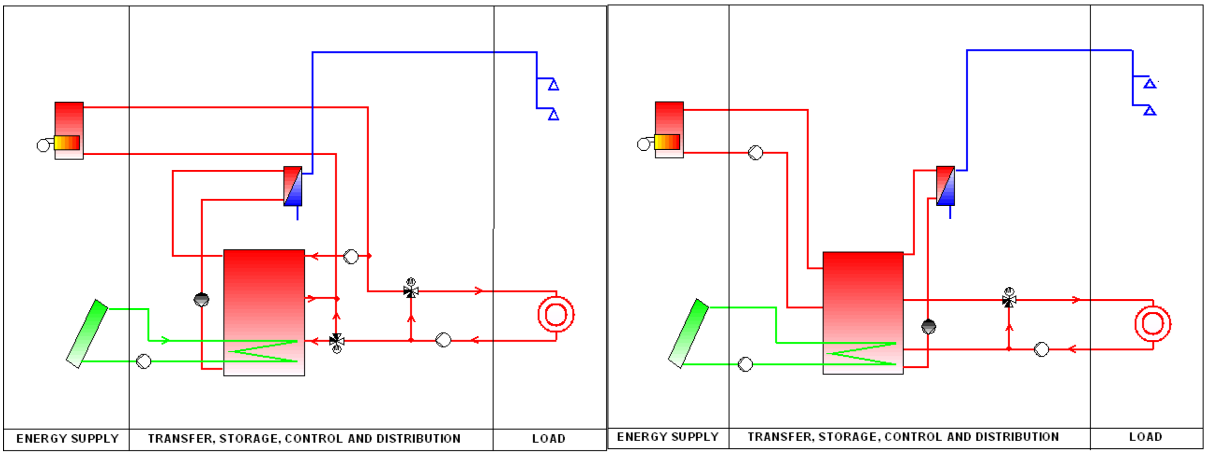


Figure 9: Solar heating plant with a fresh water unit – auxiliary boiler is integrated as return flow increase (left) or is charging the heat storage tank (right)

2.1.1 Domestic Hot Water Preparation

More details on Domestic Hot Water Preparation is provided below, and a synthesis of the advantages and disadvantages of each solution is then shown.

- <u>Tank in Tank (option A)</u>

The domestic hot water (DHW) preparation unit is performed in an internal tank.
Two shapes/locations are possible for this tank:

- as shown in Figure 7, the tank is in two parts and the bottom of the tank act as a pre-heater charged from the solar energy
- the tank is only located at the top of the heat storage and benefits from solar energy only when this one is at a higher temperature than those needed by the heating loop.

A temperature sensor placed either into the DHW tank or in the top part of the heating storage controls the requirement of auxiliary energy. This one is brought either trough a heat exchanger into the DHW tank or directly into the top part of the heat storage.
A thermostatic mixing valve is place at the outlet of domestic hot water, for protection against burning risks, especially in summer time when a very high temperature can be reached in the tank.

- <u>Immersed DHW Heat Exchanger (option B)</u>

Domestic hot water is prepared in one heat exchanger extending over the full height of the store, or two heat exchangers one in the bottom part and one in the top part. These heat exchangers are made of finned copper tubes (common in Sweden) or ribbed stainless steel, often with a significant internal volume (common in many other parts of Europe). The top part of the tank has to be kept above the minimum temperature required to prepare the desired DHW temperature. The greater the flow the higher is the required temperature in the top part of the store. Hot water is then mixed with cold water to the desired temperature before reaching the user.

- External DHW Unit (option C)

The domestic hot water (DHW) preparation unit is performed as an external flat plate heat exchanger unit. This DHW-unit is heating up hot water exactly at the same time when hot water tapping takes place. Based on a signal from a sensor that realizes some hot water tapping the pump in the primary loop is started and the pre-defined DHW temperature is controlled automatically depending on the actual hot water power demand. For this DHW temperature control in principle two different power control strategies are offered on the market: a) mass flow control or b) temperature control on the primary side of the flat plate heat exchanger.

a) Mass flow control is realized either with a speed controlled pump in combination with a DHW temperature sensor and a PI(D) controller, or:
with a full speed running pump in combination with a flow control valve which is mechanically controlled by a temperature sensor mounted directly at the hot outlet of the DHW heat exchanger and/or a flow sensor measuring the tap water flow rate.
Additionally a mixing valve might be used on the primary side which limits the inlet temperature at the heat exchanger (typically 55 to 60 degree) resulting in more stable DHW tap temperature and to avoid lime deposit on the secondary side of the DHW heat exchanger.
b) Temperature at the primary inlet side of the DHW heat exchanger can be controlled by a mixing valve which is mechanically controlled by a temperature sensor mounted directly at the hot outlet of the DHW heat exchanger; the pump in this case is running full speed.

In Table 1, we tried to summarize each typology, but this table is definitely NOT a complete characterisation:

	Advantages	Disadvantages
Tank in Tank (option A)	• Possibility to meat high DHW demand through the DHW stored in the internal tank • Lime scale problems are almost impossible; should they occur, then they will only have a minimal effect. • No parasitic (additional electric) energy for hot water preparation • No extra connections for DHW preparation	• Depending on details of how the hot water tank is designed, medium to bad cooling characteristics of the bottom part of the heat store • Depending on details of how the hot water tank is designed, some volume in the lower part could be on temperature level for legionella growth • Maintenance and replacement of the DHW tank is almost impossible, but depends on the tank design
Immersed DHW Heat Exchanger (option B)	• No parasitic (additional electric) energy for DHW-preparation • High legionela security because only a very little volume is kept warm • No extra connections for DHW preparation	• Low peak power • Depending on details bad to worse cooling effect of the heat store • Lime problems possible if temperature in heat store exceeds 60°C • Maintenance and replacing is almost impossible, depending on the design
External DHW Unit (option C)	• Depending on design and size of heat exchanger high peak power is possible • Good cooling effect in the heat store (if appropriate control of the pump) • Best usage of the stored energy in the tank • No lime problems when forward temperature is controlled • Highest legionela security because almost no volume is kept warm • Maintenance and replacing is easy possible	• A pump is necessary to run the DHW preparation unit • Parasitic energy (electricity for the pump) is required • Thermal performance and thus solar savings are strongly dependant of the behaviour of the pump controller. When the design is poor can lead to a complete de-stratification of the storage

Table 1: Summary of advantages and disadvantages of different DHW preparation typologies

2.1.2 Auxiliary energy and its integration in a solar combisystems

Several types of auxiliary heater are available to be used in solar combisystems and they might have quite different operating conditions. For example a condensing natural gas boiler needs very low return temperatures (<<57°C) to be able to use the condensation effect, whereas a wood log or pellet boiler on the other hand needs a minimum return temperature (>55°C) in order to avoid corrosion and deposit problems due to condensation of the flue gas. Also different boilers have different characteristics how they can be controlled. A natural gas boiler can change the power by modulating quite fast and easy; other boiler types just can change power by the stop or go principle.
Since the boundary conditions of each house, each country, each system concept, availability of different fuel types, etc. are different, it can not be stated the one or the other auxiliary heater is the best. Therefore just some main characteristics important for integration in a solar combisystem are mentioned:

- <u>Auxiliary as Return Flow Increase (Option 1)</u>

Depending on SH return temperature and heat storage temperature the heat storage is bypassed or SH flow is preheated by solar heated water in the heat storage and finally heated to the set temperature by the auxiliary heater. Therefore the auxiliary heater is operating within the full range of power: between almost zero and maximum power.
The DHW-tank is heated up by the auxiliary volume in the buffer tank up to a set temperature. The set temperature is typically controlled with a temperature sensor immersed inside the DHW-tank, sensor locations at the buffer tank are also possible but less precise. The auxiliary heating stops when set temperature is reached.
This configuration is well adapted to auxiliary boiler with a wide range of power modulation and able to provide the required flow temperature to the SH loop according to the ambient temperature like gas boilers.

- <u>Auxiliary Charging Heat Storage (Option 2)</u>

The auxiliary heater has to keep the middle part of the heat storage at a sufficient high temperature if the input of solar energy is not sufficient. Due to the inertia effect of the water in the tank, the auxiliary heater is operating mostly at its maximum power during time periods long enough to minimize harmful exhaust gas emission of the burner.
This configuration is well adapted to auxiliary boilers with a low range of power modulation, which require long running cycles like wood boilers.

The table below summarizes some advantages and disadvantages for the two options.

	Advantages	Disadvantages
Auxiliary as Return Flow Increase (option 1)	• Can fully take advantage of power modulation of boilers, and variable flow temperature control • Reduced storage volume dedicated to auxiliary	• More difficult to take into account two SH loops at different temperature (radiator and floor heating) • As long as SH is needed, boiler is irrigated, thus increasing potential thermal losses
Auxiliary Charging Heat Storage (Option 2)	• Well adapted for boiler that need thermal buffer or long running cycles • Depending on the storage, easier connections of two SH loops at different temperature • Boiler flowrate is independent of SH flowrate	• Higher storage volume required or reduced volume dedicated to solar energy • Higher mean temperature of the storage, thus increasing potential thermal losses

Table 2: Summary of advantages and disadvantages of different auxiliary integration typologies

2.1.3 Typical solar loops

For solar combisystems flat plate or vacuum tube collectors can be used. Typically vacuum tube collectors have better properties in the transition- and winter periods, but the investment costs are higher than for flat plate collectors as well.
The heat transfer from the collector loop to the heat store can happen in two ways. The first option is that a heat store with an immersed heat exchanger is used. In this case the collector fluid is pumped through one or more immersed heat exchanger. This system needs only one pump for the solar heating system and is mostly installed in small plants like up to 20 m². The second option is an external heat exchanger. In this case the collector loop is shared in two parts: primary collector loop and secondary collector loop. This system is used in solar combisystems with collector area of about 15 m² and upwards.

- <u>Stratification Strategies</u>

In order to optimise the process of charging solar energy into the solar heat storage it is possible to use different kinds of stratification strategies. This means that depending on the collector flow line temperature the solar energy is charged into the heat storage at the height where the temperature is more or less equal.
If just one immersed heat exchanger is used, like in principle shown in Figure 10 no stratification is possible. The heat is put into the heat storage in the bottom part and is heating up the heat storage uniformly from the bottom up to the top. If two or more immersed heat exchangers are installed, in a simple way it is possible to realize stratified energy input into the tank by using external valves which chose the right heat exchanger depending on the temperatures (see Figure 11).

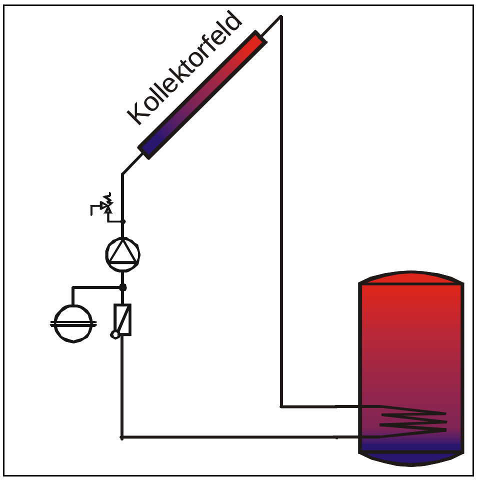


Figure 10: Immersed/internal heat exchanger at one level

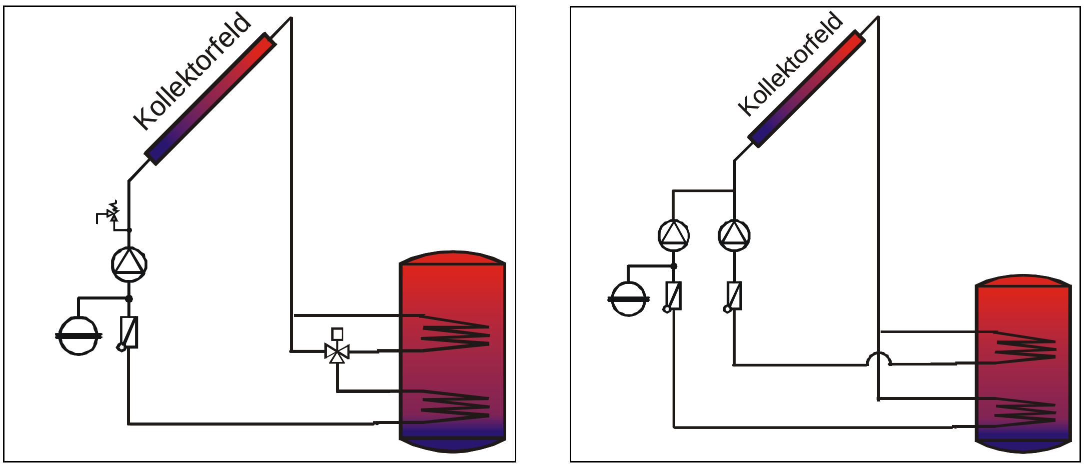


Figure 11: Examples of immersed heat exchanger at two levels; left: one or BOTH heat exchanger are used; right: one OR the other heat exchanger is used

If an external flat plate heat exchanger is used, stratification is possible either by pipe connections at the heat storage at different heights and choosing the right connection by controlled switching valves or by any stratification devices integrated in the heat storage. Such stratification devices are using the characteristic of different density of water at different temperatures. Hot water is moving to the upper part of the heat storage until the equivalent temperature level is reached. These stratification devices do not need any active control unit. In Figure 12 two examples are shown.

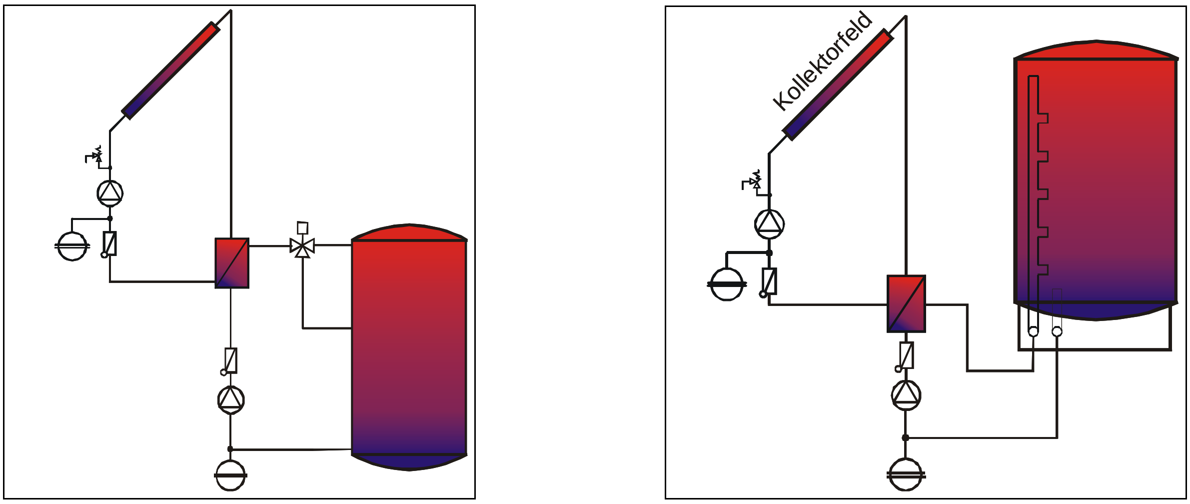


Figure 12: External heat exchanger with: left: two pipe connections at two different level (external stratification via switching valve); right: internal stratification device

- <u>Flow Rate Strategy</u>

The collector itself and the collector loop can be designed in different ways according to the flow rate strategies: high flow, low flow or matched flow.
Depending on the flow rate in the collector loop the temperature lift between collector inlet and outlet is different: at high flow (typically around 50 l/h per m^2 collector area) the temperature difference is around 10°C where low flow operation (typically around 15 l/h per m^2 collector area) the temperature difference is around 30°C. If the low flow strategy is chosen also a stratification device should be used in order to get a good performance of the system.
Matched flow means, that the controller is changing the flow rate based on specific charging strategies between low flow and high flow. Such a strategy might be to operate first in low flow in order to reach as fast as possible the set temperature and later to change more and more to high flow in order to keep the flow temperature constant at the set temperature and to avoid high operation temperatures with reduced collector efficiency.

- <u>Overheating Protection / Stagnation</u>

Some components of a solar thermal system must be protected against high temperatures due to stagnation in the collector as temperatures above 200°C can be reached and steam with temperatures up to 150°C can be pressed into the pipes of the system. For solar combisystems stagnation can be a daily operating condition in the summer period. If planner and installer observe some major rules, stagnation becomes a normal and harmless condition for the solar combisystem. Overheating protection can be achieved by:

- Passive protection. Passive protection is achieved by applying some rules during the design process and the installation of the system, like the installation of the expansion vessel to avoid high temperature in contact with the membrane, the design of the collector field to promote a good behaviour when steam is produced, and additional equipment like stagnation cooler. Passive protection strategies should be used, because they are fail-save in cases of no electricity.
- Active protection. Active protection could be night cooling where the collector loop is started during night and heat is dissipated from the heat storage to the ambient air via the collector, additional radiator loop or ground loop installed used for heat dissipation, …

2.2 *Products and tendencies*

During the last decade, a significant change in solar combi-systems was observed with the market introduction of prefabricated component groups, and compact prefabricated systems.

2.2.1 Prefabricated component groups

Some manufacturers provide a wide variety of prefabricated component groups that could be used for a solar combisystems:

- **Solar charging unit** which combines pump, non return valves, thermometer, safety valves and in most cases the controller of the solar loop.
- **External DHW unit** which includes DHW heat exchanger, pump, thermostatic valves, …
- **Space heating unit** with various hydraulic layouts depending on the heating loop designed. These units includes pumps, 3 way-valve, …

Figure 13: Solar Charging Unit (Viessmann, SOLution, Tisun, Sonnenkraft, Bosch-Junkers)

Figure 14: External DHW unit (SOLution, Sonnenkraft)

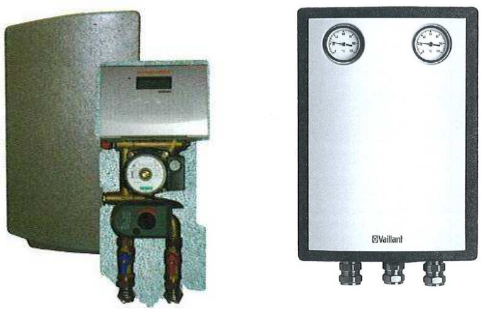


Figure 15: Space Heating Units (Sonnenkraft, Vaillant)

In some cases, the prefabricated component groups can be directly fixed to the water storage and plugged to the various connections of the storage thanks to flexible stainless steel hoses. This design reduced the time spent by the installer and also the risks of wrong connections, but insulation of the storage as well as the flexible pipes and pre-fabricated component groups has to be well realised to limit the heat losses.

2.2.2 Compact prefabricated systems.

The first step was to produce some prefabricated component groups to reduce man-power on site and to limit the risks of wrong connections or bad dimensioning components. The second step that more and more manufacturers are crossing is to produce complete, compact prefabricated systems.

These systems sometimes include the auxiliary boiler and are designed as a complete heating and DHW preparation system using solar energy and auxiliary. These solutions offer significant advantages as compactness, limited time spent for installation, reduction of mistakes risks during the installation process and reduction of heat losses thanks to reduced number and length of connection pipes.

Figure 16 to Figure 20 illustrate some compact prefabricated systems including various auxiliary boilers: Gas boiler, heat pump, pellet boiler.

Figure 16: Compact combisystems including condensing gas boilers (Solvis, DeDietrich, Bösch, Clipsol)

Figure 17: Compact combisystems including condensing gas boilers (Rotex, Capito, Sonnenkraft)

Figure 18: Compact combisystems including gas or oil burner (Olymp)

Figure 19: Compact combisystems including heat pump (Sonnenkraft)

Figure 20: Compact combisystems including pellet boilers (Solarfocus, Okofen)

3 Qualitative inspection

Main Author : Alexander Thür

Within the CombiSol project 70 recently built solar combisystems in Austria (20), Germany (6), France (24), and Sweden (20), were qualitatively analyzed by experts from the respective countries using an evaluation tool specially developed within the CombiSol project. On the project webpage available as download is the evaluation tool itself (D5.1a) and a guideline how to use it (D5.1b), a two-page documentation of all 70 evaluated solar combisystems (D5.2), and a summary report on the result of all qualitative evaluations (D5.4).

3.1 Procedure

The evaluation tool used in CombiSol basically is a check-list divided in eight main parts of the plant as shown in Figure 21 and consisting of 113 evaluation points in total. The evaluation tool consists of the document D5.1b (Figure 23) describing each evaluation point in detail and giving hints what should be expected in positive cases plus an evaluation form D5.1a. Public output of this excel tool is a two-page documentation for each of the 70 evaluated plants as shown in Figure 24.

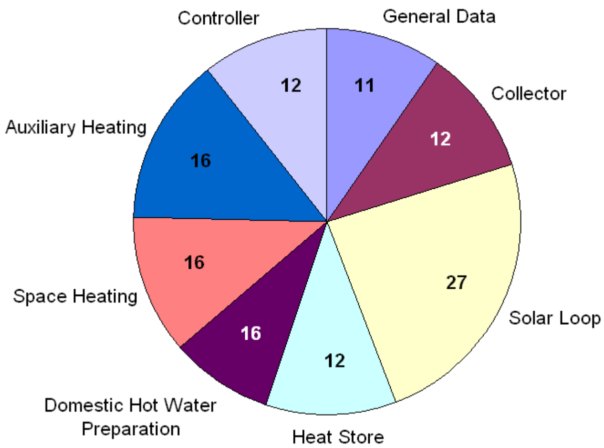


Figure 21: Partition of the Evaluation Points

An overview on collector sizes over space heating area of all 70 evaluated solar combisystems in Austria, France, Germany and Sweden is shown in Figure 22. Target values were single family houses with about 80 to 220 m^2 heated area and solar combisystems with 8 to 30 m^2 collector area. As it can be observed, quite clear separated groups of points for each country show a strong "cultural" influence on typical design values in terms of collector area where the sizes of the houses are well balanced.

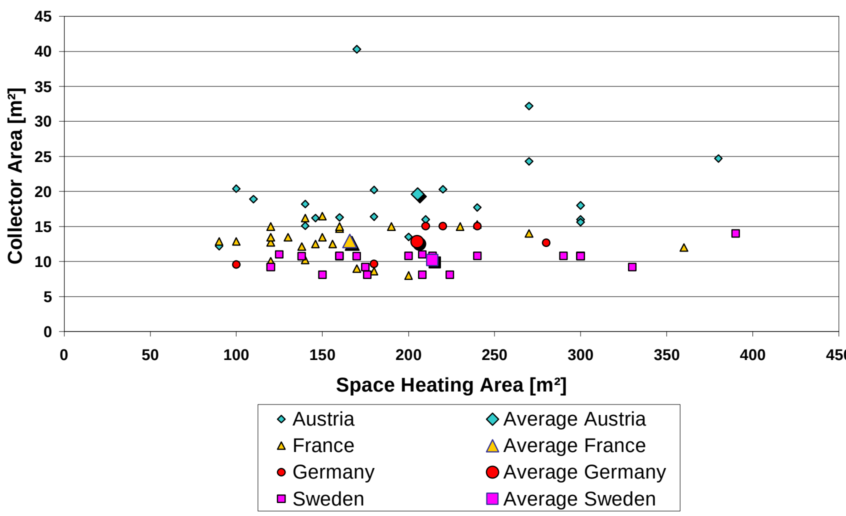
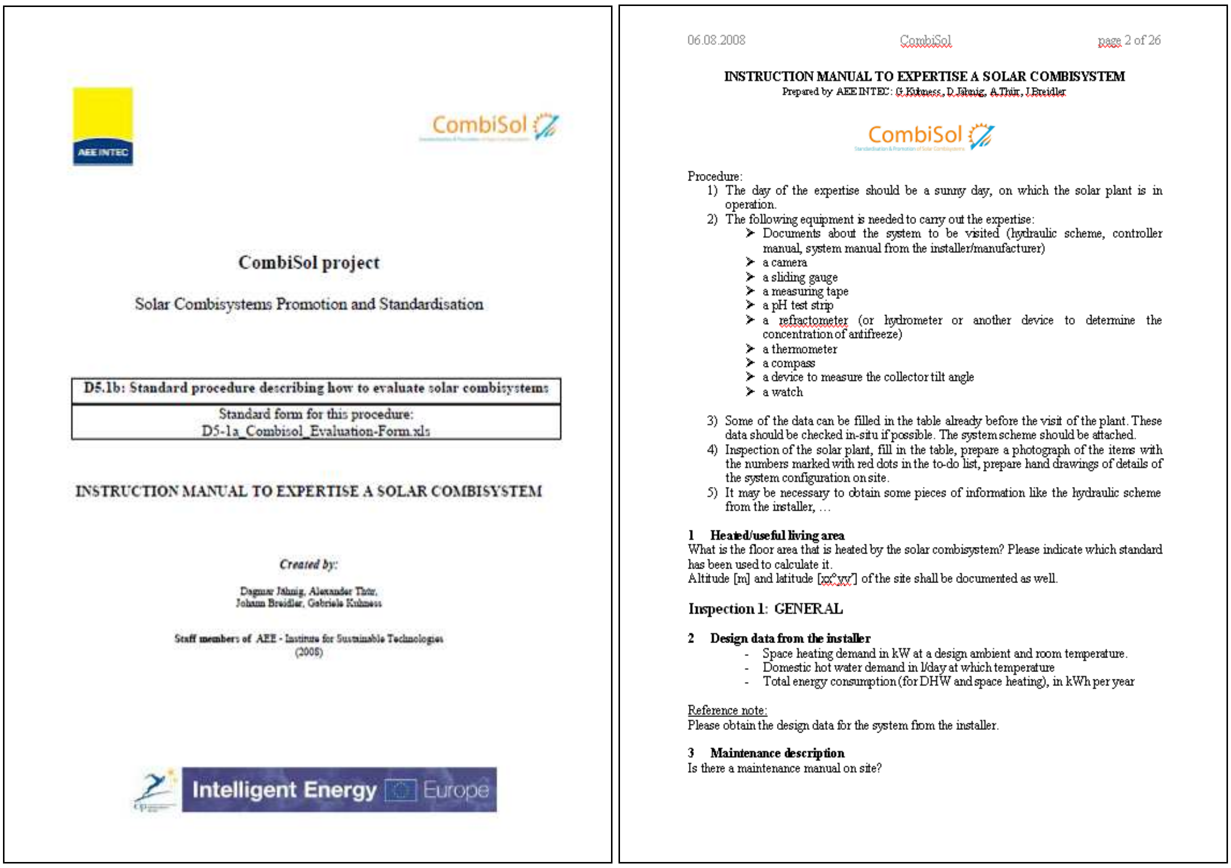


Figure 22: Space heating Area and Collector Area of the evaluated houses.



AEE INTEC

CombiSol

CombiSol project

Solar Combisystems Promotion and Standardisation

D5.1b: Standard procedure describing how to evaluate solar combisystems

Standard form for this procedure:
D5-1a_Combisol_Evaluation-Form.xls

INSTRUCTION MANUAL TO EXPERTISE A SOLAR COMBISYSTEM

Created by:

Dagmar Jähnig, Alexander Thür,
Johann Breidler, Gabriele Kuhness

Staff members of AEE - Institute for Sustainable Technologies
(2008)

Intelligent Energy Europe

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INSTRUCTION MANUAL TO EXPERTISE A SOLAR COMBISYSTEM
Prepared by AEE INTEC: G.Kuhness, D.Jähnig, A.Thür, J.Breidler

CombiSol

Procedure:
1) The day of the expertise should be a sunny day, on which the solar plant is in operation.
2) The following equipment is needed to carry out the expertise:
   - Documents about the system to be visited (hydraulic scheme, controller manual, system manual from the installer/manufacturer)
   - a camera
   - a sliding gauge
   - a measuring tape
   - a pH test strip
   - a refractometer (or hydrometer or another device to determine the concentration of antifreeze)
   - a thermometer
   - a compass
   - a device to measure the collector tilt angle
   - a watch
3) Some of the data can be filled in the table already before the visit of the plant. These data should be checked in-situ if possible. The system scheme should be attached.
4) Inspection of the solar plant, fill in the table, prepare a photograph of the items with the numbers marked with red dots in the to-do list, prepare hand drawings of details of the system configuration on site.
5) It may be necessary to obtain some pieces of information like the hydraulic scheme from the installer, …

1 Heated/useful living area
What is the floor area that is heated by the solar combisystem? Please indicate which standard has been used to calculate it.
Altitude [m] and latitude [xx°yy'] of the site shall be documented as well.

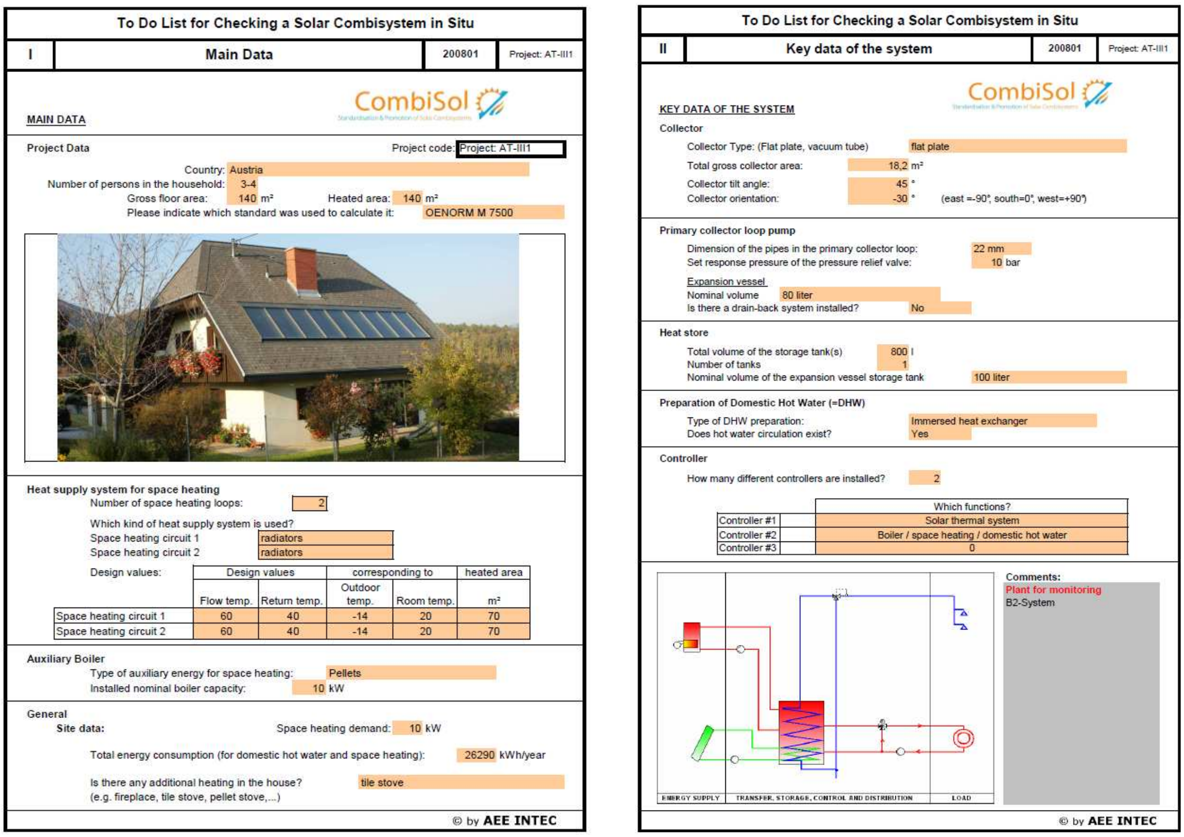
Inspection 1: GENERAL

2 Design data from the installer
- Space heating demand in kW at a design ambient and room temperature.
- Domestic hot water demand in l/day at which temperature
- Total energy consumption (for DHW and space heating), in kWh per year

Reference note:
Please obtain the design data for the system from the installer.

3 Maintenance description
Is there a maintenance manual on site?

Figure 23: Standard Procedure for Evaluation available as D5.1a and D5.1b.



To Do List for Checking a Solar Combisystem in Situ

I	Main Data	200801	Project: AT-III1

CombiSol

MAIN DATA

Project Data — Project code: Project: AT-III1

Country: Austria
Number of persons in the household: 3-4
Gross floor area: 140 m² Heated area: 140 m²
Please indicate which standard was used to calculate it: OENORM M 7500

Heat supply system for space heating
Number of space heating loops: 2
Which kind of heat supply system is used?
Space heating circuit 1: radiators
Space heating circuit 2: radiators

Design values:

	Design values		corresponding to		heated area
	Flow temp.	Return temp.	Outdoor temp.	Room temp.	m²
Space heating circuit 1	60	40	-14	20	70
Space heating circuit 2	60	40	-14	20	70

Auxiliary Boiler
Type of auxiliary energy for space heating: Pellets
Installed nominal boiler capacity: 10 kW

General
Site data: Space heating demand: 10 kW
Total energy consumption (for domestic hot water and space heating): 26290 kWh/year
Is there any additional heating in the house? (e.g. fireplace, tile stove, pellet stove,...) tile stove

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To Do List for Checking a Solar Combisystem in Situ

II	Key data of the system	200801	Project: AT-III1

CombiSol

KEY DATA OF THE SYSTEM

Collector
Collector Type: (Flat plate, vacuum tube) flat plate
Total gross collector area: 18,2 m²
Collector tilt angle: 45 °
Collector orientation: -30 ° (east =-90°, south=0°, west=+90°)

Primary collector loop pump
Dimension of the pipes in the primary collector loop: 22 mm
Set response pressure of the pressure relief valve: 10 bar
Expansion vessel
Nominal volume 80 liter
Is there a drain-back system installed? No

Heat store
Total volume of the storage tank(s) 800 l
Number of tanks 1
Nominal volume of the expansion vessel storage tank 100 liter

Preparation of Domestic Hot Water (=DHW)
Type of DHW preparation: Immersed heat exchanger
Does hot water circulation exist? Yes

Controller
How many different controllers are installed? 2

	Which functions?
Controller #1	Solar thermal system
Controller #2	Boiler / space heating / domestic hot water
Controller #3	0

Comments:
Plant for monitoring
B2-System

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Figure 24: Example of 2 Page-Documentation available as D5.2 for each of the 70 plants.

3.2 Main results

For the evaluated solar combisystems the main findings of the qualitative evaluation are summarized for all countries for the following main component groups:

- Overall System Aspects
- Solar Collector and Solar Primary/Secondary Loop
- Heat Storage
- Space Heating Loop
- Domestic Hot Water Preparation (incl. DHW Circulation)
- Auxiliary Heater

3.2.1 Overall System

As described in the "State of the Art Report" (D2.4) the systems were classified in six categories, three Domestic Hot Water Types (DHW-Type A, B, C) and two Auxiliary Types (AuxType1, 2).

Figure 25 shows the distribution of different system types within the four participating countries. System type B2 (Immersed heat exchanger + auxiliary boiler is charging the heat storage tank) was the most evaluated type, but it is necessary to take into account that this is the only type evaluated in Sweden.

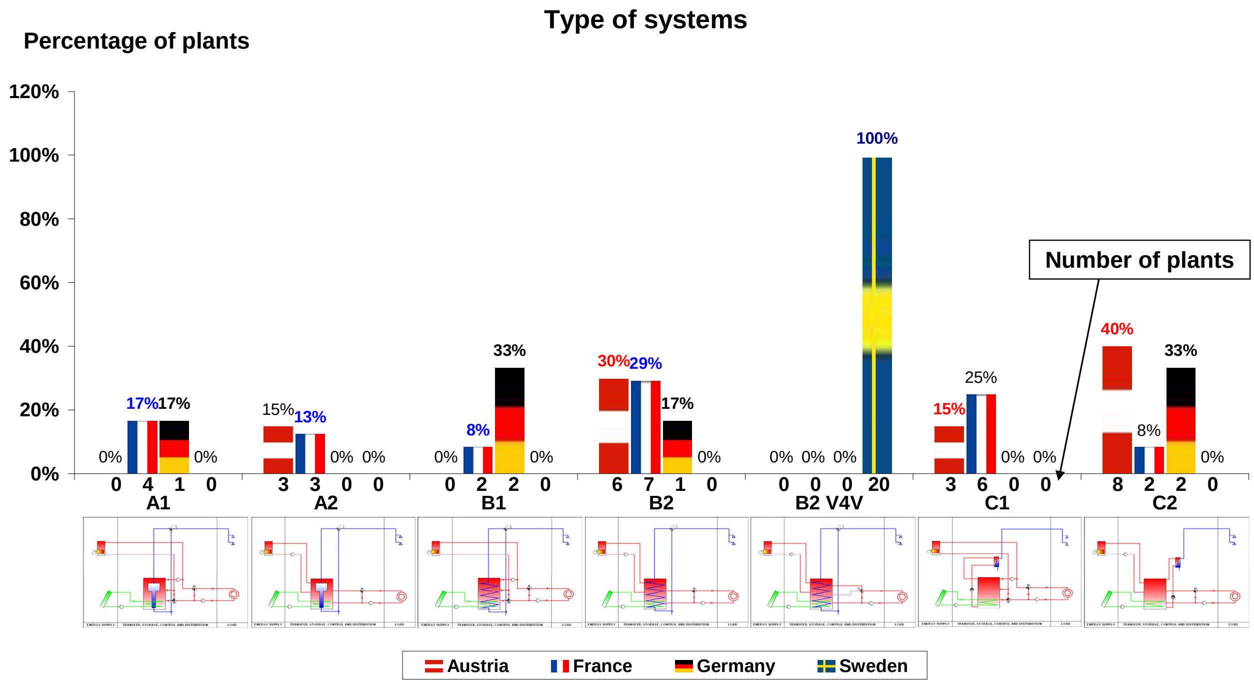


Figure 25: Type of systems evaluated within CombiSol

A first general check was the availability of documents for documentation of design, installation and commissioning on site and how the system owner in general was satisfied. As Figure 26 shows, the first 3 points beside France were quite poor evaluated. Only in few cases a maintenance manual or an instruction manual could be found or provided by the owner.

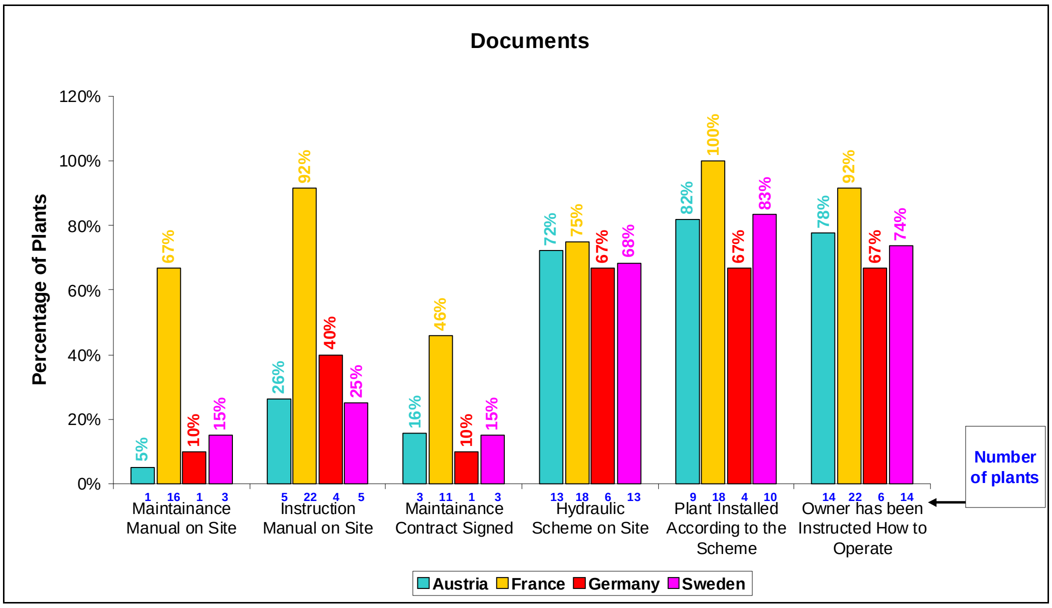
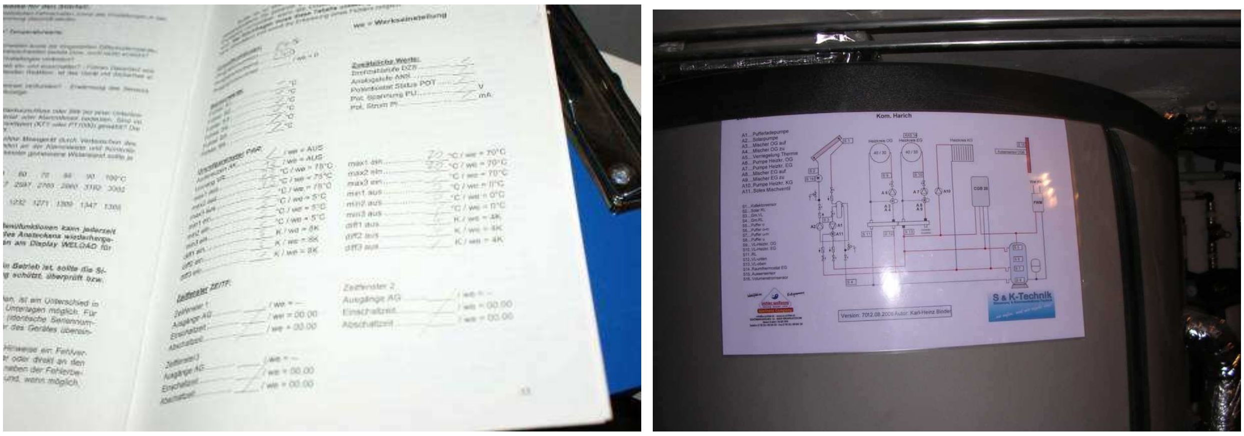


Figure 26: Available documents on site



Source: AEE INTEC

Figure 27: Example of documentation of controller settings and hydraulic scheme on site

3.2.2 Solar Loop

Flat plate collectors were installed in 94% of all 70 evaluated installations, just 6% were vacuum tubes. Most of the collectors (79%) were installed on the roof (on roof above the tiles or integrated in the roof between the tiles), just one collector was mounted at the façade and 20% were mounted on flat roof or ground or on walls elevated with a special support construction (see Figure 28).

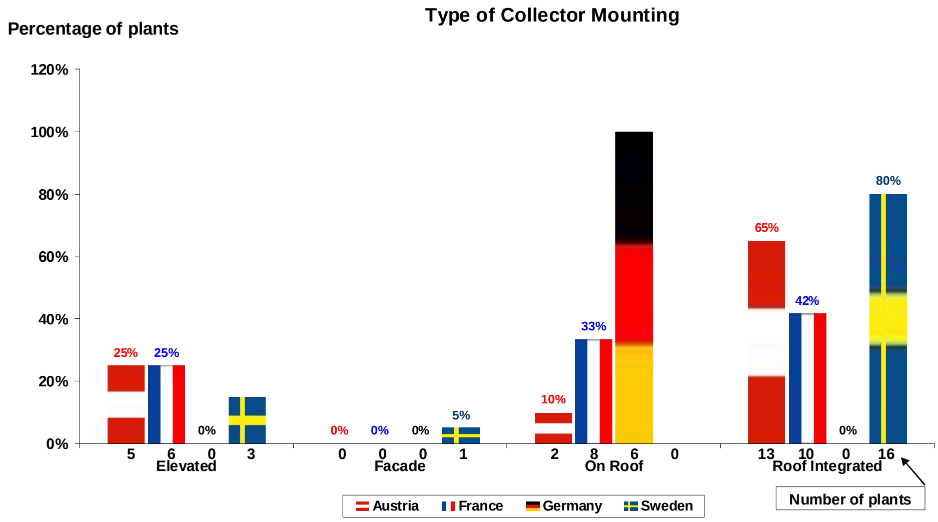


Figure 28: Type of collector mounting

In the following from each country several examples of collectors are shown how they are mounted and integrated in the building.

Figure 29: Examples of collector mounting (Source: Ines Education / France)

Figure 30: Examples of collector mounting (Source: SERC / Sweden)

Figure 31: Examples of collector mounting (Source: AEE INTEC / Austria)

Figure 32: Examples of collector mounting (Source: ITW / Germany)

About half of the evaluated collectors are roof integrated and therefore pipes are mounted inside the building. But the second half of collectors is mounted on the roof or elevated somehow on flat roofs, on the wall or on the ground. In these cases a certain length of the primary solar loop is mounted outside the building and pipe insulation should be well protected against animal bites and ultra-violet radiation. As Figure 33 shows, only 6 (18%) external pipes out of 34 (100 %) were in an acceptable way mounted, insulated and protected against damage.

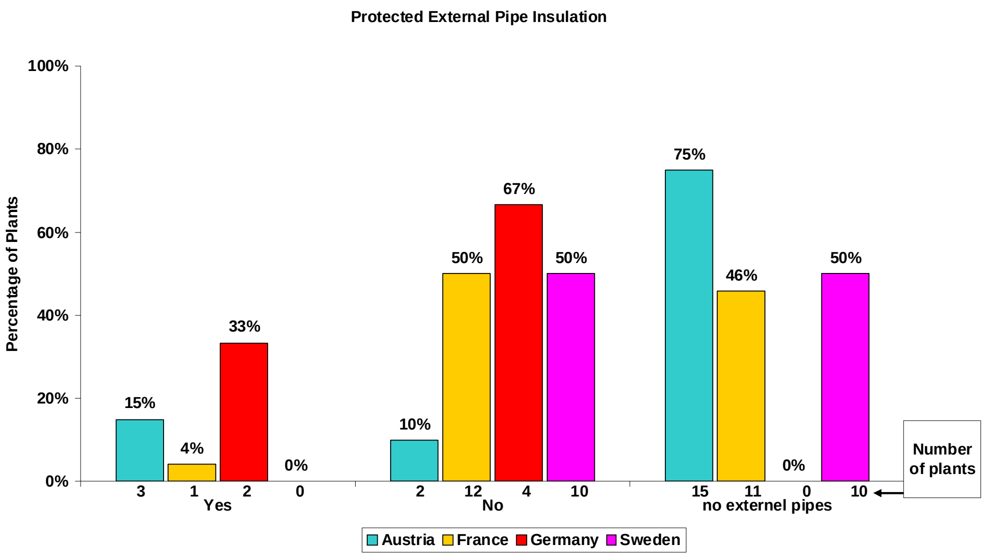


Figure 33: External pipe insulation

The following pictures show some good and bad examples as observed within the CombiSol project.


Figure 34: External pipe insulation (Source: Ines Education / France): left side good quality of insulation and protection; right side well insulated but no protection.

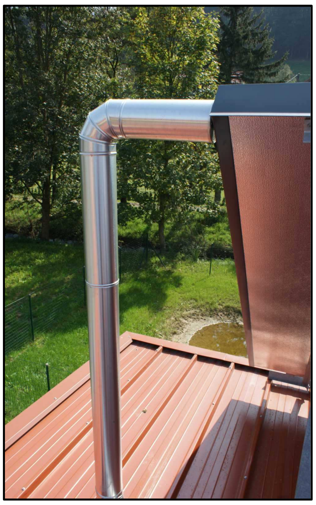



Figure 35: External pipe insulation (Source: AEE INTEC / Austria): good quality of insulation and protection


Figure 36: External pipe insulation (Source: AEE INTEC / Austria): left side: partly no insulation and no protection; right side: absolutely no insulation, therefore nothing which could be protected ☹

In summertime typically solar combisystems are over-dimensioned which leads to relative high number of hours where the solar pump is switched off because the heat storage has reached the maximum temperature. In such cases the collector is in stagnation and steam is produced which causes high expansion rates asking for well dimensioned expansion vessels and sufficient measures to avoid overheating of components. Further the “emptying behaviour” of the collectors and the entire collector field is of high importance in order to avoid mechanical stress or even damage due to pressure shocks when steam bulbs implode. If evaporation starts, depending on the “emptying behavior” the peak pressure which occurs in worst case can cause opening of the pressure relief valve leading to losses of solar fluid. As Figure 37 shows just slightly more then half of the systems show collector designs with good emptying behavior and only 2/3rd of the systems have collecting tanks installed at the outlet of the overpressure valves (e.g. Figure 38, middle and right).

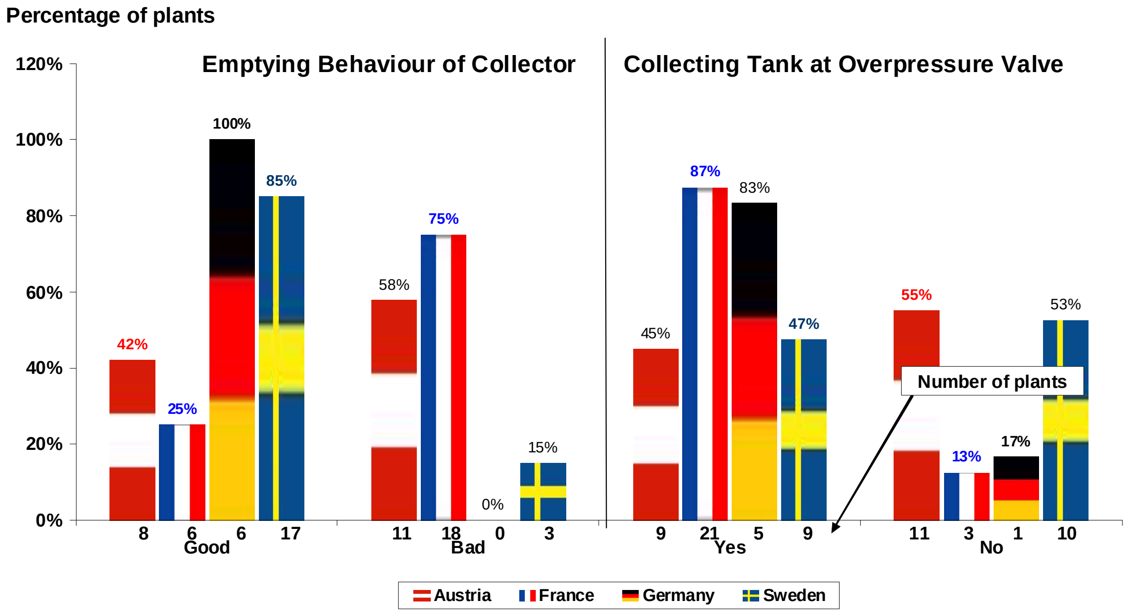


Figure 37: Stagnation characteristics

The expansion vessel in the primary solar loop is an essential component which is important to make sure that the pressure keeps within the necessary range and the collector loop keeps tight even under hard operating conditions like stagnation which occurs with quite high temperatures (up to around 200°C) and high peak pressure shocks. All the systems showed sufficient large dimensioned expansion vessels. Also almost all of them were mounted in the right position within the solar loop, which means that the fluid can enter the expansion vessel coming from both sides of the solar loop and is not blocked by a non return valve.
But still in a large number of systems the expansion vessels are not connected from above but from below. This can cause damage of the internal rubber membrane within much shorter time than expected due to overheating.
In most evaluated cases expansion vessels were connected correctly without a manual operable valve or the handle of this valve was dismounted. But still in 18 cases (13%) expansion vessels were connected wrong with a manual operable valve with the risk that this valve easy can be closed by unauthorized persons (children).

Source: AEE INTEC | Source: SERC | Source : SERC

Figure 38: Solar expansion vessel connection correct

Two more advanced solutions of connecting the expansion vessel are shown in Figure 39. On the left side before the expansion vessel a so called “stagnation cooler” is mounted which has a lot of fins helping to dissipate high temperature heat to the ambient air and assures that the liquid entering the expansion vessel is not too hot. On the right side before the expansion vessel an additional small preposition vessel (not insulated!!) is mounted which is filled already with cold liquid and due to mixing and heat losses the temperature is reduced as much that the expansion vessel itself is not overheated by the entering liquid.

Source: AEE INTEC

Source: INES Education

Figure 39: Solar expansion vessel connected via stagnation cooler (left) or "preposition vessel" (right)

In terms of other temperature critical components installed in the primary solar loop like ball-valves, flow adjustment valves or de-aeration valves or automatic de-aeration valves the evaluation result was mostly good, but still some wrong products were used.

3.2.3 Heat Storage

As Figure 40 shows, the majority of the investigated systems chosen for the evaluation show a collector size of about 8 to 20 m^2 and a storage volume of 700 to 2000 litres. This results in specific storage volumes in the range of around 50 to 100 litres per square meter collector area, with peak values above 200 litres per square meter. A typical rule of thumb is 50 litres per square meter collector area.

As it can be observed in Figure 40 it is not possible to see any dependency of specific storage sizes and the type of auxiliary heater or the type of hydraulic scheme (type 1 or type 2). It could be expected that fast reacting auxiliary heater like oil or natural gas boiler and much more type 1 systems "Auxiliary as Return Flow Increase" (all triangles in Figure 40) in general are realized with a smaller specific heat storage volume since there is no need (or no possibility as in type 2!) for an extra space heating auxiliary volume in the tank.

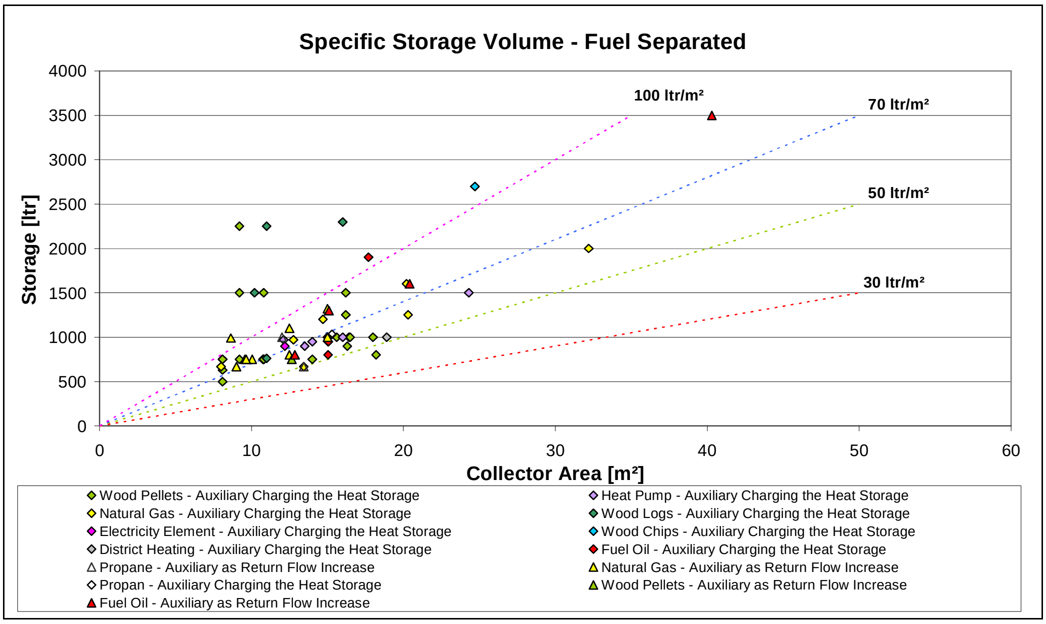


Figure 40: Specific storage volume versus collector area – fuel separated

As Figure 41 shows, in 65% of the systems just one tank as heat storage is installed, but in 23% two tanks are installed and 12% of the systems consist of more than 2 tanks. Multi-Tank systems always lead to increased heat losses due to significant worse ratio of heat-loss-surface to heat-storage-volume and typically much more cold bridges due to a higher number of pipe connections (which might be used or not).
The problem is increased by a huge percentage of not insulated unused pipe connections and still almost no usage of thermosiphon heat traps (Figure 42) in cases of pipe connections to the tanks.

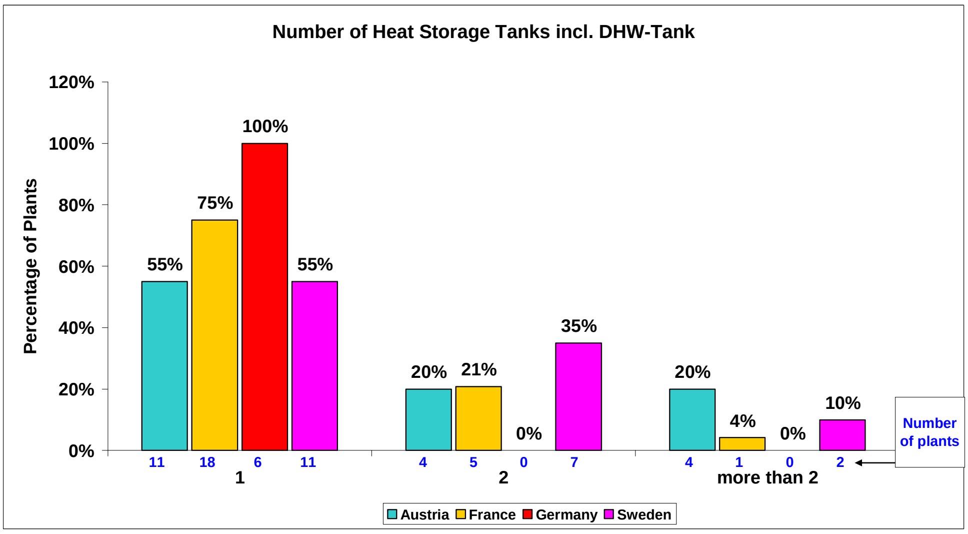


Figure 41: Number of heat storage tanks

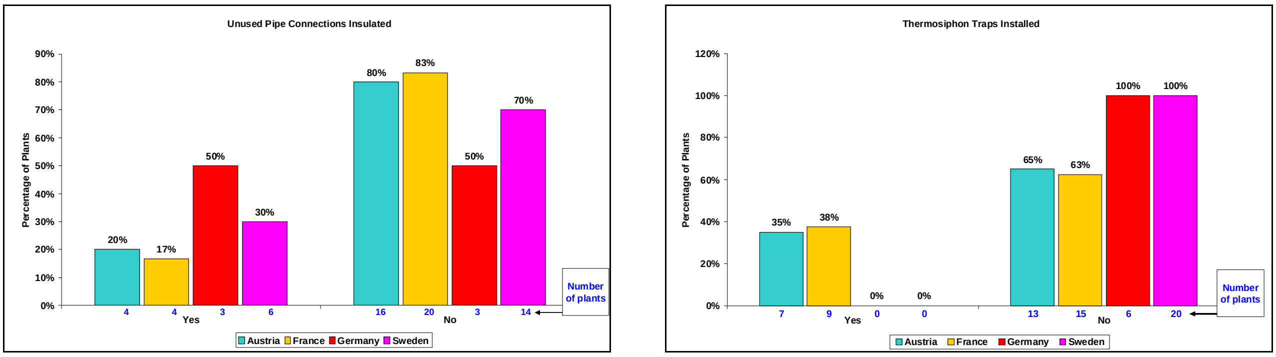


Figure 42: Unused pipe connections insulated (left), Thermosiphon heat traps installed (right)

Beside these facts also the tank insulation itself often was not mounted correctly or carefully enough, especially the top insulation parts of the tank. Even if high quality prefabricated insulation elements with low heat conductivity material are provided by the manufacturer, bad mounting taking place on site leads to high heat losses. Some poor and some good examples of details about heat storage insulation quality are shown from all participating countries in the next four figures.

Figure 43: Multistore system in Sweden (left), bad top insulation of a tank in tank system in Austria (right).

Figure 44: Not insulated and upwards connected pipes at the top of a tank in France (left), not insulated pipe connections and cold bridges due to temperature sensors at a tank in Germany (right).

Figure 45: Perfect insulated thermosiphon heat trap (left), good closed top tank insulation and insulated pipe connection (middle), pipe connection downwards and insulated temperature sensor immersion sleeve and insulated unused pipe connections (right). (Source: INES Education and AEE INTEC)

Figure 46: Heat storage with thermosiphon heat traps at all pipe connections and all pipes insulated (left), prefabricated insulation elements for unused pipe connections (middle), pipes connected at the tank are good insulated completely to the tank (right). (Source: INES Education, SERC and AEE INTEC)

3.2.4 Space Heating

As Figure 47 shows, only in Germany and Sweden a clear majority is using a single radiator space heating system (1 x Radiator). In the opposite in Austria and France most of the systems have a mix of both floor and/or wall heating systems plus radiator heating loop (Floor/Wall+Radiator). Quite a lot of houses have more than one space heating loop which typically means also more than one space heating pump which has a big influence on the parasitic electricity consumption because space heating pumps are in operation for very long periods during the year.

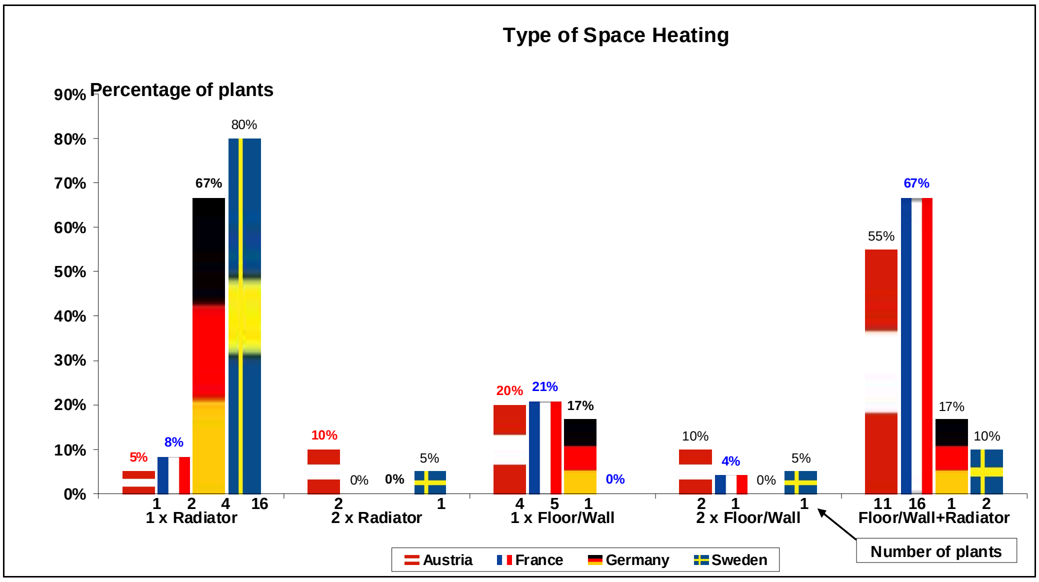


Figure 47: Type of space heating

In all four countries about 55% of the systems showed good insulation quality of the space heating piping and pump groups, 15% was acceptable and 30% showed simply no insulation of the piping in the technical room. The following pictures show some examples of the installation quality.

Source: ITW / Germany

Source: AEE INTEC / Austria

Figure 48: Examples of space heating pump groups, left: non insulated pipes but nice insulated pumps; right: good insulation of heat storage and all pipes and pumps as a basis of a good performing solar combisystem.

In general the hydraulic connection of space heating loops to the heat storage was correct. In some cases the return flow pipe was too high, obviously overestimating the cooling effect in the bottom part of the heat storage due to the domestic hot water preparation. But also systems were evaluated where the floor heating return pipe was connected above the radiator return pipe or both return pipes were mixed together and the potential of the lower return temperature levels for higher solar gain was lost.

The most important point of the space heating loop is to have lowest possible return temperature in order to maximize the heat storage capacity of the tank and to minimize heat losses of the tank. To reach this goal the space heating loop should be controlled with thermostat valves and hydraulic pre-adjustment should be done properly. This characteristic could not be checked during such short visit as it was possible during the quality evaluation.

3.2.5 Domestic Hot Water

As Figure 49 shows more than the half (51%) of the systems were installed with an immersed heat exchanger for domestic hot water preparation, 21% were equipped with an external heat exchanger module, 13% were installed with the tank in tank concept and still 14% used an extra domestic hot water tank (most time an old existing one).

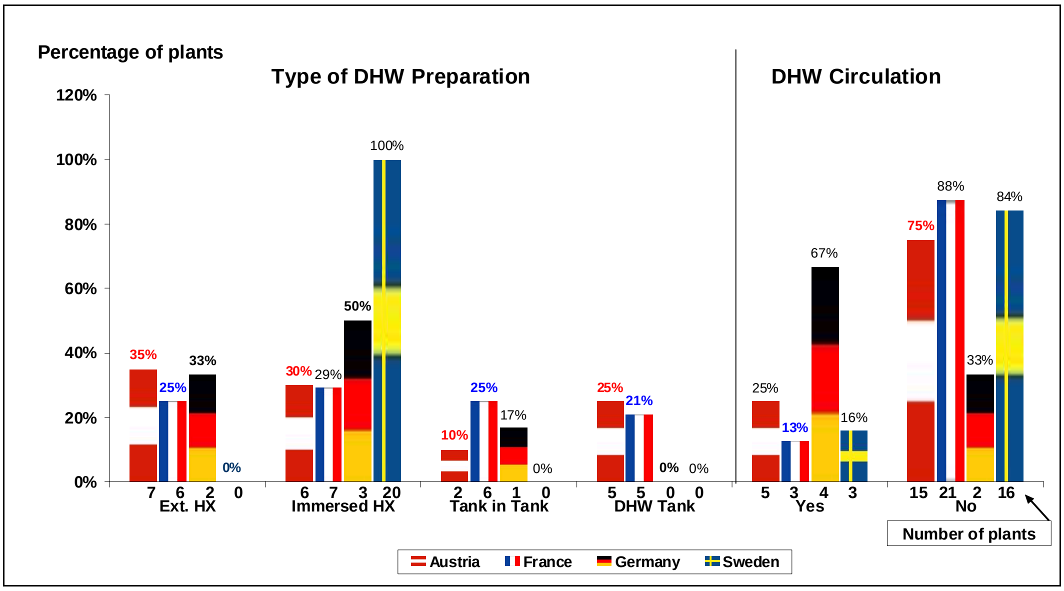


Figure 49: Type of domestic hot water preparation

Bad insulation quality in some cases could be found in tank in tank systems with pipe connections at the top where significant cold bridges in the hottest part of the heat storage lead to high heat losses.

Figure 50: Heat storage insulation quality of tank in tank systems: pipe connections at top and bad (left) and good insulation (middle) or well insulated pipe connections at the side of the tank (right) which could be improved with pipes leading downwards immediately (thermosiphon heat trap).
(Source: INES Education and AEE INTEC)

External heat exchanger modules for domestic hot water preparation were evaluated as well prefabricated modules and operating as expected by the costumers. Optimized in terms of heat losses are those modules which are mounted direct on the heat storage because this results in minimized pipe length of the primary loop between tank and module with high temperature.

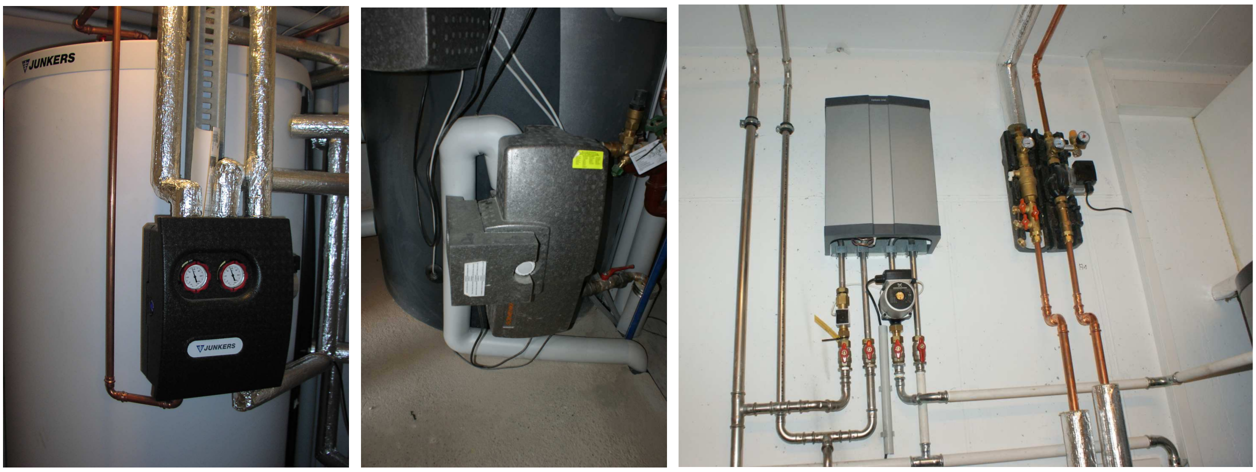


Figure 51: External Heat exchanger modules direct mounted at the tank (left and middle) or extra mounted at the wall (right). (Source: ITW and AEE INTEC)

In about 30% of the houses domestic hot water circulation pumps were installed. At least some of them already used the “circulation on demand” concept, which means that the circulation pump is manually started and automatically stopped after some minutes. Some of those systems were monitored and the results showed with heat losses less than 30% of the domestic hot water demand how successfully this concept works in comparison to timer controlled systems where heat losses up to about 80% of the domestic hot water demand were measured.

3.2.6 Auxiliary Heater

As auxiliary fuel 47% of the systems use biomass like wood pellet, wood logs and wood chips. Natural gas or propane is installed in 31%, oil in 11%, heat pumps in 7% of the systems and district heating and direct electric heating just once each. About 25% of the systems are installed as type 1 “Auxiliary as Return Flow Increase”, which means that space heating return flow first passes the heat storage for pre-heating, if the tank temperature is higher than space heating return temperature. Then it is further heated up to the set temperature by the auxiliary heater and sent directly to the space heating distribution again.

The majority of the systems (75%) are installed as type 2 “Auxiliary Charging the Heat Storage”, which means that the auxiliary heater heats up the heat storage and energy for space heating is taken directly from the heat storage, all hydraulic flows are connected directly to the tank and therefore acting independently.

In many cases of type 2 systems it could be found that the hydraulic integration of the auxiliary heater and much more the control concept was not done properly. The heat storage often is not used as a buffer which is charged and discharged periodically but much more as a huge hydraulic switch which is kept hot all the time. Especially in cases with natural gas boilers this strategy is quite disadvantageous and significant potential of improvement exists.

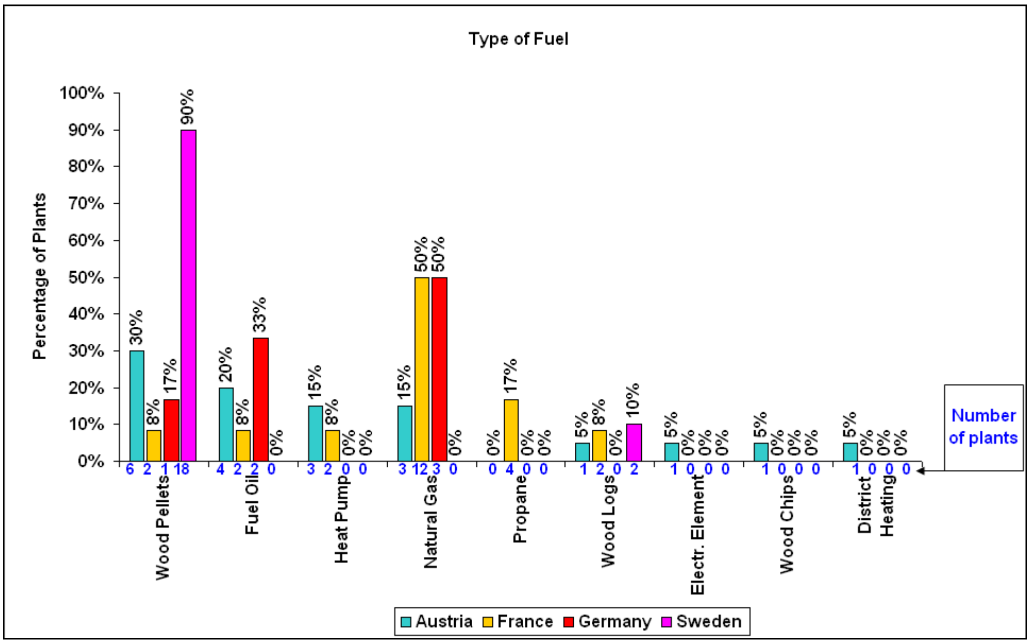


Figure 52: Type of auxiliary heater

Figure 53 shows the distribution of the nominal installed auxiliary heating power. There is no dependency on the size of the house or some country specific characteristics. This is the case because many boundary conditions influence the choice of the nominal power and not only the heat demand calculation.

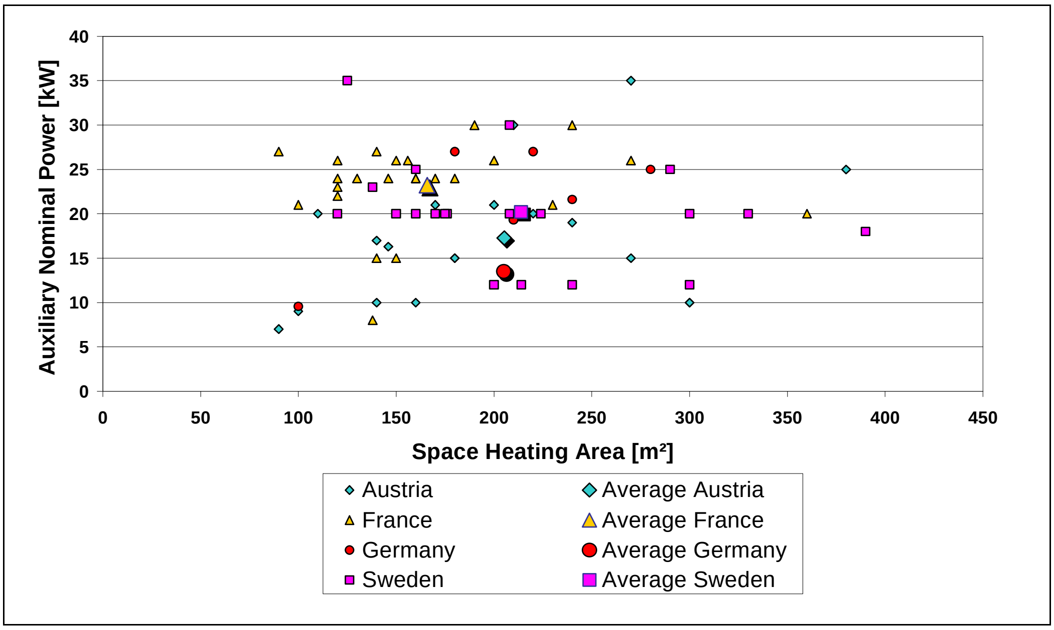


Figure 53: Nominal auxiliary power versus space heating area

Anyway, since solar combisystems have at least a sufficient large domestic hot water auxiliary volume, in most cases auxiliary heater with much lower nominal power and therefore higher potential of adjustment of the actual power by power modulation with the potential of increasing boiler efficiency would be possible.

3.3 Conclusion

Overall summarizing a high majority of customers was satisfied or very satisfied with their solar combisystem. Even though most of them had some problems in the beginning, the problems were solved and finally the systems operate to their satisfaction. Only not satisfied are some in terms of thermal comfort in the house most probably due to hydraulic adjustment problems and/or missing thermostat valves.

From the experts evaluation point of view it could be confirmed that the solar combisystems in the main points were installed as expected and fulfilled the tasks asked for: gaining solar heat and supplying the house with heat for domestic hot water and space heating at required temperature level and power. But in almost each installation some important efficiency related details had to be criticized which typically a standard customer does not realize.
Generally speaking, the main focus of thinking about product and system improvements should not be that much on increasing solar gains by better performing solar collectors or very special stratification devices in heat stores but much more on reducing heat losses in the complete solar combisystem. Since a solar combisystem has more components (mainly tanks and pipes) therefore – unfortunately – more potential exists for having heat losses compared to what conventional heating systems typically have. Further potentials exist in increasing the auxiliary heater efficiency by improving the integration concept in details.

As a result of the qualitative evaluations done within the CombiSol project manufacturer, system supplier, installer and planers might take in consideration the following points for improvements:

- Recommendations for installers from system supplier and/or planner should be much more detailed in terms of how to chose the heat storage volume taking in consideration the chosen system concept (type 1 or type 2) and the type of auxiliary heater (fast reacting powerful natural gas or oil boiler in comparison to slow reacting biomass boiler) with the goal to avoid multi-store systems if not absolutely necessary. In many cases higher quality of tank and pipe insulation, which gives benefit 365 days per year would be much more effective than larger solar heat storage capacity which might be of advantage in terms of energy savings just some days in spring and autumn. High performance of the solar combisystem in terms of auxiliary fuel savings should be more important than selling an additional tank.
- Insulation fittings for unused pipe connections at the tanks must become a standard as fast as possible.
- Thermosiphon heat traps must become a standard. Manufacturer and system suppliers should strongly increase the effort to convince or better force the installer to install thermosiphon heat traps when connecting pipes to the tank by pre-mounted connection pipes facing downwards.
- Prefabricated tank insulation elements not always are designed carefully enough to avoid bad mounting quality. Especially the top of the tank which is hot all the year round should be perfect insulated. The design of the tank should avoid pipe connections at the top of the tank. Pipe connections at the side in combination with internal pipes to the top of the tank and thermosiphon heat traps at the external pipe connection are strongly recommended instead.
- Recommendations for installers how to integrate the auxiliary boiler into the system must be defined in absolutely clear concepts from a hydraulic and control point of view. It is not possible to hand out hydraulic schemes with the note “boiler integration shall be done in cooperation with boiler manufacturer”. Boiler manufacturer know, how to control the boiler or conventional heating systems but typically they do not know, how a solar combisystem works. It is needed to give the installer only the choice between clear defined and fitting concepts for different boundary conditions, not only ideas of proposals how it could be done.
- A clear and complete documentation of the finally installed system should become a standard. At least a correct hydraulic scheme including the control concept with all sensors and actors, documentation of all controller settings and a clear instruction and maintenance manual is required.
- The performance of the solar combisystem is strongly influenced by the space heating circuit, mainly the return temperature occurring in practice. For sure it is not easy, but it is necessary to find solutions to ensure hydraulic pre-adjustment of the space heating circuit and the installation of thermostat valves and most important the correct operation by the house owner.
- Like fully prefabricated pipes for district heating networks to be mounted in the ground it is necessary to develop/improve fully prefabricated pipes for outside piping from collector into the building including the correct weather proof insulation AND outside cover as protection against UV-radiation and animal bites.
- Hydraulic concepts for collectors and collector fields with better emptying behavior during stagnation periods in summer time need to be offered, especially if solar combisystems with more than 20m^2 collector area shall be installed in future in order to increase share of solar thermal energy in Europe.
- Diameter of temperature sensors and immersion sleeves often do not fit together. Adapter should be developed and offered, which can be used to fix properly temperature sensors with good thermal contact in tank integrated immersion sleeves or other foreseen mounting positions.

4 In-Situ Monitoring of solar combisystems

Main Author : Thomas Letz, Xavier Cholin

In four countries (Austria, France, Germany and Sweden), several Solar Combisystems (SCS) have been equipped with monitoring equipment described in paragraph 4.1 [1]. Results are presented according a methodology which gives as an output a value for the annual fractional energy savings F_{sav} as a function of the Fractional Solar Consumption FSC. This method is based on the calculation of monthly balances from energy measurements. F_{sav} is evaluated by comparison between the auxiliary energy used by the SCS and the one used by a conventional system without solar collector, using the same energy.

4.1 Procedure

Diagrams in figure 54 present the methodology proposed for measurements analysis, in order to determine the parameters FSC and F_{sav} [2].

- The first step consists in calculating the monthly values for the solar irradiation available on the collector area.
  The best method is to use a pyranometer located in the collector plane. A calibrated PV cell can also be used, but provides usually less accuracy.
  If no irradiation measurements are done on site, the meteorological data from the nearby station will be used: monthly sun duration or monthly irradiation available on the horizontal plane. Shading line should be taken into account when calculating corresponding irradiations in the collector plane.
- The second step consists in calculating reference monthly consumptions. Two options are possible depending on whether solar heat is stored in the building itself (heating floors or walls) (figure 2) or not (figure 1). In that latter case, the real space heating load can be assessed with the energy injected in the space heating loop. At the opposite, if the building is used as space heating storage for solar heat, the real space load must be assessed by using an identification process, which allows determining the real parameters describing the thermal behavior of the building: heat loss coefficient of the building, internal gain factor, equivalent South area used to estimate the passive solar gains.
- The third step consists in calculating the Fractional Solar Consumption.
- The fourth step consists in calculating thermal and extended Fractional Energy Savings. Proposed indicators $F_{sav,th}$, $F_{sav,ext}$ are calculated with regard to a conventional system, that must be exactly defined.

In order to be able to compare two different combisystems, it is necessary for the conventional systems to be independent of the studied combisystems. The conventional system will just be chosen to deliver the same comfort as the studied combisystem: same space heating emitter(s), Domestic Hot Water produced in a water store.

At a national level, one can use a national reference system, defined for example according to the national thermal regulation. For international comparison, the definition of one common reference system is mandatory. Detailed description of all reference parameters and equations is given in [2]. References have been defined for main auxiliary heaters available on the market, according the auxiliary energy they consume:

- Remote electric heaters
- Electric boilers
- Combustion generators (gas, oil, wood logs, wood pellets)
- Heat pumps

A software has been developed for quick analysis of a one year monitoring period [3].

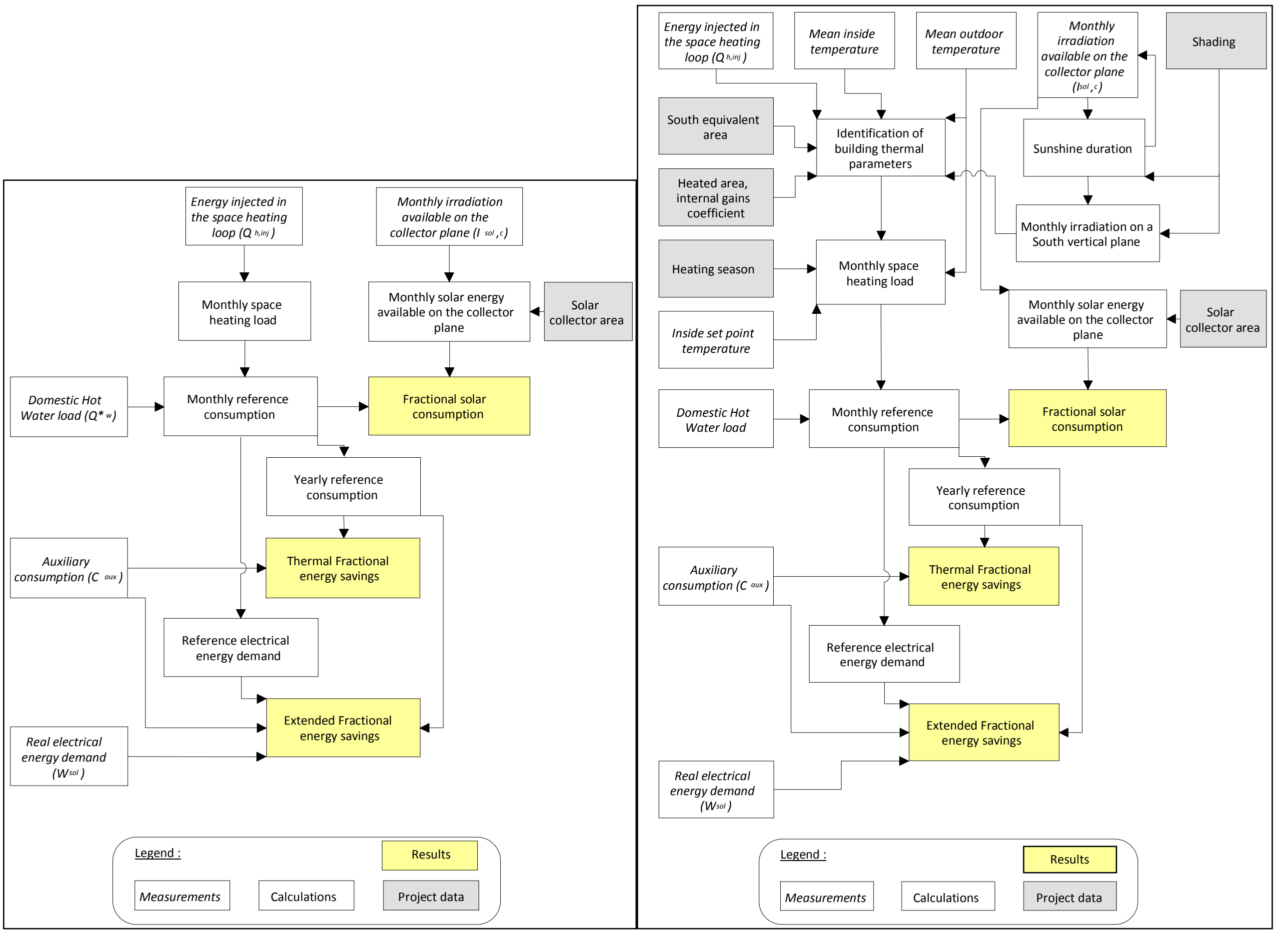


Figure 54: Monitoring diagram for systems without (left) and with (right) storage for space heating in the building

Presentation of results is made according the FSC method elaborated within the framework of Task 26: Solar Combisystems [4], [5]. Plotting on the same diagram Fractional energy savings vs FSC allows to quickly visualize the efficiency of the whole system or of the solar part of it, without including the behavior of the auxiliary heater.

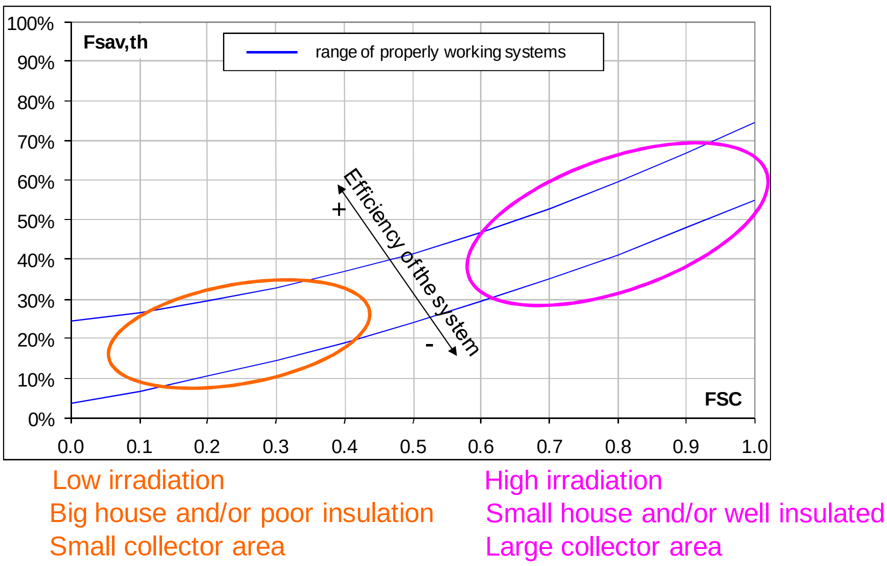


Figure 55: F_{sav} vs FSC diagram with the range of properly working systems, for systems evaluated at the auxiliary heater inlet

An extrapolation procedure has been elaborated in order to derive annual indicators ($F_{sav,th}$ and FSC) from monitoring period shorter than one year.

4.2 Monitoring equipment

In order to calculate the indicators $F_{sav,th}$, $F_{sav,ext}$ and FSC, sensors and meters shown in figure 56 have been installed:

- Space heating load is measured with heat-meter C3 (and eventually C3' in case of a second space heating loop.
- Domestic Hot Water load is measured with heat-meter C2. In case of a DHW circulation loop, the heat losses of this loop are measured with heat-meter C5, and added to the DHW load.
- Auxiliary energy consumed is measured with meter C1 (oil-, gas- or electric meter). This is not possible with a reasonable cost for auxiliary heaters using wood (logs or pellets)
- For wood auxiliary heater, heat delivered by the boiler is measured at the outlet with heat-meter C1'. This heatmeter can also be installed if auxiliary energy is already measured at the boiler inlet with C1, and allows calculating the efficiency of the boiler.
- Solar irradiation on the collector area is measured with sensor Ic, ambient temperature with temperature sensor θ_e and inside temperature with sensor θ_i.
- Parasitic electricity used by all electric devices in the system is measured with electric meter W_{sol}.

Optionally, solar energy delivered by the collector can be measured with heatmeter C4, and collector efficiency can be calculated. If they exist, the loop cooling down the solar loop ("discharge" loop) or the one heating a swimming pool have to be equipped with heatmeters (C6 and C7).

A datalogger stores with a small time step (generally 1 minute to 10 minutes) temperatures, flows and energies calculated on the different loops:

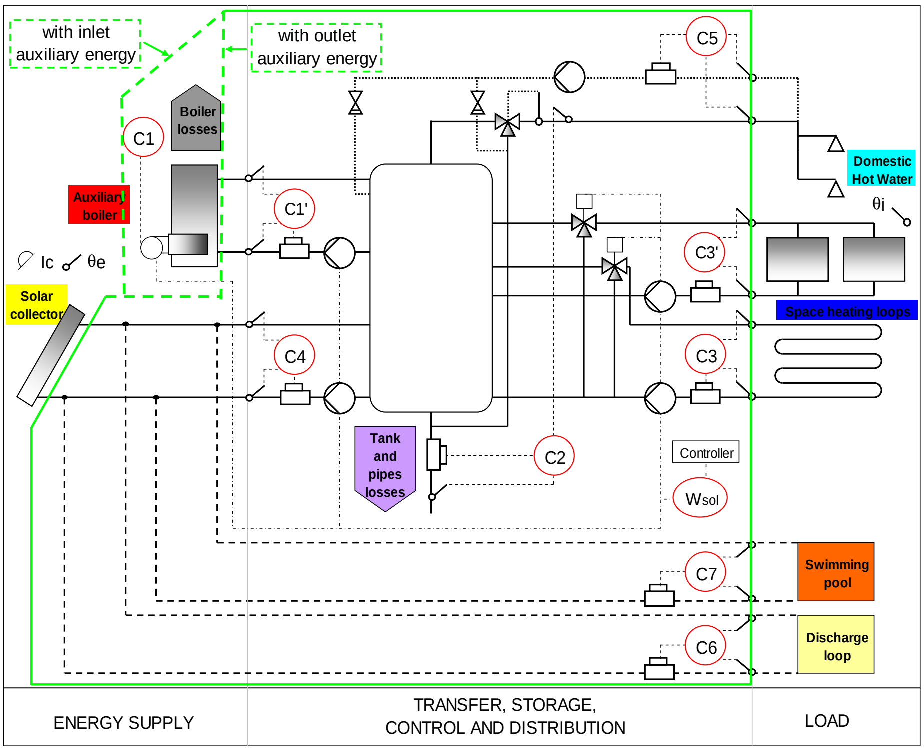


Figure 56: Location of sensors and meters

4.3 Presentation of monitored systems

Monitored systems are located around the place where partners involved in monitoring have their headquarters, except for some systems in the western part of France.

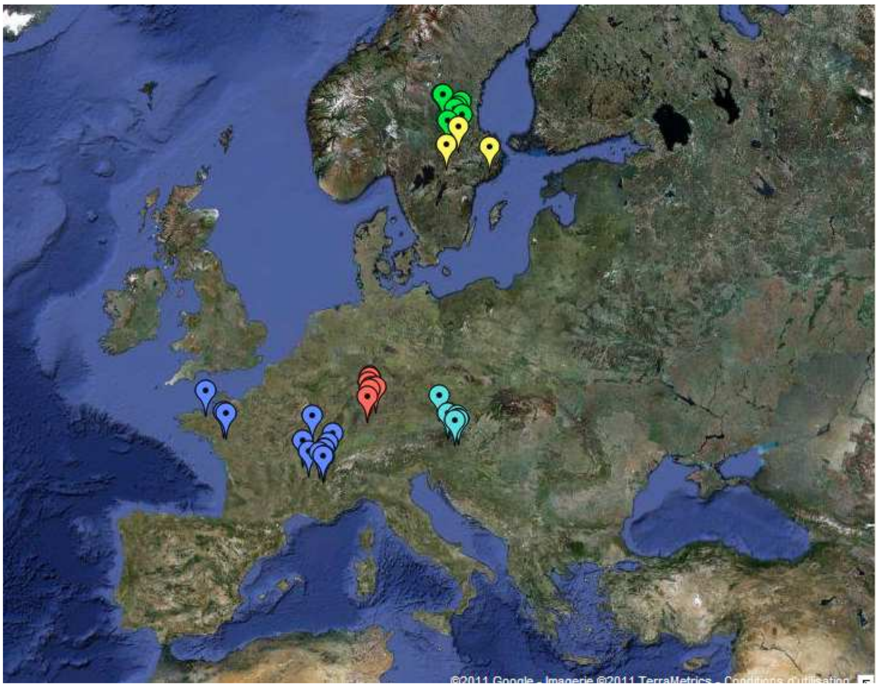


Figure 57: Location of monitored systems in Austria, France, Germany and Sweden

This paragraph presents some statistical elements on the monitored systems (table 3). Figure 58 shows the repartition of systems between the different categories of hydraulic diagrams described in [1]:

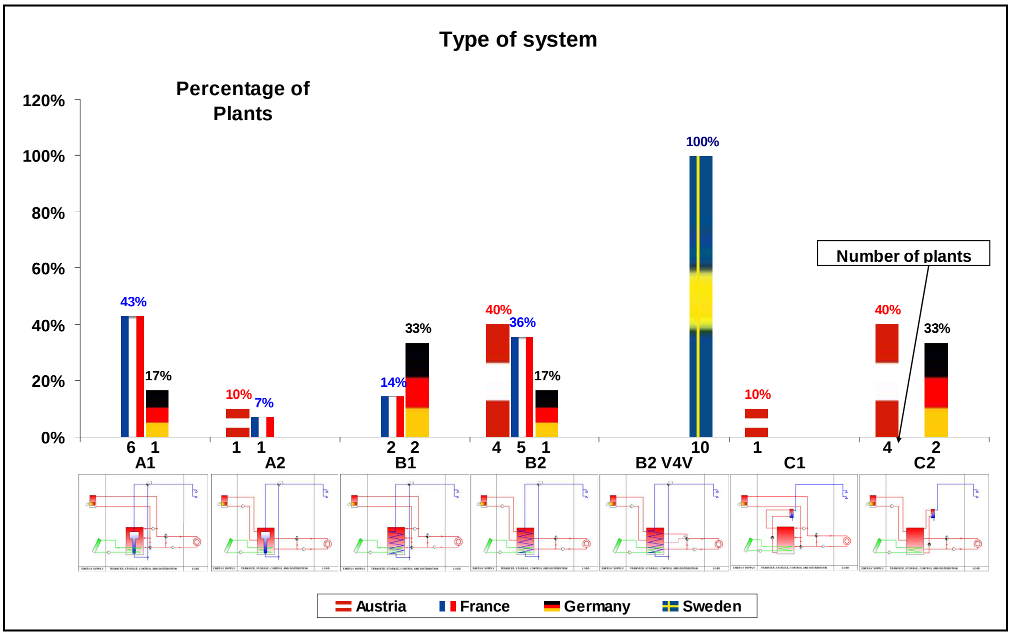


Figure 58: Typology of monitored systems

- In Sweden, all monitored systems have the same hydraulic scheme, with a special 4-way valve, which allows taking heat for space heating from the store at different levels according to the temperatures in the different layers.
- In France, no systems with an external heat exchanger for DHW preparation have been measured.

	N°	System type	Heated area (m²)	Auxiliary energy	Solar collector area (m²)	Tilt angle (°)	Orientation (°)	Storage volume (l)	Space heating loop 1	Space heating loop 2
Austria	1	A2	110	District heating	18,9	43	-45, 0, 45	1000	Radiators	Radiators
	2	C2	220	Natural gas	20,3	30	-7	1250	Floor heating	Floor heating
	3	C2	300	Air heat pump	16	45	35	1000	Floor heating	
	4	B2	180	Wood pellets	16,4	45	44	1000	Radiators	
	5	C2	180	Natural gas	20,2	25	30	1600	Radiators + floor heating	
	6	C1	100	Fuel oil	20,4	61	-21	1600	Radiators	Floor heating
	7	C2	300	Wood pellets	18	45	25(15)/-20(3)	1000	Floor heating	Radiators
	8	B2	140	Wood pellets	18,2	45	-30	800	Radiators	Radiators
	9	B2	270	Natural gas	32,2	45	0	2000	Wall- and floor heating	
	10	B2	270	Geothermal heat pump	24,3	42	5	1500	Wall- and floor heating	Radiators
France	1	B2	150	Wood pellets	16,48	22	20	1000	Floor heating	Radiators
	2	B2	160	Natural gas	14,7	41	0	1200	Floor heating	Radiators
	3	B2	140	Wood pellets	16,2	60	0	1250	Floor heating	
	4	B2	120	Natural gas	12,75	30	0	950	Floor heating	Radiators
	5	B2	270	Heat pump	14	30	0	950	Floor heating	Towel dryer
	6	A1	120	Propane	13,44	18	10	670	Floor heating	
	7	A2	138	Heat pump	12,12	45	0	820	Floor heating	Floor heating
	8	A1	170	Natural gas	9	30	0	670	Floor heating	Radiators
	9	B1	180	Natural gas	8,64	35	-55	870	Floor heating	Air convectors
	10	B1	120	Natural gas	10,04	45	0	750	Floor heating	Radiators
	11	A1	100	Natural gas	9	30	0	642	Radiators	
	12	A1	90	Natural gas	9,33	30	-90	642	Radiators	
	13	A1	235	Natural gas	10,5	25	-45	642	Radiators	
	14	A1	180	Natural gas	10,5	45	0	642	Radiators	
Germany	1	A1	100	Natural gas	9,6	30	2	750	Floor heating	
	2	B1	280	Wood pellets (oil shut off)	12,7	30	10	750	Floor heating	Radiators
	3	B2	210	Fuel oil	15,1	30	4	950	Radiators	
	4	B1	180	Natural gas	9,6	30	10	750	Radiators	
	5	C2	240	Natural gas	15,0	35	100	950	Radiators	
	6	C2	220	Fuel oil	15,0	28	87	800	Radiators	
Sweden	1	B2 V4V	240	Wood pellets	10,8	33	-20	750	Radiators	
	2	B2 V4V	214	Wood pellets	10,8	15	30	750	Radiators	
	3	B2 V4V	300	Wood pellets	10,8	45	30	750	Radiators	
	4	B2 V4V	390	Wood pellets	14,0	27	0	750	Radiators + heat coil	
	5	B2 V4V	150	Wood pellets	8,1	30	40	750	Radiators	
	6	B2 V4V	176	Wood pellets	8,1	90	-40	750	Radiators	
	7	B2 V4V	330	Wood logs and wood pellets	9,2	37	-10	2 250	Radiators	Radiators
	8	B2 V4V	120	Wood pellets	9,2	49	-10	750	Radiators	
	9	B2 V4V	290	Wood pellets	10,8	35	0	1 500	Radiators + floor heating	
	10	B2 V4V	300	Wood pellets	10,8	30	0	750	Radiators	

Table 3: Characteristics of monitored systems

Pictures of figure 59 show some trends:

- Big houses in Sweden and small solar collector areas
- Smaller houses in France and Germany, and intermediate solar collector areas
- Larger solar collector areas in Austria
- Wood pellet is widely used as auxiliary energy (exclusively in Sweden) and natural gas is the second used energy, especially in France
- Heat exchanger immersed in the main water store is the most common system (exclusively in Sweden)
- Most systems have only one water store (favourable point toward the promotion of standardized systems, having less storage and pipes heat losses)
- 15 % of systems equipped with vacuum tubes solar collectors
- Almost half of systems equipped with two space heating loops. Systems using low temperature space heating loops, like floor or wall heating, which are a favourable factor to increase efficiencies of solar heat collection, are a minority

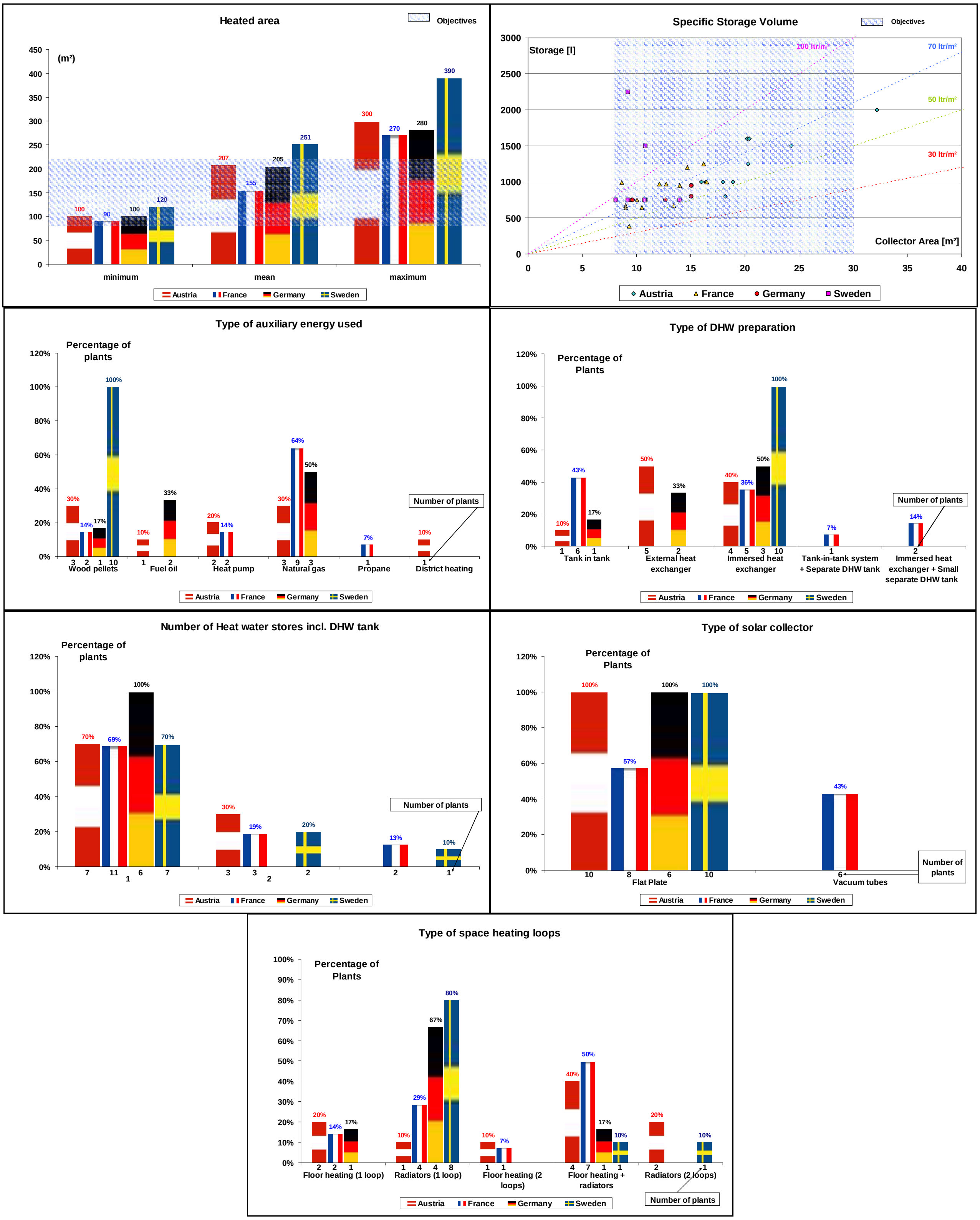


Figure 59: Characteristics of monitored systems

4.4 Main results

In this chapter, all results from the different countries are presented together, in order to analyse if some tendencies can be observed. Four sets of diagrams are presented hereunder, each set showing evaluations at the auxiliary heater outlet and at the auxiliary heater inlet. At the auxiliary heater inlet the fuel consumption of the auxiliary boiler is measured whereas at the auxiliary heater outlet the auxiliary thermal energy going into the system (space heating circuit, water store) is measured. By measuring both quantities the boiler efficiency under dynamic operation conditions can be analyzed and the primary energy consumption of the heating system can be determined.

At the auxiliary boiler outlet, the thermal fractional energy savings is related to the way solar energy will decrease the need of auxiliary energy, taking into account the quality of the "solar part" of the system: heat storage, hydraulic scheme, control strategy.

At the auxiliary boiler inlet (fuel consumption), the thermal fractional energy savings include the quality of the auxiliary heater, of its connection to the "solar part" of the system, and its control strategy.

4.4.1 Results sorted by country

Figure 60 shows results sorted by country. Three zones can be observed, related to the size aspects of the systems:

- In Sweden, small collector areas (mean value : 9 m²) are installed in big houses, with high space heating loads: lowest values for FSC and Fractional energy savings are observed
- In Austria, large collector areas (mean value : 18 m²) are installed: highest values for FSC and Fractional energy savings are observed
- In France and Germany, intermediate collector areas are installed (mean value: 10 m² for France, 12 m² for Germany): points are located between in the middle of the diagram.

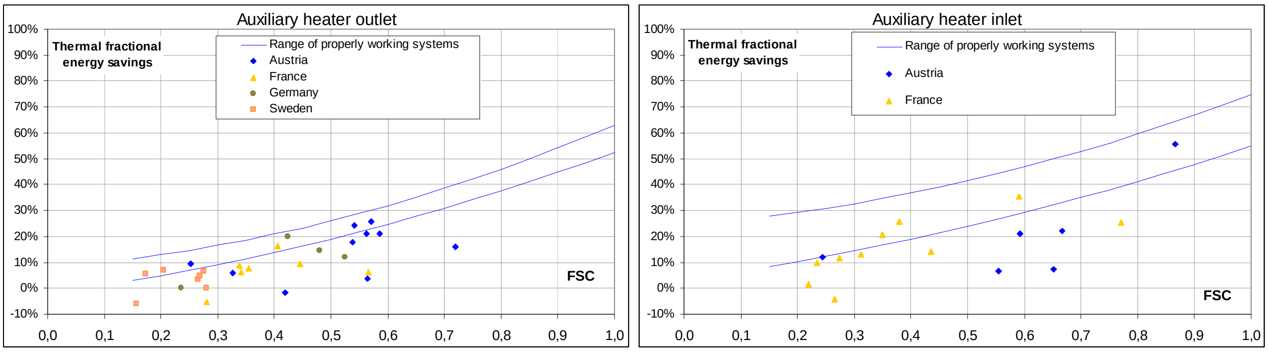


Figure 60: Results sorted by country

4.4.2 Results sorted by manufacturer

Figure 61 shows results sorted by manufacturer. No clear tendency can be observed, especially for manufacturers having systems installed in several countries (Austria, Germany and France). The case of Sweden is particular, since Swedish systems are only distributed in Sweden.

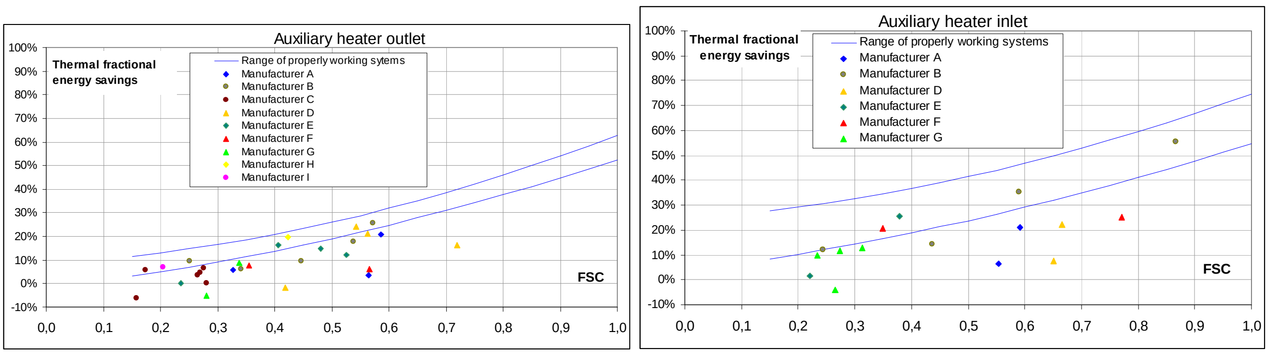


Figure 61: Results sorted by manufacturer

4.4.3 Results sorted by system type

Figure 62 shows results sorted by system type, according to figure 58. No clear tendency can be observed, especially for manufacturers having systems installed in several countries (Austria, Germany and France). Once again, the case of Sweden is particular, since Swedish systems use a special hydraulic diagram with a 4-way valve.

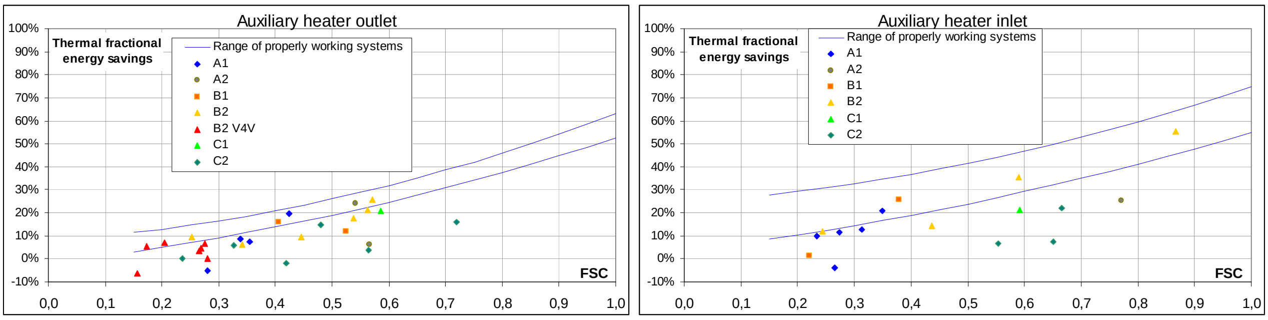


Figure 62: Results sorted by system type

4.4.4 Analysis of thermal losses and solar gains

Figure 63 compares system heat losses (heat storage and piping in technical room) and solar gains. Attention must be paid to the fact that monitoring period is not one year for all systems: number of monitoring months is given in the last line. Systems with monitored heat losses with the blue color have their representative points located in the range of properly working systems in Figure 60, Figure 61 and Figure 62.

Real heat losses are much higher than reference ones for most systems, which is not surprising since in summer period, large collector areas provide much more energy than what is needed for Domestic Hot Water preparation. This is specially the case for Austrian systems (A1 to A10), which have larger collector areas than in other countries.

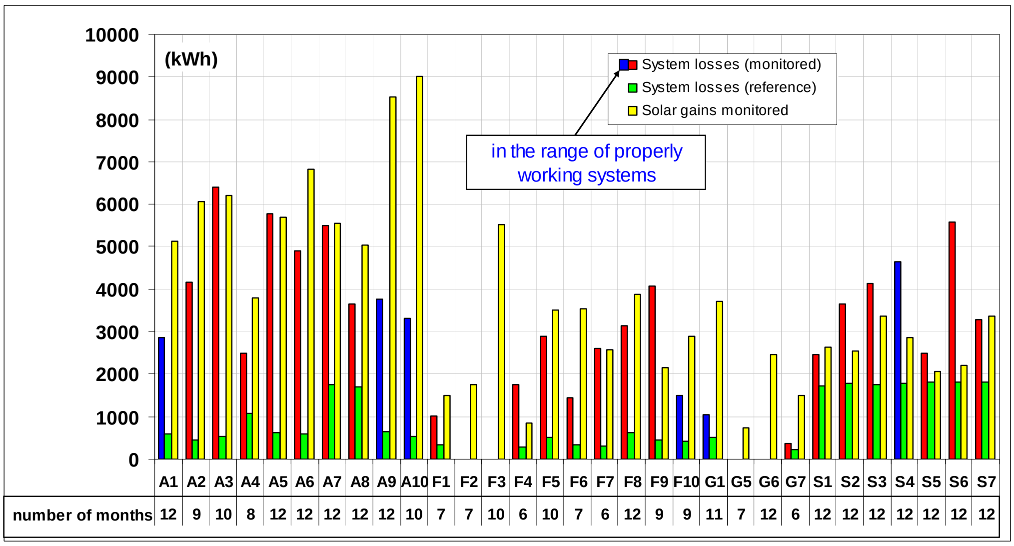


Figure 63: System heat losses and solar gains

At the opposite, Swedish systems have small collector areas, and solar gains and summer heat losses are lower.

Systems working well (blue lines), except S4, have high solar gains compared to real thermal losses of the system, and simultaneously a ratio between real thermal losses and reference ones which is lower than for other systems.

4.4.5 Analysis of parasitic electricity

Figure 64 compares real and reference consumptions of parasitic electricity. For systems with a monitoring period shorter than one year, reference parasitic electricity is calculated for the same duration. More than 50 % of houses have only one space heating loop (SH loop).

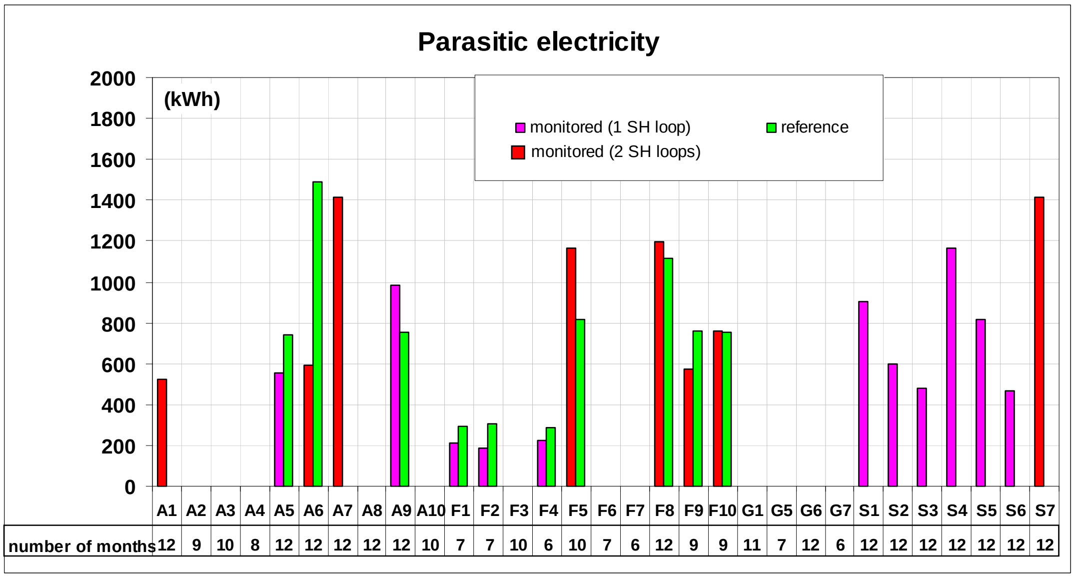


Figure 64: Parasitic electricity consumed

Most systems have comparable values for real and reference figures. Only two of them (A9 and F5), from the same manufacturer, have higher real values than reference ones, which could indicate that this topic has not been well addressed by the system supplier. For systems using wood pellets (A7 and S1 to S7) or district heating (A1) as auxiliary energy, no definition is available for reference parasitic electricity. Electricity consumption for systems using wood pellets can vary in a large range because of the type of ignition device of the boiler: some of the systems have an electrical heater used to ignite for a cold start, otherwise pellets are kept burning for start-ups. Other systems use only an electric heater for ignition, and use therefore more electricity than the previous ones.

4.4.6 Comparison between compact systems and systems assembled on site

Results from a French evaluation project called Solcombi2 have been integrated in this report, because they give an overview of results reached with compact prefabricated systems.

In figure 65 and figure 66, results of the Combisol project are compared with results of the Solcombi2 project. This last project shows better results than the Combisol project, because systems measured for the two manufacturers were homogeneous compact factory made systems, with few hydraulic connections between different subparts of the system, no unused pipes connection without insulation. However, some points are located under the range of properly working systems, due to a non optimised water store device (left diagram).

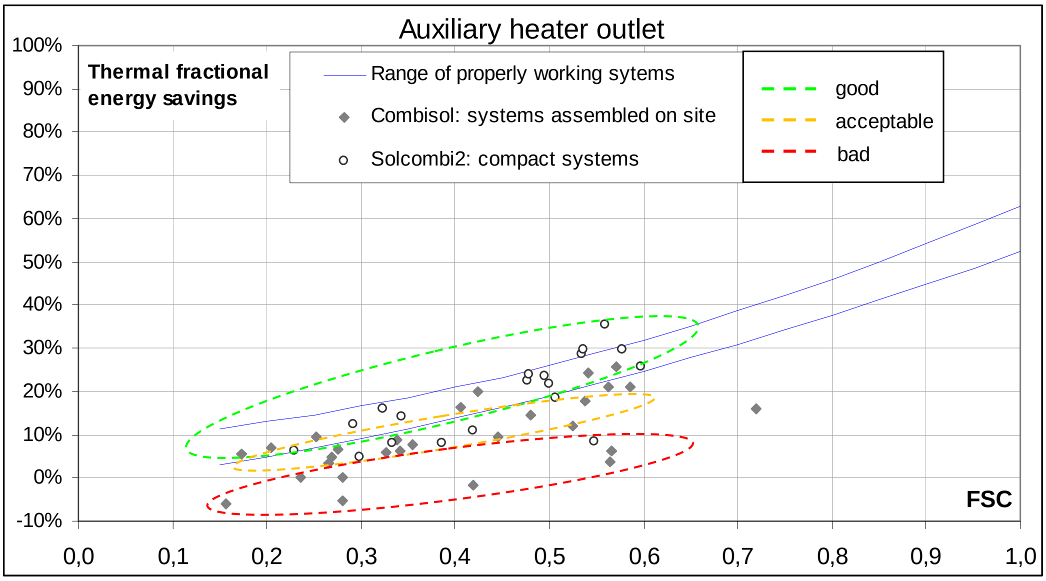


Figure 65: Global results of the Combisol project (savings evaluated at the auxiliary heater outlet)

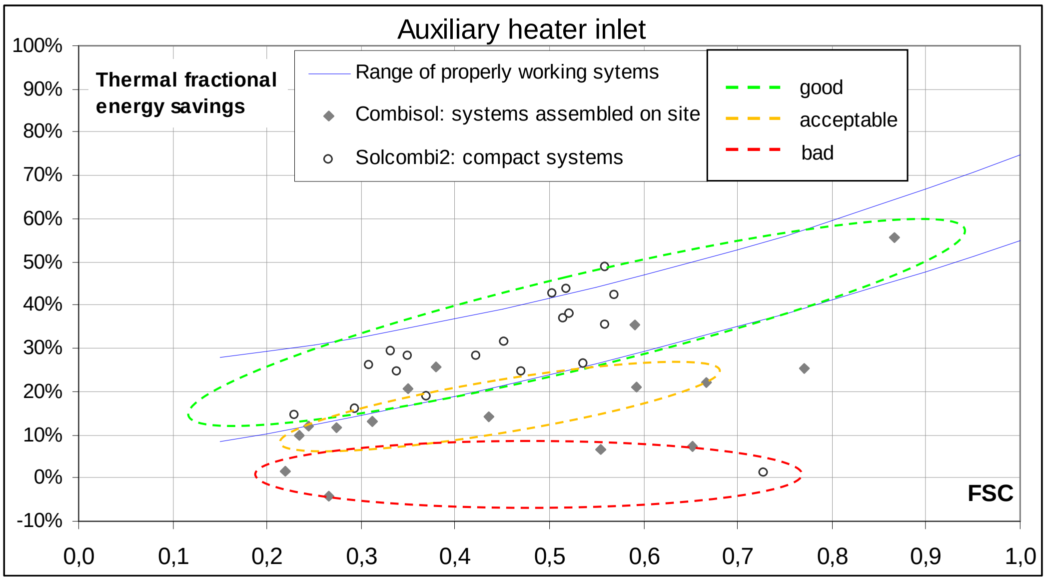


Figure 66: Global results of the Combisol project (savings evaluated at the auxiliary heater inlet)

Compact systems evaluated in the Solcombi2 project use mainly efficient auxiliary heaters as condensing boilers. Therefore, all representative points evaluated at the boiler outlet (figure 66) except one (bad functioning of an auxiliary heat pump coupled with an electrical heater) are located in the range of properly working systems. For assembled on site systems, performances lie at a lower level, with some systems not working at all.

4.5 Comparison between laboratory tests and on site monitoring

Some monitored systems have also been evaluated in laboratory test rigs, according test procedures elaborated within "WP3: Laboratory determination of primary energy savings". Table 4 shows the main parameters of three different systems that have been evaluated in laboratory, and where on site monitoring results are available. For manufacturer 1, two monitoring results are available, but for one of them, the really installed hydraulic scheme differs from the one tested in the laboratory, because an additional Domestic Hot Water store has been installed after the immersed heat exchanger in the main water store. Therefore it has not been considered for the comparison.

		Solar collector area (m²)	System type	Climate	Space heating load (kWh)	DHW load (kWh)	Total load (kWh)	FSC	Fsav	Location of auxiliary energy evaluation
Lab tests	Manufacturer 1	16,0	B1	Zürich	8914	3099	12013	0,52	30%	Auxiliary heater inlet
	Manufacturer 2		C2		11105	2709	13814	0,54	20%	
	Manufacturer 3		A1		13309	3005	16314	0,53	28%	
On site monitoring	Manufacturer 1	10,0	B1	Lyon	11971	1601	13572	0,38	26%	Auxiliary heater inlet
	Manufacturer 2	18,6	C1	Graz	9161	381	9543	0,59	21%	
	Manufacturer 3	9,3	A1	Stuttgart	13353	1745	15098	0,42	20%	Auxiliary heater outlet

Table 4: Comparison between indicators coming from laboratory tests and from on site monitoring

Climate of the locations of monitored systems are continental climates, similar to the Zürich climate use for testing. For manufacturers 1 and 3, real loads are similar to test loads. System 2 has a smaller load compared to the test load.

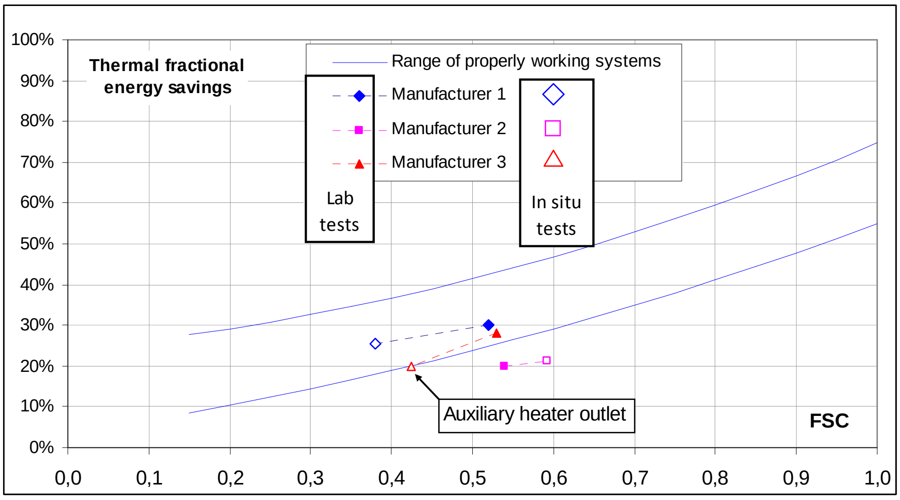


Figure 67: Comparison between laboratory and on site monitoring results

Figure 67 shows thermal Fractional Energy Savings vs FSC value, for laboratory and on site results. Following observations can be made:

- Results of on site measurements are consistent with those obtained from laboratory test, because for each manufacturer, the line between both points has a similar slope compared to the range of properly working systems.
- For systems of manufacturers 1 and 3, real points have smaller values for FSC and Fractional Energy Savings, mainly linked to smaller collector areas, since loads and irradiation available are similar.
- For systems of manufacturer 2, it is the opposite: the real point has higher values for FSC and Fractional Energy Savings, linked simultaneously to slightly larger collector areas, but mainly to a smaller load.

This comparison shows a good correlation between the results coming from testing in the lab and those coming from in situ monitoring, what in fact is a proof of the validity of the FSC approach used to evaluate the thermal efficiency of solar combisystems. It also shows that within the lab test, the annual thermal performance of the system can be predicted very well from a short (12 days) testing period.

4.6 Outcomes

At the end of the project, results are not available for all monitored systems, because for some of them, the installation of the monitoring equipment has been delayed, due to the difficulty to identify volunteers, to have the installers working in due time and to some faulty installations of the monitoring equipment. Despite these difficulties, annual indicators, obtained with one year of measurements or thanks to the extrapolation procedure from shorter periods, have been obtained for 31 of them (69 %).

Monitoring equipments installed on the different systems have allowed putting figures on what was more or less known, but not clearly measured. Main outcomes of this work are given hereunder:

- The main parameter driving the final yearly savings is the thermal losses of the whole systems. To minimize these losses, several requirements are mandatory:
  - Use one large water store instead of two smaller ones with the same overall capacity.
  - Minimize the length of pipes between the different components: from this point of view, compact systems with all components except the solar collectors prefabricated in a single unit are much more effective than several units connected on site.
  - If a system with separate units is installed, the location of components must be chosen in order to minimize the length of connection pipes. All pipes must be insulated very carefully, without any gap between insulation pieces. All unused connections on the water store must be insulated.
  - If this points are not well addressed, yearly solar gains can be smaller than yearly thermal losses of water stores and pipes
- Second important point is the quality of the auxiliary heater. A solar combisystem is a complete system, including the auxiliary heater. For new systems, high efficiency boilers as for example condensing boilers or ground coupled heat pumps must be selected. For SCS installed in existing houses, the boiler must be changed if it is too old and it has a low efficiency.
- Low temperature space heating loop allows the solar collector to work with lower temperatures and a increased efficiency.
- Parasitic electricity can vary in a large range: best systems use less than 500 kWh electricity a year, since systems where this point is not really optimised can use up to three times more electricity.
- In order to have efficient systems, all topics described before must be addressed in a homogeneous way: if not, the weakest point will push performances to the bottom.

5 Test methods

Main Authors : Barbara Mette, Mickael Albaric

Test methods are crucial to evaluate the thermal efficiency of solar combisystems, and provide information to manufactures, installers and end-users. To achieve this objective, two test methods can be used:

- The first method is the so-called CTSS method (CTSS: Component testing – system simulation) specified in the standard CEN/TS 12977-2 [30]. It is based on physical test of the main components and an annual system simulation in order to obtain the annual performance of the system.
- The second method, the so-called short cycle system performance test (SCSPT), uses a more global approach. It is based on the CCT method (CCT: concise cycle test [29], [19], [24], [28]) but has been further developed by CEA/INES, France. The SCSPT method consists of a physical test of the whole system (except the collector field) and an extrapolation of the test results to a year in order to obtain the annual performance of the system. For this testing approach no official standard has been elaborated yet.

Within the CombiSol project three different designs of solar combisystems have been tested according to these test methods. The testing according to the CTSS method has been performed at the Institute of Thermodynamics and Thermal Engineering (ITW) at the University of Stuttgart, Germany, the testing according to the SCSPT method has been performed at the Institut National de l'Energie Solaire (INES), Bourget du Lac, France. For the comparison of the test methods, two of the three systems have been tested according to both test methods.

In the following sections, the two test methods for testing solar combisystems will be briefly described. For the two solar combisystems tested according to both test methods, CTSS and SCSPT, the results of the thermal performance test will be presented and discussed.

More detailed information related to the different test methods and their intercomparison as well as the work performed within workpackage 3 entitled "Laboratory determination of primary energy savings" can be found in the reports "D3.1 : Comparison of test methods" [22] and "D3.2 Standards "Solar combisystem test methods" [23].

5.1 CTSS method

The CTSS method consists of a physical test of the main components of the solar combisystems and an annual system simulation in order to obtain the annual thermal system performance. In Figure 68 the principal structure of the CTSS method is depicted:

The combistore is tested according to CEN/TS 12977-4:2010 [31], the controller according to CEN/TS 12977-5:2010 [32] and the collector according to EN 12975-2:2006 [33]. Within the test the parameters characterizing the thermal performance of the components are determined. Based on these parameters the thermal performance of the complete system is predicted by using a component based system simulation program such as TRNSYS. The annual system simulation can be carried out for different reference conditions such as meteorological data and load profiles.

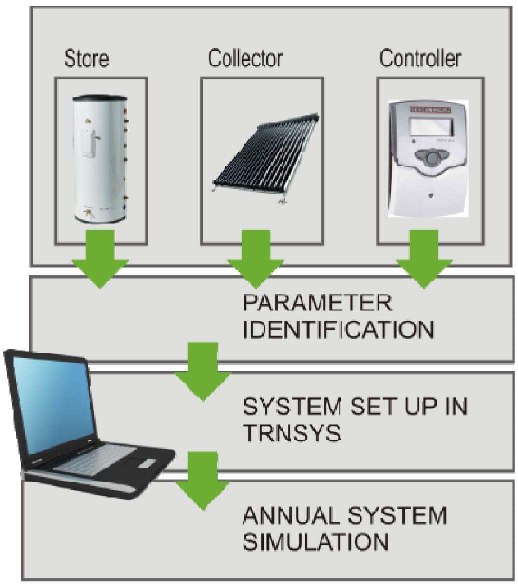


Figure 68: Principal structure of the CTSS-method

In the Annex A of the standard CEN/TS 12977-2 [30] four reference climates (Stockholm, Wurzburg, Davos, Athens) are defined. For these locations, the space heating load is specified in a load file in which the flow and return temperature and the mass flow rate are given in an hourly time step. This ensures that in each system simulation the same heat demand at the same temperature level is applied. The heating load defined in the load file is representative for the heat demand of a typical one family house at the corresponding location.

The domestic hot water draw-off is performed with a defined daily load in the range of 50 l/d to 600 l/d. The draw-off is performed 6 hours after solar noon and the required temperature is 45 °C. In case the hot water temperature delivered by the store is above 45 °C cold water is added by a thermostatic mixing valve in order to achieve the temperature of 45 °C.The cold water inlet temperature is seasonal and climate dependant.
The range of application of the CTSS method is very flexible due to its component-oriented testing approach. Hence it is possible to apply the CTSS method on nearly every system configuration of solar combisystems.
The standard series CEN/TS 12977 is currently under revision and it is expected that in 2012 it will reach the status of a European standard.

5.2 SCSPT method

For the SCSPT the whole combisystem (excluding the collector field) is mounted on an indoor test facility and tested according to a defined short term test sequence (12 days). The system installation also includes the auxiliary heater and the piping in between the system components.
During the physical test of the system, the heating load of the building and the energy gain from the collector field are computed with a simulation software and emulated by a cooling and heating circuit. According to the control strategy of the controller of the combisystem the mass flow rate and flow temperature in the collector circuit, space heating circuit and auxiliary heater circuit are adapted.
The domestic hot water draw-off is performed according to a load file in which the corresponding hot and cold water temperatures and mass flow rates are specified. The hot water temperature is set to 45 °C, the cold water inlet temperature is seasonal dependant. .

For the determination of the annual system performance, the measured test results (energy fluxes to and from the system: heat delivered for space heating and domestic hot water, solar energy delivered from the collector circuit to the store, auxiliary fuel consumption and parasitic electrical energy consumption) are extrapolated to one complete year.
The physical testing and the determination of the thermal performance of the system are performed for the location of Zurich with the reference conditions defined in Table 5.

Table 5: Boundary conditions for laboratory testing according to the SCSPT method

Main characteristic	One family house, 140 m² heated floor area (SFH 60 building, Task 26 of the Solar Heating and Cooling Programme)
Location	Zurich
Collector area	16.1 m²
Collector orientation	South, 45° tilted
Hot water demand	200 l/d at 45 °C (3000 kWh/a) seasonal dependant cold water temperature of 9.7 °C +/- 6.3 K
Heating load	8540 kWh/a, equivalent to 61 kWh/(m²a) for Zurich climate Flow/ return temperature at design conditions: 40 °C / 35 °C
Ambient temperature of the store	15 °C
Heat demand of a conventional (non solar) heating system:	12184 kWh/a (including heat losses of a conventional domestic hot water store of 644 kWh/a)

5.3 Comparison of test methods

For the comparison of the CTSS and SCSPT method, two solar combisystems have been tested according to both testing approaches. In this section the solar combisystems tested are described and the test results are presented and discussed.

5.3.1 System design of the solar combisystems investigated

The generic hydraulic system concept of the solar combisystems according to Section 2.1 is:

- Solar combisystems 1: B1 – Immersed DHW heat exchanger, auxiliary as return flow increase
- Solar combisystems 2: A1 – Tank in Tank, auxiliary as return flow increase

A sketch of the system design of the solar combisystem 1 is depicted inFigure 69 , of the solar combisystem 2 in Figure 70.

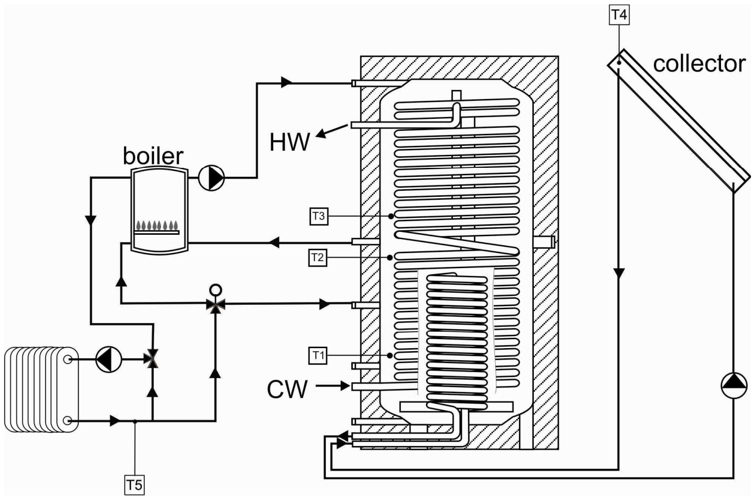


Figure 69: System design of the solar combisystem 1

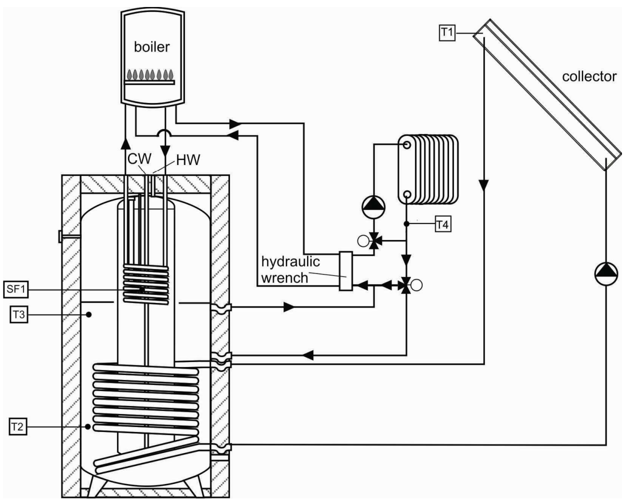


Figure 70: System design of the solar combisystem 2

The solar combisystem 1 has a combistore with a nominal volume of 950 l. The domestic hot water preparation is realized by an immersed heat exchanger. The upper part of the combistore is kept at a minimum temperature of 50 °C. An external auxiliary boiler is heating up the upper volume of the combistore in times with low solar irradiation. Solar assisted space heating is based on the principle of a return flow increase. Depending on the space heating return temperature and store temperature the combistore is bypassed or space heating flow is preheated by solar heated water in the water store and finally heated to the space heating set temperature by the auxiliary heater.
The solar heat is transferred to the water in the combistore by an internal heat exchanger located at the bottom part of the store.

The solar combisystem 2 has a combistore with a nominal volume of 750 l. In the combistore an internal tank is integrated for heating up the domestic hot water by the surrounding water. The upper part of the store is kept at a minimum temperature of 55 °C by an external auxiliary boiler heating up the upper part in times of low solar irradiation.
The solar heat is transferred to the water in the combistore by an internal heat exchanger located at the bottom of the store. Solar assisted space heating is based on the principle of a return flow increase. If the return temperature of the space heating T_4 is below the store temperature T_3, the return flow is directed through the store (return flow increase to use solar heat). If necessary the return flow is than heated up by the auxiliary heater via the hydraulic switch. If T_4 is abolve T_3 the space heating return flow is directly circulated through the boiler.

5.3.2 Quantities characterizing the thermal performance of a thermal solar system

For characterising and comparing the thermal performance of a thermal solar system the following quantities are commonly used:

- heat demand for domestic hot water $Q_{d,hw}$ in kWh/a
- heat demand for space heating $Q_{d,sh}$ in kWh/a
- net auxiliary energy demand $Q_{aux,net}$ in kWh/a
- parasitic energy demand W_{par} in kWh/a
- fractional energy saving f_{sav} in %

The fractional energy saving compares the energy demand of a conventional (non solar heating) system to the auxiliary energy demand of the solar thermal system and is calculated with equation 5.1:

$$f_{sav} = \frac{Q_{conv} - Q_{aux}}{Q_{conv}} \cdot 100 \quad (5.1)$$

In the equation:

- Q_{conv} is the energy demand in kWh/a of a conventional (non solar) heating system taking into account an annual utilization factor of the boiler $\eta_{conv} = 0.75$ and annual heat losses of a reference store $Q_{l,conv}$.

$$Q_{conv} = \frac{Q_d + Q_{l,conv}}{\eta_{conv}} \quad (5.2)$$

Q_d is the overall heat demand for space heating and domestic hot water ($Q_{d,sh}$ + $Q_{d,hw}$) in kWh/a.

- Q_{aux} is the auxiliary energy demand in kWh/a taking into account an annual utilization factor of the auxiliary boiler delivering the auxiliary heat demand of $\eta_{aux} = 0.75$

$$Q_{aux} = \frac{Q_{aux,net}}{\eta_{aux}} \quad (5.3)$$

The solar fraction is defined as the energy supplied by the solar part of the system (Q_L in kWh/a) divided by the total system load (Q_d in kWh/a) and is calculated with equation 5.4:

$$f_{sol} = \frac{Q_L}{Q_d} \cdot 100 \quad (5.4)$$

The system efficiency η_{sys} is calculated with equation 5.5:

$$\eta_{sys} = \frac{f_{sav} \cdot Q_{conv,net}}{E_{glob,K} \cdot A_c} \cdot 100 \qquad 5.5$$

In the equations the following abbreviations are used:

- $E_{glob,K}$: Global irradiation in collector plane in kWh/(m² a)
- A_c: Collector area in m²

5.3.3 Test results of the CTSS method and SCSPT method

If applying the CTSS method the annual system performance is usually calculated with the reference conditions specified in CEN/TS 12977-2. Since it is not possible to determine the thermal performance with the SCSPT method for this standardised reference conditions the approach described in the following was used for comparing the two test methods.
For the comparison of the two test methods the annual system simulation of the CTSS method is performed with the boundary condition of the SCSPT method (cf 5.2). The collector area is set to 16.1 m² for both combisystems and the simulation is performed with the same collector parameters as used for applying the SCSPT method. The combistore is modelled by using the parameters determined according to CEN/TS 12977-4 for each system. Detailed information on the system control strategy implemented in the software and the thermal performance parameters of all components is given in the deliverable “D3.1: Comparison of test methods”.

With the SCSPT method, the annual thermal performance is determined by extrapolating the results of the physical test to a complete year. The extrapolation is done according to equation 5.6.

$$Q_i = \frac{Q_{i,12-day}}{12} \cdot 365 \qquad 5.6$$

In the equation is Q_i [kWh/a] the (extrapolated) annual energy yield or need of the system, $Q_{i,12\text{-day}}$ [kWh] is the energy yield or need measured in the physical test.

In Table 6 the heating load ($Q_{d,sh}$ in kWh/a) and the heat demand for domestic hot water ($Q_{d,hw}$ in kWh/a) determined with the SCSPT and CTSS method are listed. For the CTSS method the values directly represent the figures of the reference condition of the SFH 60 building located at Zurich (see also Table 5)

Table 6: Heat demand of the SCSPT and CTSS methods

System	Test method	$Q_{d,sh}$ [kWh/a]	$Q_{d,hw}$ [kWh/a]
Solar combisystem 1	SCSPT	9000	3103
	CTSS	8540	3000
Solar combisystem 2	SCSPT	13298	3002
	CTSS	8540	3000

There is a large deviation between the two methods in the heating load, especially for the space heating load.
The main reasons for the deviations in the heat demand for space heating are:

- In the CTSS method the heating load is simulated by a load file in which the mass flow rate and the flow and return temperature of the space heating circuit is defined. This ensures that in each system simulated the same load is applied. Hence the values are similar for the two combisystems.
  In the SCSPT method the controller of the system directly controls the heat supply for space heating. According to the control strategy of the system, the controller automatically adapts the flow temperature and the mass flow rate of the space heating circuit. If the control strategy is not well adapted a higher (or lower) heating load is obtained in conjunction with a higher (or lower) room

temperature in the building simulation.
In the solar combisystem 2 the control strategy implemented was solely ambient temperature dependant. Hence, no feedback from the actual room temperature is given to the controller. This explains the much higher heating load than the one required. The mean temperature in the building was 21.8 °C instead of 20.0 °C.

- In the CTSS method no heat losses of pipes and components (valves, pumps) from the store to the space heating or domestic hot water circuit or the auxiliary heater circuit are included. Only heat losses of pipes in the collector circuit are considered.
  In the SCSPT method the complete system is setup on the test facility and heat losses of pipes between the different components and of the components themselves are taken into account. The heat losses in the heating circuit have to be compensated. This results in a higher energy demand in the space heating circuit.

The deviation in the heat demand for domestic hot water in the CTSS method and the SCSPT can be explained by:

- Differences in the hot water and cold water temperature during a draw-off.
  In the simulation of the CTSS method the draw-off temperature and cold water temperature are exactly specified (draw-off temperature: 45 °C, cold water temperature: seasonal dependant)
  In the SCSPT method the same set temperatures as in the CTSS method are implemented in the testing software. However, the measurements performed during the SCSP test show that the draw-off temperature varies between 44 °C and 52 °C with a mean temperature of 48 °C. Reason for this is that the thermostatic mixing valve used for in the system test set up does not provide the right draw-off temperature. Furthermore, due to cold water stagnation between two draw-offs, the cold water temperature is higher than the specified temperature, especially for low flow rates (lower than 100 kg/h). As the draw-off is time-controlled a defined hot water volume is drawn and not a defined energy quantity.

5.3.4 Adaption of the CTSS method to the boundary condition of the SCSPT method

For the comparison of the two test methods, the boundary conditions in the annual system simulation of the CTSS method are further adapted to the laboratory test of the SCSPT method. For the determination of the heating load a building model (TYPE 56) of the SFH60 building is implemented in the simulation software. The corresponding flow temperature and flow rate to cover the load are adjusted directly by the controller of the solar combisystem.
In addition, in the simulation software, the piping between the components have been adapted to the real system set up during the SCSPT by means of piping length, piping insulation and heat loss coefficients of the piping insulation. In this case the control strategy is adapted according to the control strategy described in the Combisol deliverable D3.1.
In the flow chart in Figure 71 the methodology for the comparison is shown. The nomenclature “Sim_{CTSS}” is introduced to differ from the CTSS method where the annual system simulation is performed with the reference boundary condition according to EN 12977-2, Annex A.
The comparison of the test methods was performed in two stages:

1. Comparing the results of the 12 day test
2. Comparing the annual results

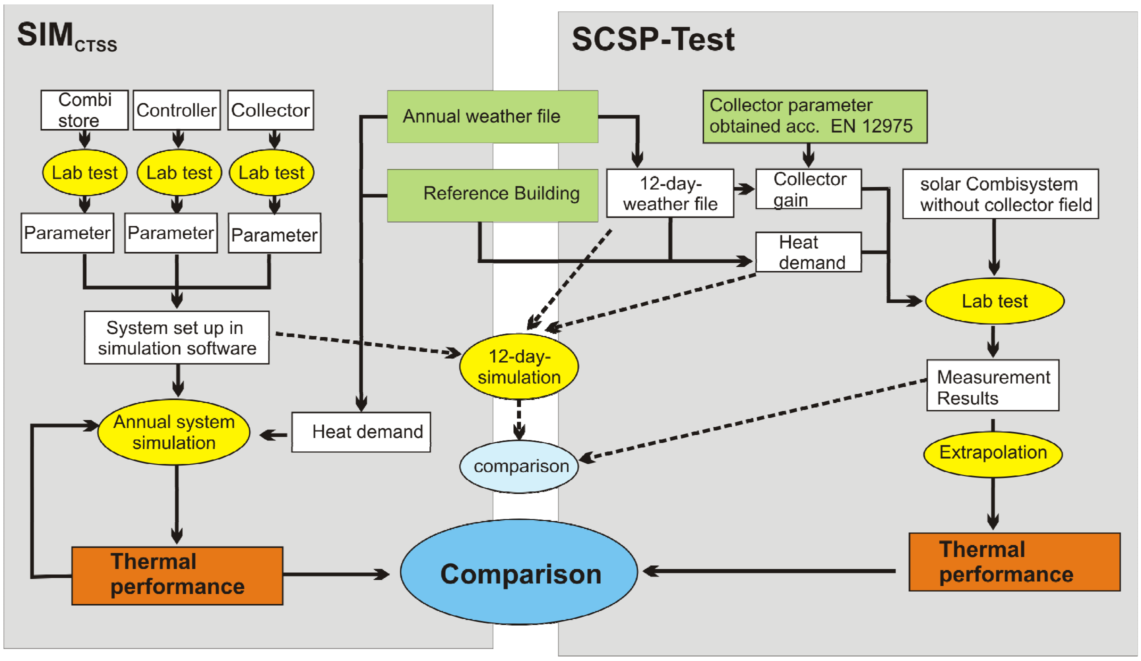


Figure 71: Method for the comparison of the test results of the CTSS method and the SCSP test method

In this report only the comparison of the annual results will be presented. Information on a comparison of the 12-day test results can be found in Combisol deliverable D3.1.

In Table 7 the annual results for the solar combisystem 1 and 2 determined with the annual simulation of the Sim_{CTSS} test method and extrapolated from the test sequence of the SCSPT method are presented. Listed are the heat demands for space heating ($Q_{d,sh}$) and domestic hot water ($Q_{d,hw}$), heat gains from solar (Q_{solar}) and auxiliary heater ($Q_{aux,net}$) and heat losses of the store and pipes (Q_{loss}).
In the last row of Table 7, the fractional energy savings f_{sav} is presented. For the calculation of the fractional energy savings, the reference heat demand is calculated according to equation 5.7.

$$Q_{ref} = Q_{d,sh} + Q_{d,hw} + Q_{l,conv} \qquad (5.7)$$

with the reference heat losses of a typical domestic hot water store of a conventional system of $Q_{l,conv} = 644$ *kWh/a* $Q_{loss} = 644 \frac{kWh}{a}$.

Table 7: Annual energy demand and gain on the different circuits determined by the annual simulation of the SimCTSS test method and the extrapolated results of the SCSPT method.

Test method	$Q_{d,sh}$ [kWh/a]	$Q_{d,hw}$ [kWh/a]	Q_{solar} [kWh/a]	$Q_{aux,net}$ [kWh/a]	Q_{loss} [kWh/a]	f_{sav} [%]
Solar Combisystem 1						
SCSPT	9000	3103	4824	9563	2284	25.0
Sim_{CTSS}	8957	3287	4287	9376	1419	27.2
ε_{ref}	-0.5 %	5.6 %	-12.5 %	-2.0 %	-61.0 %	8.1 %
Solar Combisystem 2						
SCSPT	13298	3002	4918	12954	1573	23.5
Sim_{CTSS}	13603	3168	5139	12435	803	28.6
ε_{ref}	2.2 %	5.2 %	4.3 %	-4.2 %	-95.9	17.8 %

In Table 7 the relative error ε_{ref} is calculated according to equation 5.8:

$$\varepsilon_{ref} = \frac{Q_{i,CTSS} - Q_{i,SCSPT}}{Q_{i,CTSS}} \cdot 100 \qquad 5.8$$

with:

- $Q_{i,SCSPT}$: heat demand / gain obtained with the SCSPT method in kWh
- $Q_{i,SimCTSS}$: heat demand / gain obtained with the Sim_{CTSS} heat kWh

The relative error of the heat demand for space heating for the solar combisystem 1 is ε_{rel} = -0.5 %, and for the solar combisystem 2 ε_{rel} = 2.2 %. As already mentionned, the deviations can be explained by disparities between the physical test of the SCSP test and the simulation of the Sim_{CTSS}:

- The control strategy of the controller for space heating implemented in the Sim_{CTSS} simulation might differ from the control strategy of the real system setup in the SCSPT method.
- In the Sim_{CTSS} simulation additional pipe losses have been implemented. These pipe losses might still differ from those of the real test set up.

Concerning the deviation in the heat demand for hot water preparation, the same reason as described in the previous section are valid: In the SCSPT the hot and cold water temperature during draw-offs vary from the set temperature. This results in a higher or smaller heat quantity withdrawn from the store than demanded.

High deviations between the two approaches exist for the system heat losses. The following reasons are responsible for the deviations:

- A higher heat demand in the SCSPT method which results in higher heat losses in the different circuits
- Higher heat losses of the store and the pipes in the SCSPT than in the simulation of the CTSS method. Even if the heat loss rate of the store was determined by applying the CTSS method by a separate test of the store different heat losses might be possible in case the thermal insulation of the store is performed in a different way during the SCSPT test.
- During the physical test of the SCSPT method high heat losses occur in the auxiliary heating circuit. This is mainly due to a hydraulic switch which is installed between the boiler circuit and the space heating circuit. During the test set up the boiler pump was running most of the time which causes relatively high temperatures in the auxiliary heating circuit and hence comparatively high heat losses. In the Sim_{CTSS} simulation no losses in the auxiliary heating loop are considered.

The fractional energy savings determined with the SCSPT method is lower than the fractional energy savings determined with the CTSS method. The absolute difference is 2.2 % for the solar combisystem 1 and 5.1 % for the solar combisystem 2. For the SCSPT method both combisystems have to provide a higher heat quantity than in the Sim_{CTSS}. The main reason for this is that the heat losses determined with the SCSPT method are higher than the heat losses determined with the CTSS method. These heat losses can be partly compensated by higher solar gains especially during summer. The larger part of the heat losses has to be compensated by the auxiliary heater. The increase in auxiliary energy demand reduces the fractional energy savings.

5.4 Performance prediction for different boundary conditions

Often, customers and manufactures are interested in getting information of the thermal performance of a solar combisystem for different boundary conditions.
With the CTSS method a thermal performance prediction for any arbitrary conditions can be performed by adapting the annual system simulation.

For the SCSPT method the annual performance is obtained by extrapolating the results of the physical test to a complete year. Hence, the performance prediction is only possible for the boundary conditions, for which the physical testing of the solar combisystem has been performed. To overcome this limitation, within the CombiSol project it is analyzed if an extrapolating of the SCSP Test results to other boundary conditions is possible based on the standard EN 15316-4-3:2007 [34]. The quality of this extrapolation is verified by comparing the results extrapolated from the SCSPT method to the results of the annual system simulation of the CTSS method.

The performance prediction has been performed for two different climates and loads (Wurzburg, Stockholm). Figure 72 and Figure 73 show the fractional energy savings of the solar combisystem 1 and 2 for these locations and for two different daily hot water demands (110 l/d and 200 l/d). The values are determined by the annual system simulation of the CTSS method (blue bars) and extrapolated from the test results of SCSPT method using the calculation method of EN 15316-4-3:2007 (red bars) implemented in COMBI-EN tool. The absolute deviation of the fractional energy savings f_{sav} between the two methods is less than 5 % for both systems.

A further analysis has shown that the deviation increases with increasing annual solar irradiation in collector plane. Hence, for Athens and Davos the extrapolated results from the SCSPT differ significantly from those of the CTSS method.

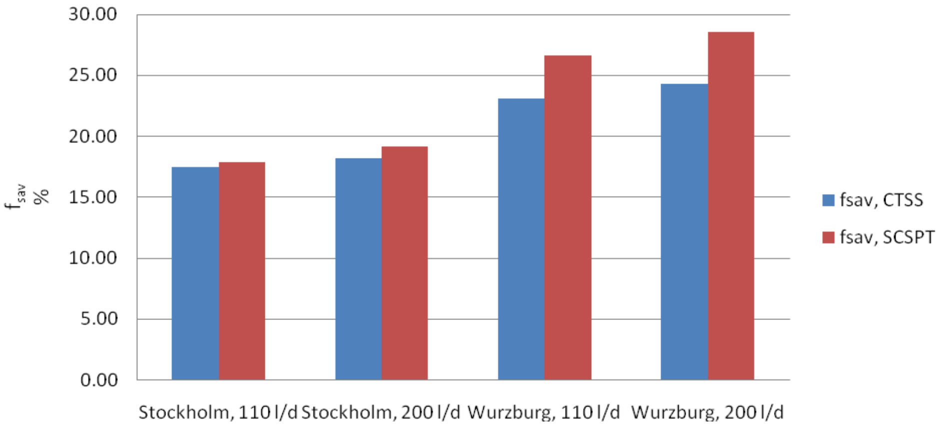


Figure 72: Fractional energy savings of the solar combisystem 1 for different climates (Stockholm, Wurzburg) and daily hot water loads (110 l/d, 200 l/d) determined according to the CTSS method (blue bars) and extrapolated from the test results of the SCSPT test method using the COMBI-EN tool (red bars).

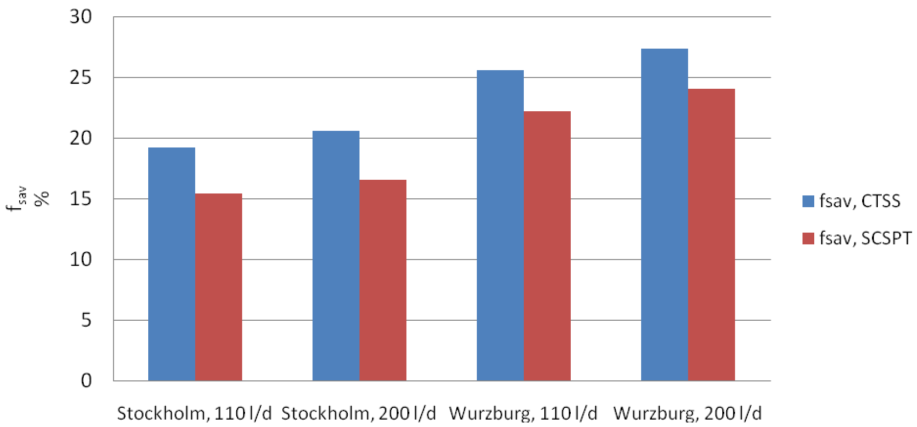


Figure 73: Fractional energy savings of the solar combisystem 2 for different climates (Stockholm, Wurzburg) and daily hot water loads (110 l/d, 200 l/d) determined according to the CTSS method (blue bars) and extrapolated from the test results of the SCSPT test method using the COMBI-EN tool (red bars).

5.5 Summary and conclusion

Two test methods for testing solar combisystems, a component orientated approach (CTSS) and a system testing approach (SCSPT) are presented and compared.

The CTSS method is based on a physical test of the main components and on an annual simulation of the entire system to determine the annual performance of the combisystem. The test method is defined in the standard series CEN/TS 12977 and well accepted within Europe and beyond.

The SCSPT method, based on the CCT – approach and further developed by CEA/INES, France, is based on a physical test of the entire system except the collectors. The annual performance of the combisystem is obtained by extrapolating the results of this short term test sequence to a complete year. For this testing approach no official standard is available up to now. However, within the CombiSol project it has been demonstrated that a good correlation exists between laboratory testing and in situ monitoring.

In the SCSPT method the focus is set on the performance of the whole solar heating system. A central element of the testing is to take into account the overall control strategy - and hence the interaction of the different hydraulic circuits. In addition, as for the physical test the entire system is installed on the test facility, heat losses of pipes and components are taken into account in a realistic way. During the physical test the energy gains from the collector and the heat demand for space heating are simulated online by using a simulation model of the collector and the building. According to the control strategy of the heating system the mass flow rate and flow temperature in the collector circuit, space heating circuit and auxiliary heater circuit are directly adapted.

The CTSS method sets its focus on the performance of the solar part of the heating system. In the system simulation, the heat demand for space heating is defined in a load file with the corresponding flow and return temperatures and mass flow rates. This ensures that in each system simulation the same heat demand at the same temperature level is applied.
For comparing of the auxiliary energy demand of the solar combisystem with the reference system within the CombiSol project the same annual efficiency of the auxiliary boiler of 75 % is assumed. Heat losses of pipes which also arise in the conventional system e.g. in the auxiliary heater circuit and space heating circuit are not taken into account.

Due to the different focus of testing a direct comparison of the test results of the CTSS method and SCSPT method is not possible yet (cf. section 5.3.3). However, when the system simulation of the CTSS method is adapted to the SCSPT method comparable results between the two approaches are obtained (cf. section 5.3.4).

With the CTSS method the thermal performance of the solar combisystem can be predicted for any arbitrary conditions. An extrapolation of the test results from the SCSPT method with the calculation methodology described in EN 15316-4-3:2007 shows good agreement for the locations of Stockholm and Wurzburg but not for locations with much higher solar irradiation such as Athens or Davos.
At present, the CTSS method is more advanced. One main advantage it the flexibility especially with regard:

- to test complete system families with varying sizes of collector areas and / or store volumes
- to test solar combisystems which are individually adapted to a specific system set up
- to carry out performance prediction for other climates, heating loads or collectors

On the other hand, the SCSPT method is well adapted:

- to test prefabricated systems
- to take into account the thermal losses of the system (pipes) in amore realistic way
- to take into account in detail the overall control strategy of the system combined with the interaction of different hydraulic components

Future work should concentrate on a further development and validation of the SCSPT method. It has to be ensured that the test method allows a direct comparison of the thermal performance of different combisystems. This is only possible if for each system tested the annual heat demand for space heating and domestic hot water is similar. Another important aspect is to be able to extrapolate the test results to other boundary conditions such as heat loads, climates and collector orientation and sizes,. Additional work is thus required to adjust EN 15316-4-3 or to develop extrapolating procedures for the SCSPT method (on-going work at INES).

The CTSS method is very suitable to determine the thermal performance of the solar part of a heating system. However, with the growing complexity of the system design and with the growing importance of an energy efficient operation of the whole heating system the control unit is gaining relevance. This can only be ensured if the control strategy of the different hydraulic circuits of a solar combisystem is optimal adjusted to each other. Here, future work should concentrate on the development of more advanced controller testing procedures or even the integration of the real control unit into the dynamic comupter simulaton of the entire solar heating system. A first step towords this direction are the test procedures for multi-function controllers already specified in the new standard CEN/TS 12977-5:2010 [32] [26].

Concerning the testing of solar combisystems two parallel existing performance test methods might in general be an option for the future. The same situation already exists for solar domestic hot water systems with regard to the CTSS method and the DST (cf. ISO 9459-5, [21]) or CSTG (cf. ISO 9459-2, [20]) method respectively. The main advantage of two test methods for the same product category is the option to apply for a specific test the most appropriate and cost effective method. However, in order to implement the SCSPT method as a standardised performance test method it has to be further developed with regard to the aspects mentioned above and applied and validated for a broad spectrum of different system concepts.

In the future, with the energy-labelling of products, the two test methods will have to converge to provide comparable results, and thus inform the end-user about the real thermal performance of solar combisystems.

6 Main recommendations for an efficient solar combi-systems

Main Author: Alexander Thür

Generally speaking, based on experiences within CombiSol project, the main focus of thinking about product and system improvements should not be on increasing solar gains but much more on reducing heat losses within a solar combisystem, which has more components causing heat losses (mainly tanks and pipes) and therefore – unfortunately – more potential of overall heat losses than conventional heating systems typically have. Further a solar combisystem consist of two main parts: the solar thermal and the auxiliary heating system. The integration of both in terms of hydraulic AND control integration is a complex problem and needs to be handled with sufficient design and planning effort in order to achieve high performance of all subparts during heat generation (solar thermal and auxiliary) but also during heat storage and heat distribution.

6.1 Overall System Concept

As stated in section 2.1, modern solar combisystems nowadays can be classified in six categories, three domestic hot water types (DHW-Type A, B, C) and two auxiliary types (AuxType 1, 2):

- DHW type A: Tank in tank system (DHW tank inside the space heating tank)
- DHW type B: Immersed heat exchanger (DHW heat exchanger inside the space heating tank)
- DHW type C: Fresh water unit (DHW flat plate heat exchanger outside the space heating the tank)
- Auxiliary type 1: Tank in tank system + auxiliary boiler is involved as return flow increase
- Auxiliary type 2: Tank in tank system + auxiliary boiler is charging the heat storage tank

Of course different sub-types are possible, for example:

- DHW-type C*: Instead of external DHW heat exchanger an external DHW tank with immersed heat exchanger; this is occasionally used when a solar combisystem is added to an existing heating system.
- Auxiliary type 2*: Auxiliary boiler is charging the heat storage tank and a 4-way valve is used to discharge the space heating tank from two different temperature levels.

Auxiliary type 1 systems are typically used for:

- Auxiliary heater which can modulate the power in a wide range and still operate with high efficiency and their own heat losses are very low when they are heated passive by the solar tank; such auxiliary heater are mainly natural gas boiler or small oil boiler or district/community heating or top heat pumps with speed controlled compressor (or direct electric heater).
- Solar combisystems with small solar fraction (e.g. <20%), because then it happens relative few hours that space heating is on and the burner is off because sufficient heat is available from the solar heat storage which would result in increased heat losses by the boiler.

Auxiliary type 2 systems are typically used for:

- Auxiliary heater which need long running periods for high efficiency: standard heat pumps or pellet boilers or large dimensioned oil boilers.
- Solar combisystems with medium to large solar fraction (>20 to 50% or up to 100%) where significant long periods with space heating demand occur which can be covered by solar energy directly. During these periods the auxiliary boiler in a auxiliary type 1 system would act as a significant heat loss element within the space heating loop.

Auxiliary type 2 systems are mandatory for:

- Auxiliary heater which can not be switched off easily when started until the fuel is out: wood log boiler
- Auxiliary heater which need to run a minimum time period to be acceptable efficient, like wood chip boiler or large dimensioned pellet boiler.

In principle all DHW types can be combined with all types of auxiliary heater. In general it should be kept in mind that a large domestic hot water volume which is kept at set temperature of course guarantees domestic hot water comfort all time, but also is one of the main reasons for heat losses. Since it is not possible to have pipe connections at the tank flexible in terms of height, it should at least be possible with flexible height positions of temperature sensors at the tank to optimize (=minimize) the domestic hot water auxiliary volume according to the specific need of the residents of the house.

DHW type A and B fit best to biomass boiler which have minimum flow temperatures of typically 60 to 65°C which always is sufficient for domestic hot water preparation. Further biomass boiler typically need auxiliary type 2 systems and therefore the DHW auxiliary volume automatically is kept hot during space heating operation.

DHW type C with special advantage can be used in combination with modulating, fast reacting and sufficient powerful auxiliary heater like natural gas boiler, oil boiler or district/community heating. In this combination it is possible to keep the DHW auxiliary volume very little because even a small remaining volume of hot water in the top of the heat storage allows preparing domestic hot water at set temperature. Using this characteristic in a optimised way, most of the heat storage capacity can be kept free for the solar heating system or is kept cold leading to minimized heat losses. This leads to the possibility to choose relative small (cheaper) heat storage without disadvantage in solar fraction.

Further important influencing boundary characteristics for choosing the best system concept will be discussed in the case of auxiliary heater in chapter 6.4, for heat storage in chapter 6.2 and chapter 6.3 and for the space heating circuit in chapter 6.5.

6.2 Single or Multi Store Concepts

A very rough and well known rule of thumb for the ratio heat storage volume to collector area is about 50 Liter/m^2. According to the qualitative evaluation of 70 solar combisystems done within the CombiSol project, the majority of the systems have a specific heat storage volume between 50 and 100 Liter/m^2, about 1/3rd of the systems have installed more than one tank.

Multi store systems have serious disadvantages in terms of heat losses due to several effects:

- The ratio of heat loss surface to volume of two tanks in comparison to one tank with the same total volume is 1/3rd higher, consequently leading to significant higher heat losses.
- Two tanks need to be connected to each other resulting in additional cold bridges for each tank due to the pipe connections AND additional piping within the system both further increasing the heat losses.
- If not smart and clever designed, two tanks connected in parallel typically lead to almost double high temperature auxiliary volume since pipe connections and/or temperature sensor positions are not adapted at standard tanks depending if the tank is used in a single or a double tank concept.

It is strongly recommended to proof very carefully, if it is really necessary to install a multi store system and if the advantage of larger heat storage capacity is high enough in comparison to increased heat losses and double cost for heat storage. The specific storage volume of 50 liter/m^2 is not a general rule which fits in all cases and which is a must. In combination with fast and sufficient powerful auxiliary heater, smart hydraulic and control concept and high insulation quality a specific heat storage volume of 25 liter/m^2 might be reasonable and resulting in a very well and maybe better performing solar combisystem as well, provided that a smart control strategy is implemented and a minimum total volume higher than 400 liter is used.

Unfortunately prepared standard configurations in standard simulation programs for solar combisystems typically do not give the possibility to calculate such details in an easy way, in most cases some tricks and reasonable assumptions are necessary to do such comparison calculations and getting reliable results. Alternatively it is recommended to use simulation programs which give sufficient freedom in creating the system concept as it should look like, the effort for modelling the system of course is somewhat higher and more complex.

Further important influencing boundary characteristics for choosing the right heat storage volume and number of tanks will be discussed in the case of auxiliary heater in chapter 6.4 and for the space heating circuit in chapter 6.5.

6.3 Heat Storage

As mentioned in previous section quite high system heat losses were measured within CombiSol and the qualitative evaluation gave some reasonable explanations how heat losses of the heat storage can contribute to these bad results. Tank insulation very often was not mounted properly, many holes in the insulation for pipe connections and temperature sensors creating cold bridges significantly increase the heat loss rate compared to tested heat storages with typically well closed insulation around the whole tank. Only in 1/3rd of the systems evaluated in CombiSol, unused pipe connections were insulated, naked steel of around 5cm diameter typically is open to the ambient air. Thermosiphon heat traps were almost not installed, just 20% of the systems showed more or less correct pipe connections. In some cases the top insulation of heat storages, where in average the highest temperatures occur, was partly not or bad insulated because of pipe connections leading to highest heat losses.

It is recommended to chose a tank design which has no pipe connections at the top but at the side of the tank (if possible at the height of the lower border of the domestic hot water auxiliary volume) with internal pipes leading to the top in order to reach the hottest water for discharge. Also long pipes for air vent shall be avoided at the top of the tank. A small air valve directly mounted at the top of the tank is sufficient since it is in use only when filling the tank or in case of special maintenance work. Otherwise 99.99% of the time it is not used and shall be covered by tank insulation completely.
For temperature sensors the immersion sleeves do not need to cross the tank insulation. It is sufficient to stop the immersion sleeve at the tank and to lead the electric cable of the temperature sensor inside the insulation downwards. Prefabricated tank insulation elements relatively easy can be taken away if the sensor needs to be changed.In such a case it is possible to realise a completely closed insulation around the top part covering at least the complete domestic hot water volume which is the hottest part especially during the long winter period.

If there is no pipe or cable passing the top insulation plate or the side insulation of the tank, it is also much easier to take this insulation components apart, if it is needed to reach for example the small air valve at the top for maintenance work or to change a temperature sensor which is broken.

There are tank designs available on the market, which have pipe connections ONLY at the bottom part of the tank side with internal PEX-pipes reaching to different heights as needed depending on the specific function. Those PEX-pipes are sufficient temperature resistant and if the wall thickness is more than 4 mm the internal heat transfer effect is negligible. Such a tank can be provided with a completely closed insulation without any cold bridge and pipe connections with thermosiphon heat trap are realized automatically.

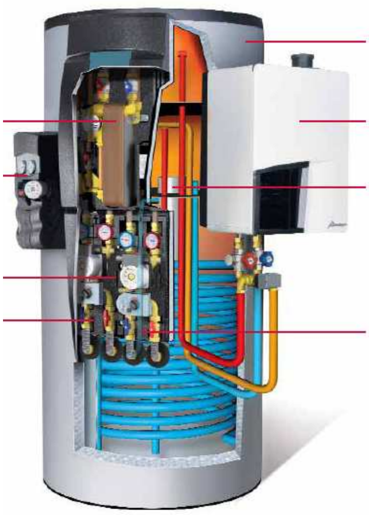




Figure 74: Examples of tank designs with pipe connection at tank side in medium/low temperature zones with internal pipes to the top; Source: Pink (left) Bösch (middle); example of well insulated piping and thermosiphon heat traps at all pipe connections at the heat storage (right; Source: Tisun)

Figure 75: Examples of good insulated top of heat storages and best case (right) of a totally closed top insulation of a heat storage. (Source : AEE INTEC)

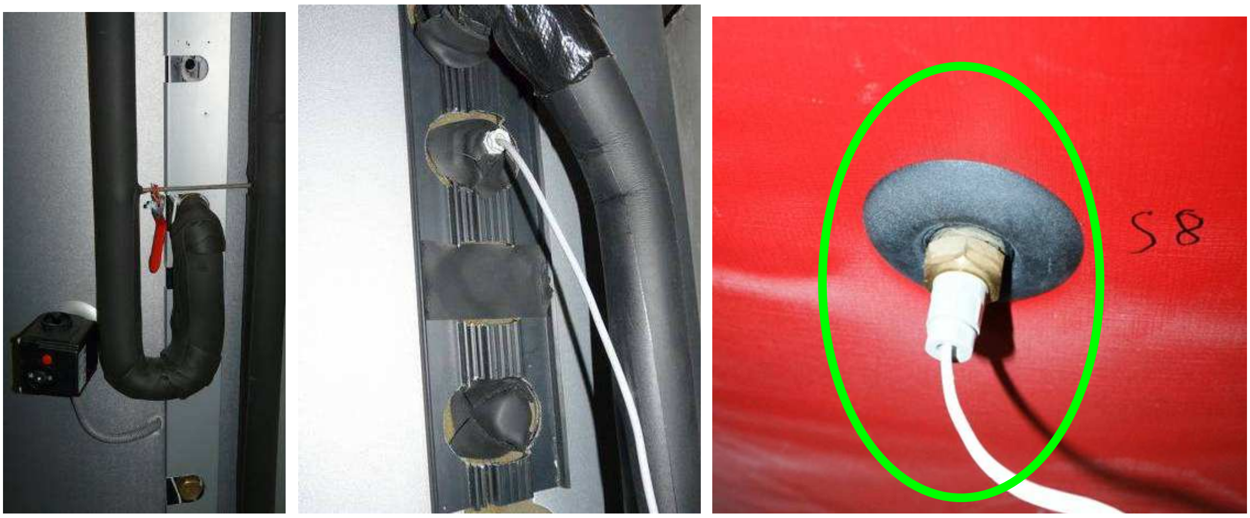


Figure 76: Example of good/acceptable installation details: insulated thermosiphon heat trap (left, Source: INES Education); basic insulation of temperature sensor and unused pipe connections (middle, Source: INES Education); temperature sensor well fixed and pipe for immersion sleeve insulated (right, Source : AEE INTEC)

Source : AEE INTEC

Figure 77: Good examples of prefabricated insulation elements for unused pipe connections (Source: Sonnenkraft (left) Bösch (right)).

6.3.1 System with two heat storages:

If it is unavoidable to install two heat storages in parallel, heat losses can be reduced if the pipe connection at the top of the two tanks is equipped with a non return valve with the goal that only the auxiliary volume of the one tank which is directly heated by the auxiliary heater is kept hot all the time. Only solar heat can heat up the top part of the second tank and this heat is transported to the main tank passing the non return valve in the right direction by means of natural forces in case of temperature difference between the two tanks.

6.3.2 Connection of space heating return pipe:

Often discussed point is where to connect the space heating return pipe at the heat storage. In the case of floor and/or wall heating systems it is simple, return pipe should be connected at the bottom of the tank. The volume exchanged in the tank due to space heating is much higher than due to domestic hot water preparation and due to internal heat conductivity inside the tank the some degree lower temperature in the bottom part of the tank due to domestic hot water preparation is heated up in very short time.
In the case of radiators in the space heating circuit, the situation is slightly different. If the space heating circuit is adjusted and controlled correct with thermostat valves and the radiators are large enough designed as low temperature radiators (or maybe oversized after thermal renovation of the house), the return temperature always should be lowest possible and the return pipe can be connected at the bottom of the heat storage. If high return temperature has to be expected during high space heating load periods or the house residents keep windows open without closing thermostat valves it might be of advantage to use a 3-way valve in order to decide in combination with a temperature sensor if the return flow shall enter the tank in the bottom or at the height where the auxiliary heater return pipe is connected.

6.4 Auxiliary Heater

Several types of auxiliary heater are available to be used in solar combisystems and they might have quite different operating conditions. For example a condensing natural gas boiler needs very low return temperatures (<<57°C) to be able to use the condensation effect, whereas a wood log or pellet boiler on the other hand needs a minimum return temperature (>55°C) in order to avoid corrosion and deposit problems due to condensation of the flue gas. Also different boilers have different characteristics how they can be controlled. A natural gas boiler can change the power by modulating quite fast and easy; other boiler types just can change power by start and stop of the burner.
Since the boundary conditions of each house, each country, each system concept, availability of different fuel types, etc. are different, it can not be stated the one or the other auxiliary heater is the best.

The integration of the auxiliary heater turned out to be a critical point in many installations evaluated within the CombiSol project, especially if the solar combisystem is not delivered as a complete package from ONE system supplier. The main problem is in many cases, that the auxiliary volume of the heat storage in fact is not used as a buffer but much more as a huge hydraulic switch which is kept hot all the time with high potential of excessive heat losses. Especially in cases with condensing natural gas boilers this strategy is quite disadvantageous and significant potential of improvement of boiler and system efficiency exists.

6.4.1 Problem of over-dimensioned auxiliary heater:

Since a solar combisystem has a relative large domestic hot water auxiliary volume there is no need to design the boiler according to domestic hot water peak load. The average power for domestic hot water preparation over 24 hours in a one family house is about 0.5 kW (200 litre per day with 10/60C°) or less. The boiler should have a nominal power not higher than the design space heating load.

This point of keeping the nominal boiler power as small as possible is true for all boiler types, but the efficiency effect is most likely less critical with light and small boilers like natural gas boiler or oil boiler than for pellet boiler or wood chip boiler with big internal heat capacity and big heat loss surface. Therefore later in this chapter in contradiction to this paragraph a concept is discussed which uses high power condensing natural gas boiler but reducing dramatically heat storage volume (maybe number of tanks) and therefore heat losses and investment cost as well.

6.4.2 Typical specific problems in auxiliary type 1 systems “auxiliary boiler as return flow increase”:

In auxiliary type 1 systems the auxiliary boiler during space heating operation is operating as in any conventional heating system without any possibility to buffer heat in the heat storage. Therefore it is important to choose a boiler type which has highest possible part load efficiency because this is the huge part of operation during the year.

Therefore also the nominal power of the boiler MUST NOT be over-dimensioned. Very often the minimum power of the boiler is in the range of the maximum space heating load of the house, therefore the boiler never is operating in a constant and efficient mode but in a less efficient start/stop mode all the time.
Further it was observed that the temperature sensor controlling the domestic hot water volume is placed too close to the space heating auxiliary volume leading to the effect that this sensor is strongly influenced by the space heating flow rate and therefore the boiler most of the time is operating in high temperature domestic hot water mode which leads to much worse or no condensation effect and therefore much worse boiler efficiency. In fact this system than partly is somehow operated as auxiliary type 2 system, because due to heating the domestic hot water volume in the top heat also is transferred downwards into the solar volume due to several heat transport effects and then used for space heating.
The temperature sensor should be placed at least 20 maybe better 30 cm above the boiler inlet pipe to avoid such effects. Since the domestic hot water auxiliary volume typically is in the range of 200 to 300 litres, it might be useful to set time periods in the boiler controller when he is allowed to operate in domestic hot water mode, e.g. 1 hour in the morning and 1 hour in late afternoon, depending on the need of the residents. Conventional heating systems in one family houses often have domestic hot water tanks with about 150 litres and a time controller is used in a similar way to allow hot water preparation only during specified periods.

6.4.3 Typical problem of auxiliary volume as hydraulic switch:

In auxiliary type 2 systems "auxiliary boiler charging the heat storage" in combination with condensing natural gas boiler it happens that the boiler pump is in operation all time with constant speed and just the burner is controlling the flow temperature by modulation or start/stop mode. The result is that the auxiliary volume of the heat storage in fact is used as a hydraulic switch and kept all the time at the high set temperature as controlled by the natural gas boiler.
Second, a follow up effect is that therefore the boiler return temperature is more or less equal to the flow temperature depending on the ratio of boiler flow rate and space heating flow rate. In combination with floor/wall heating systems the problem is less critical than in combination with radiator systems because those typically change the flow rate much more when (hopefully) controlled by thermostat valves. In combination with radiators the risk is very high that the temperature level of both flow and return flow is getting that high that no or only very little condensation occurs which decreases the boiler efficiency dramatically.
Third, if the solar collector heats up the heat storage the boiler loop including the boiler itself is heated up and generating absolutely avoidable heat losses if the boiler pump would be switched off.
Further number four, also in auxiliary type 2 systems it was observed that the temperature sensor controlling the domestic hot water volume is placed too close to the space heating auxiliary volume leading to the effect that this sensor is strongly influenced by the space heating flow rate and therefore the boiler most of the time is operating in high temperature domestic hot water mode which leads to much worse or no condensation effect and therefore much worse boiler efficiency.
The temperature sensor should be placed at least 20 maybe better 30 cm above the boiler inlet pipe to avoid such effects. Since the domestic hot water auxiliary volume typically is in the range of 200 to 300 litres, it might be useful to set time periods in the boiler controller when he is allowed to operate in domestic hot water mode, e.g. 1 hour in the morning and 1 hour in late afternoon, depending on the need of the residents.

In auxiliary type 2 systems in combination with condensing natural gas boilers and especially with DHW type A or B it might be a good solution just to heat the domestic hot water auxiliary volume with constant 50°C (maximum 55°C) independent of the ambient temperature. In this case the domestic hot water volume is kept hot all the time and due to the flow around the inner tank or the immersed domestic hot water heat exchanger (if the boiler is in operation) the heat transfer rate for domestic hot water preparation is increased that much that typically also peak domestic hot water load can be covered without problems.
The advantage of this strategy is that the condensing natural gas boiler is not switching all the time between domestic hot water mode and space heating mode but operating constant in one standard operation mode with a constant flow temperature which is low enough (in combination with the lower return temperature) to have good condensation effect and high enough to allow a sufficient high domestic hot water temperature. Further it is possible to adjust the boiler flow rate according to the maximum space heating power which forces the condensing natural gas boiler at least to modulate to this power rate. In case of a peak domestic hot water demand the boiler return

temperature will decrease and automatically the natural gas boiler increases the power because the set flow temperature must be reached.
Since a solar combisystem anyway needs a mixing valve to control the space heating flow temperature it is not needed that the boiler is doing this task as in conventional heating systems.

In combination with DHW type C systems due to the domestic hot water preparation with an external flat plate heat exchanger it might be a problem to keep the boiler flow temperature below 55°C, if for the domestic hot water temperature more than 48°C at full load is required.

In order to reduce start/stop frequency, someone should also consider that auxiliary volume for space heating can be discharged completely before heated up again. If space heating power is reduced for 10 to 15 minutes because the flow temperature is not reached exactly according to the control settings, this does not result in freezing in the house. Thanks to the huge heat storage effect of the house itself nobody will notice reduction of a room temperature. In fact this is the same situation as when the boiler is switched to domestic hot water preparation for typically around 15 minutes. This way the auxiliary volume is used really as a buffer than a hydraulic switch and due to in average lower temperatures in the tank the heat losses will decrease as well.

6.4.4 Auxiliary heater flow rate setting or control:

In many cases in auxiliary type 2 systems it was observed that the boiler flow rate was at the maximum all time, just as a result of pressure drop and flow capacity of the pump at highest power set point. Based on the fact that maximum boiler heating power typically is much too high (see before the discussion of over-dimensioning) this leads to very short operating periods with high heating power.
If the flow rate of the boiler loop is adjusted based on nominal space heating power and typical temperature difference (depending on boiler type and controller settings) it can be achieved that the boiler is operating under longer constant part load conditions than in very short intervals with maximum power at least at the beginning. Of course it must be avoided that the boiler is forced to operate with less power than possible due to power modulation. If done correctly, this should result in higher average boiler efficiency.

A further improvement could be reached if the boiler loop pump is speed controlled within a reasonable range with the effect that the boiler is forced to modulate the heating power according to the load. But this typically is not possible with standard options in existing controllers, it would be necessary to develop a special control algorithm in each case. However, if an external boiler pump is used, a reasonable control strategy in combination with an additional small controller beside the boiler controller could be to control the pump speed (with a minimum limitation) on a first level in order to keep the temperature difference of boiler return and flow temperature constant at a relative high level (depending on the demand temperature difference conditions: mainly if floor/wall heating and/or radiator heating). As second – overruling – level the space heating forward temperature must be controlled: if the forward temperature does not reach the set or minimum temperature anymore, the boiler pump speed needs to be increased. This will be the case in situations when the actual demand power is higher than minimum boiler power. Consequently this effort of speed controlling the boiler pump only makes sense, if the boiler is able to modulate to significantly less power than the maximum space heating power of the house and the part load efficiency of the boiler is reasonable high enough.
Free programmable controllers are on the market which are able to manage such tasks and which can be used by system supplier and installers to realize such a concept if the integrated controller of the boiler is not able to manage this task.

6.4.5 How to control the space heating auxiliary volume:

In principle two different boiler types exist for this problem: those which are able to control the boiler temperature in the same range as the demand temperature occurs (natural gas boiler, oil boiler, district/community heating, heat pumps, electric heater) and biomass boiler (pellet-, wood chip- and wood log boiler) which typically have a minimum supply temperature higher than the demand temperature of space heating and/or domestic hot water.

Many boilers have integrated in their own controller only the possibility to use just one temperature sensor which is typically mounted in the tank at the lower border of the auxiliary volume. If set temperature is reached the boiler is switched off and if set temperature minus hysteresis is reached the boiler starts again. Typically to be sure and to have no problems with the customer the set temperature of the auxiliary volume is set clear higher then the set demand temperature because also set temperature minus hysteresis must be above set demand temperature.
This is forcing the temperatures in the system to be higher and higher and heat losses are increased and heat capacity of the tank for solar energy is reduced because almost the complete tank is hot anyway due to heat conductivity which also heats the lower parts of the tank.
Second problem: if only one temperature sensor is used and hysteresis is little practically only a very little volume around the temperature sensor is really used as buffer. It does not help if pipe connections give the possibility to use a larger auxiliary volume.

Improvement step 1 could be reached if the temperature sensor is placed at the top of the auxiliary volume and the set temperature to stop the boiler is slightly above the set flow temperature of the boiler. Only if the complete auxiliary volume is heated up and the boiler return temperature starts increasing that much that the boiler is not able to reduce the power to keep the set flow temperature the flow temperature increases as well and the set temperature for switching off will be reached. Problem is the risk that first the internal controller stops the boiler due to overheating. So it is necessary to find all the right settings with all different controllers active in the complete procedure. This or other similar tricky solutions might be possible if one supplier is offering the complete system with matched controller settings. For the installer on site most likely it is not an easy task to find the right settings.

In the case of biomass boiler where the hysteresis of the internal controller typically is relatively high (about 10°C or more) it is easier to find the right settings with the sensor placed at the top of the auxiliary volume. If boiler flow set temperature is 70°C, set temperature for switching off is 75°C and hysteresis for switching on is 40°C (switching on temperature is 35°C in case of floor heating) quite a long running period for the boiler can be expected. The question is, if the boiler controller allows such a wide range of settings, what is not always the case.

Improvement step 2 is to use 2 temperature sensors, one at the top and one at the bottom of the defined auxiliary volume; this also can be different places than flow and return pipes are connected. In this case the set flow temperature of the boiler can be equal to the set demand temperature, the set temperature for switching on the boiler (= top sensor) can be set even lower than the demand temperature (in order to cool down completely the auxiliary volume, see before) and the set temperature for switching off the boiler (=bottom sensor) can be set just a little higher than space heating return temperature in order to guarantee that return temperature to the boiler is low until stop of the boiler in order to have good condensation until the end of operation (or the sensor is placed clear above return pipe connection).
Alternatively it is also possible to chose a switch off set temperature relatively high in order to get long running time and to charge the auxiliary volume as much as possible (most probably in case of non condensing boilers).

6.4.6 Potentials for keeping heat storage small and avoid multi store systems:

In principle the tank volume is split into 3 parts: DHW-auxiliary volume, SH-auxiliary volume and solar volume, mainly depending on the auxiliary type both auxiliary volumes can be minimized in order to increase the available solar volume. As discussed in chapter 6.2 the well known rule of thumb is to install 50 litre/m^2 collector area. But the main question is which volume is really needed for the auxiliary heater how much volume is available for being charged with solar energy. There is a huge difference if the auxiliary heater is a wood log boiler, a pellet boiler or a condensing natural gas boiler.

<u>Auxiliary type 1 system “auxiliary boiler as return flow increase”:</u>
The auxiliary type 1 system per definition has no space heating auxiliary volume. Therefore in such a system the solar volume typically is at least 100 to 200 liters larger than in auxiliary type 2 systems.

A very special case is the condensing natural gas boiler in terms of system optimization. Such natural gas boiler can be activated very fast, if domestic hot water mode is activated typically within 20 to 30 seconds the boiler is in operation with full power. For a natural gas boiler with sufficient peak power for direct domestic hot water preparation in combination with DHW type C system (external flat plate heat exchanger) and auxiliary type 1 systems

there is a quite big potential to have almost no auxiliary volume and to have almost the complete tank as a solar tank. It might be worth to try the following strategy since the only risk is to replace a temperature sensor to another place:
If the pipe connection of the boiler flow pipe and the domestic hot water discharge pipe both are in the very top of the heat storage it is sufficient to have the temperature sensor for the domestic hot water not in the tank but directly at the outlet of the discharge pipe of the domestic hot water preparation loop. If DHW set temperature for taping is 45°C and the outlet temperature decreases below 55°C the natural gas boiler shall start with set flow temperature of 60°C. Within the delay period of about 30 seconds the DHW outlet temperature might further decrease from 55 to 53°C but still enough for hot water preparation. After these 30 seconds the very small volume in the very top of the tank is heated up by the boiler again until the temperature sensor at the DHW outlet pipe reaches boiler set temperature of 60°C plus hysteresis, the boiler is switched off again or switching back to space heating operation. Important installation point is that the natural gas boiler is placed very close to the heat storage to avoid extended delay time due to long pipes.
In fact this is nothing different than a conventional heating installation with a domestic hot water tank controlled by a temperature sensor in this tank. The advantage of the space heating heat storage is that there is no low power immersed heat exchanger between natural gas boiler and space heating water like in a conventional domestic hot water tank which is the real bottle neck for fast heating up the water in the tank.

If this concept does not work with sufficient comfort, it is just necessary to replace the temperature sensor from the outlet pipe position to a place lower in the tank in order to get a larger DHW auxiliary volume.
But if this is realized that way, about 90 to 95% of the heat storage is free to be charged by solar energy and even a 25 to 30 m^2 collector field can be realized in combination with ONE heat storage of 800 or 1000 liter volume with high overall performance thanks to minimized heat losses. Instead of a second tank effort and money should be invested in perfect insulation of the tank and thermosiphon heat traps as pipe connections at the tank.

Auxiliary type 2 system “Auxiliary boiler charging the heat storage”:
In auxiliary type 2 systems in combination with very small dimensioned and modulating boilers like condensing natural gas boiler, oil boiler or even pellet boiler it is also possible to keep the space heating auxiliary volume in practice small and cold (as also already described before):
If an external boiler pump is used, a reasonable control strategy in combination with an additional small controller beside the boiler controller could be to control the pump speed (with a minimum limitation) on a first level in order to keep the temperature difference of boiler return and flow temperature constant at a relative high level (depending on the demand temperature difference conditions: mainly if floor/wall heating and/or radiator heating). As second – overruling – level the space heating forward temperature must be controlled: if the forward temperature does not reach the set or minimum temperature anymore, the boiler pump speed needs to be increased. This will be the case in situations when the actual demand power is higher than minimum boiler power. Consequently this effort of speed controlling the boiler pump only makes sense, if the boiler is able to modulate to significantly less power than the maximum space heating power of the house and the part load efficiency of the boiler is reasonable high enough.
Free programmable controllers are on the market which are able to manage such tasks and which can be used by system supplier and installers to realize such a concept if the integrated controller of the boiler is not able to manage this task.

6.5 Space Heating

For a solar combisystem the space heating distribution is in most cases (except extreme low energy houses) far the most important influencing heat demand circuit since still 70 to 90% of the overall heat demand is caused by space heating and just 10 to 30% is caused by domestic hot water consumption. Also the space heating demand mainly takes place in the winter period with bad operating conditions for the solar collector like reduced solar radiation and low ambient temperatures. Therefore the space heating system has a large influence on the system behavior:

- As lower the forward temperature as more heat can be used from the heat storage because the auxiliary can start heat up again later at lower tank temperatures. Additionally for condensing boiler low forward temperature is essential to achieve high condensation rate and following up high efficiency.

- As lower the forward temperature as lower can be kept the heat storage temperature by the auxiliary heater and following the heat losses are reduced.
- As lower the forward temperature as more heat capacity has the heat storage because the temperature difference useful forward temperature to the maximum possible temperature is maximized.
- As lower the return temperature as more heat capacity has the heat storage because the potential of useful temperature difference is maximized.
- As lower the return temperature as lower the average temperature in the heat storage as lower the heat losses.
- As lower the space heating return temperature as lower the solar collector return temperature which increases the collector efficiency and reduces the needed solar radiation to start gaining solar energy.

Temperatures are depending on different boundary conditions like:

- Return and forward temperature is depending on the used components like old, small designed high temperature radiators or new, large designed low temperature radiators, wall/floor heating systems or often in Passivhouses used air distributing space heating system.
- Return temperature is strongly depending on the operating conditions, for example if the hydraulic loop is adjusted or not. Also the control strategies like ambient temperature controlled or controlled by thermostatic valves, etc. have a high influence on the return temperature of the space heating loop.

Several simulation studies done within the IEA SHC Task26 program showed that in general most influencing factor is the space heating return temperature and less strong influencing is the forward temperature. Therefore the most important focus should be on achieving lowest possible return temperatures from the space heating distribution system.
For example if the auxiliary set temperature is 60°C and space heating return temperature is 40 or 30°C, this leads to useful temperature difference of 20°C (60-40) or 30°C (60-30) which is equal to a difference of heat storage capacity for the same volume of additional 50% in the case of 30°C space heating return temperature. In principle the following space heating systems can be classified based on the temperature level:

6.5.1 High temperature space heating systems

Old radiator systems with design temperatures like 90/70 (very old systems) or 70/50°C (forward/return temperature, for design outdoor temperature) are typically installed in old houses.

- Advantage: No advantage but easy decision: Do not install a solar combisystem if the heat load of the building is still high. It is possible to invest money more efficient in reducing the energy consumption for the house.
- Disadvantage: Very high return temperature to the heat store leads to high heat storage heat losses and bad operating conditions for the collector.

After thermal insulation of the building the radiators might change to a medium temperature heating system since then the radiators are oversized. Then maybe such a heating system is usable for solar combisystems with low solar fraction and good hydraulic adjustment of the space heating system.
Such systems are also often installed in old houses, which even in summertime often have little space heating demand; in such cases, a solar combisystem can be a good opportunity.

6.5.2 Medium temperature space heating systems

In new buildings, radiator systems are typically designed for medium or low temperature operation, like 60/40 or very advanced: 50/30°C (flow/return temperature, for design outdoor temperature). Also water/air heat exchanger in modern Passivhouses might operate in this category.

- Advantages:
  - Cheap space heating system
  - Very low return temperatures are possible, especially in spring and autumn; but only if the radiators are correctly designed AND hydraulically adjusted AND controlled by thermostatic valves (especially 50/30-systems) AND thermostatic valves are operated correct by the residents.
  - Because of large temperature differences (flow/return) very little mass flow occurs which causes little turbulences in the heat store.
- Disadvantage:

- Practical experience shows that in the normal case in existing houses, the return temperatures are very high caused by missing hydraulic adjustments. Especially in heating systems without thermostatic valves where standard valves are manually opened and closed, this is a big problem.

6.5.3 Low temperature space heating systems

Floor- or wall heating systems designed for temperature operation like 35/30°C (flow/return temperature, for design outdoor temperature) are in principal the best space heating systems in combination with solar combisystems, because the temperature level in general is very low.

- Advantages:
  - These systems in general have low return temperatures which lead to good operating conditions for the collector.
  - Low forward temperatures can easily be reached by the collector even in winter time; therefore the auxiliary heat source can be switched off soon.
- Disadvantages:
  - Because of little temperature differences (flow/return) very high mass flow might cause strong turbulences in the heat store. This depends on the specific boundary conditions and tank design.
  - This type of space heating system is relatively expensive.
  - Due to the direct contact to the high mass and heat capacity of the floor the hydraulic design of the floor heating pipes influence strongly the return temperature and the temperature difference respectively. If the piping is like a spiral, a very homogeneous floor temperature in the complete room can be achieved, but only a very small temperature difference and therefore relative high return temperature. In comparison if the piping is like a meander starting at the outer wall and ending in the center of the building higher temperature difference and lower return temperature can be achieved. For wall heating systems the piping typically is installed similar as a meander from top to bottom resulting also in low return temperatures.

6.5.4 How to achieve low return temperatures in practice:

- Space heating emitting elements (radiators, floor/wall heating area) should be chosen as large as possible in order to be able to operate the system at low temperatures. For example if standard calculation of a radiator with 50/30 results in a length of 70% of the window, still 100% should be chosen what does not increase the cost significantly.
- In general EACH single part (each radiator!!) of the space heating distribution system hydraulically MUST be pre-adjusted properly to the nominal design flow rate as needed at maximum space heating load, what unfortunately in practice very seldom is the case.
- Space heating distribution systems should operate as “low flow” systems with high temperature difference and low return temperatures. Therefore it is especially in radiator heating systems advantageous to operate with slightly higher flow set temperature and reduced flow rate controlled by thermostat valves at EACH radiator. Especially in autumn and spring, when radiators are over-dimensioned, this can lead to return temperatures only a few degrees above room temperature.
- Since radiator space heating systems most of the times operate as “low flow” systems (if operated properly!) especially the flow pipes which are inside the wall (as it is typically done in Austria but not in Sweden) should be insulated extra thick in order to get the set flow temperature to the inlet of the radiator. The pipe in the wall should not act as a wall heating element. Insulation thickness should be at least pipe diameter. Increased cost can be balanced by only very little insulation of the return pipe, since this pipe is cold all the time.
- Again in the case of low flow radiator (50/30) space heating systems, the very low flow rates allow non-standard small diameter pipes compared to standard installations. Often 10 or 12mm pipes are sufficient instead of typically 15, 18 or 22mm pipes. This mainly reduces cost but also increases the speed of reaction of the radiators when switched on.

6.5.5 Advanced ideas/concepts to increase the system performance:

Again within the IEA SHC Task26 simulations showed that if instead of a 3-way mixing valve a 4-way-mixing valve is installed this increases the performance of the system by increasing the usage of solar heat. In this case two flow pipes are connected to the heat storage, one at the top of the space heating auxiliary volume and one at the top of the solar volume which enables the system to discharge the heat storage at a lower height as long as possible. This is of advantage because it improves the stratification in the heat storage and keeps longer the high temperature in the top part. Such 4-way valves are used in Sweden since many years.

In new built low energy houses with sufficient passive solar gain for all relevant rooms, it might be of advantage to position the ambient temperature sensor at south side on a sunny place instead of a shadow place on north side of the building. In this case the space heating system much faster gets an input about the actual passive solar gain and due to much more reduction of space heating flow temperature energy can be saved in comparison to an ambient temperature sensor placed in the shadow on the north side of the house.

6.6 Solar Collector Circuit

Mostly in Europe for solar combisystems flat plate collectors or vacuum tubes are used which can be installed in different way:

- Roof integrated as a part of the water tight layer
- On the roof above the water tight roof cover but parallel to the roof tilt angle
- On the roof and lifted with an additional support construction to have a larger tilt angle
- Wall integrated in a vertical or tilted wall
- As part of another construction at the house like the balustrade of a balcony, extra roof for the entrance or the car-port or as extra roof for terrace, etc.
- On the roof of the garage which is placed beside the house
- On the roof of a small garden house
- On the ground in the garden tilted with an extra support construction
- …..

The size of the complete collector area is mainly depending on a) the heat load (DHW+SH) and b) the goal how much solar fraction is wished to be achieved. Market available simulation programs (T-Sol, Polysun,…) perfectly can be used to estimate the potential of solar gain and auxiliary heat consumption for different boundary conditions. Further within the CombiSol project based on an excel file “A simple calculation tool for manufacturers and installers” (D6.2) [6] for easy to use was elaborated as well and can be found to be used in English, French, German, Danish and Swedish at the webpage: www.combisol.eu.

In general collector orientation can vary about 30° from south and from 30° to 75° in slope with less than a 10% reduction in energy savings for a central European climate (see Figure 78). Within this range, it is generally easy to compensate with a slightly larger collector area (Weiss, 2003) [7].

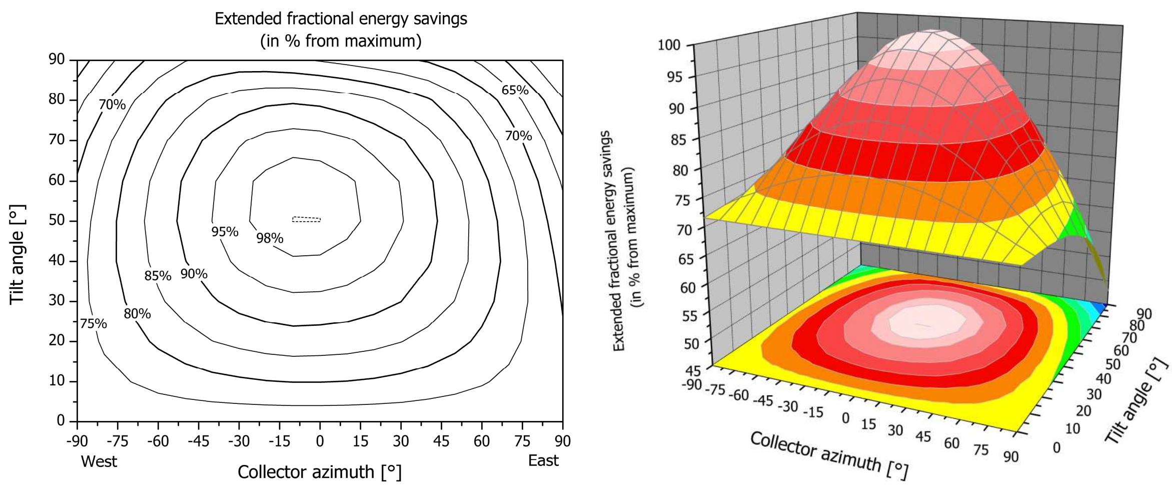


Figure 78: Dependency of the fractional energy savings on tilt angle and azimuth of the collector (climate: central Europe, 100% = 39% of extended fractional energy savings), source: Weiss 2003 [7].

6.6.1 Quality of external piping:

As the quality evaluation within the CombiSol project showed, the quality of pipe installations especially outside the building is a critical point. Due to the fact that the pipes are exposed to the ambient weather conditions and natural forces it is necessary to accept the following additional effort:

- Extended pipe insulation: insulation thickness one size thicker than pipe diameter
- Insulation material should be water proof (closed cells) or really very well water tight protected.
- Insulation material must be high temperature resistance (at least 160°C)
- Insulation material must be protected against ultra violet radiation and animal bites

In Figure 79 good quality examples of well protected pipe insulations are shown.

Figure 79: External pipe insulation (Source: AEE INTEC / Austria): good quality of insulation and protection

6.6.2 Dimensioning of Solar Heat Exchanger:

It is observed that external plate heat exchangers often are chosen too large meaning that “to be sure” the heat transfer capacity is higher than needed and/or the temperature difference (flow minus return temperature) and the flow rate respectively do not fit. It is a MUST that turbulent flow takes place inside the plate heat exchanger otherwise the heat transfer decreases close to zero. There is NO increased factor of safety allowed, this just leads to mal function. For example a 10 kW heat exchanger for about 20m^2 collector area for 10°C temperature difference usable for a high flow system can not be used for a low flow system with 30 to 35°C temperature difference.

6.6.3 How to install stagnation proof solar collector circuit:

Mainly during summer period a solar combisystem is over-dimensioned leading to periods when the heat storage has reached the maximum temperature and the problem has to be solved how to handle with the solar heat which still is gained by the solar collector and producing steam if the pump(s) of the solar circuit are switched off by the controller.

The components of a solar thermal system must be protected against such high temperatures due to stagnation where in the collector temperatures above 200°C can be reached and steam with temperatures up to 150°C can be pressed into the pipes of the system. For solar combisystems stagnation can be a daily operating condition in the summer period. If planner and installer observe some major rules, stagnation becomes a normal and harmless condition for the solar combisystem. Measures can be categorised in 1) passive protection and 2) active protection methods.

1) Passive Protection

Following some rules and devices which configures the passive overheating protection are mentioned.
The pipes from the collector to the technical room should be installed constantly downwards without any bends upwards in order for the liquid to be able to drain back to the expansion vessel without creating any steam bubbles which could "implode" very noisy and creating high pressure shocks in the piping.

The membrane in the expansion vessel typically is damaged at temperatures above 90°C. This is the reason why expansion vessels for solar thermal systems should be connected from above. In this case the cold fluid stays in the fluid reservoir of the expansion vessel. The hot medium does not reach the membrane that easy. Figure 80 shows the two described cases. It is also acceptable to install a thermosyphon heat trap in the NOT insulated and long enough piping from the collector loop to the expansion vessel and then to collect the expansion vessel from bottom if the expansion vessel volume is well dimensioned (see in the middle of Figure 81).

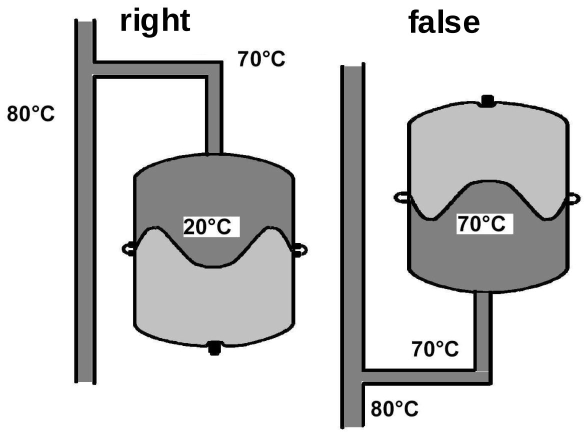


Figure 80: Right and false way for connecting an expansion vessel in a solar thermal system (left).

How to calculate the volume of the expansion vessel correct (what is very different to conventional calculation methods for hot water tanks due to the steam production in the solar collector!!) is described more detailed in an extra technical report of WP6 which is comparing different methods for calculation which is available on the project webpage: www.combisol.eu.

In order to protect the expansion vessel (and in parallel temperature critical components like pumps and valves) a stagnation cooler can be placed before the expansion vessel. The stagnation cooler is a heat dissipater with as high as possible heat transfer rate to the air around. For example this can be a pipe with a big surface area in order to cool the medium before it reaches the expansion vessel. Mostly it is a simple baseboard heating fitting (Figure 81, left). The average cooling capacity of such an element is about 750 W/m.

Another possibility is the possibility to use a "preposition vessel" with sufficient volume that takes the high temperature liquid or steam first and which has sufficient high cooling effect that the liquid entering the expansion vessel is cold enough (Figure 81, right).

Figure 81: Stagnation cooler, performed as a baseboard heating fitting (left) and mounted (middle) or "preposition vessel" (right)

In order to protect temperature critical components like the pump the right order of non return valve, pump and connection of the expansion vessel is important as shown in Figure 82. Since the pressure is much higher in the solar primary loop (cold start pressure should be about 2.5 bar) than it is typically in space heating systems, it is not necessary to have the expansion vessel at the low pressure inlet side of the pump.

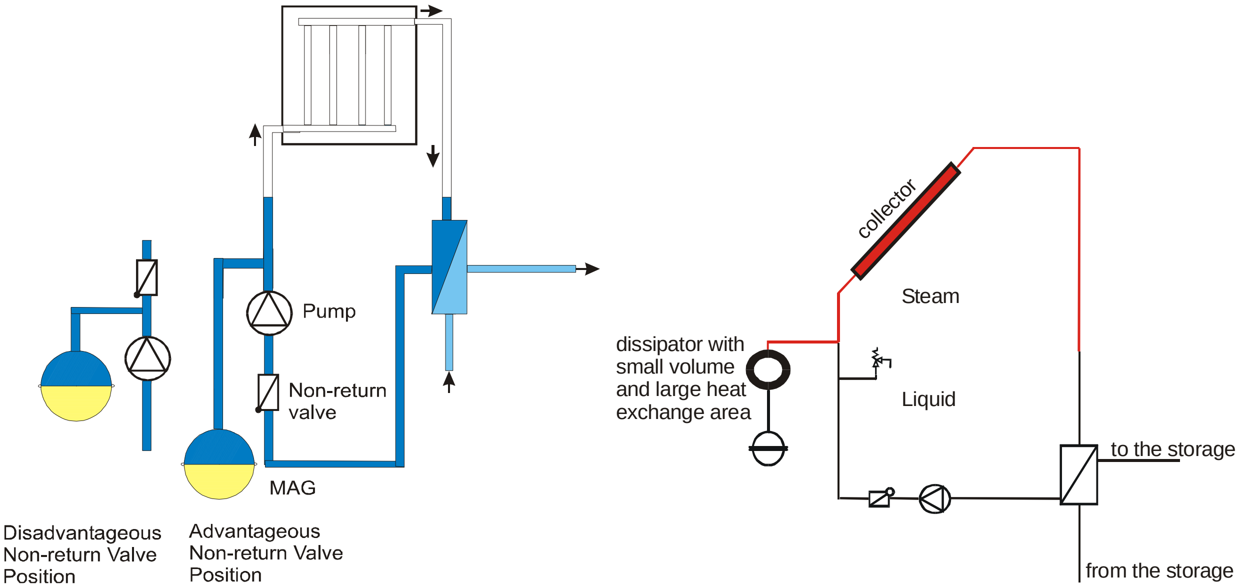


Figure 82: Correct position of the non-return valve in relation to the expansion vessel (left) and correct position of a stagnation cooler keeping the steam above temperature critical components (right) (Source: AEE INTEC)

The main point in the situation of stagnation is the amount of steam produced within the system. The more liquid heat transfer medium is trapped in u-shaped loops inside the collector, the more steam is produced during the stagnation period. Therefore in the case of stagnation, when the liquid starts vaporising as much remaining liquid parts as possible should leave the collector as fast as possible. Therefore, the collector shall have a "good emptying behaviour".

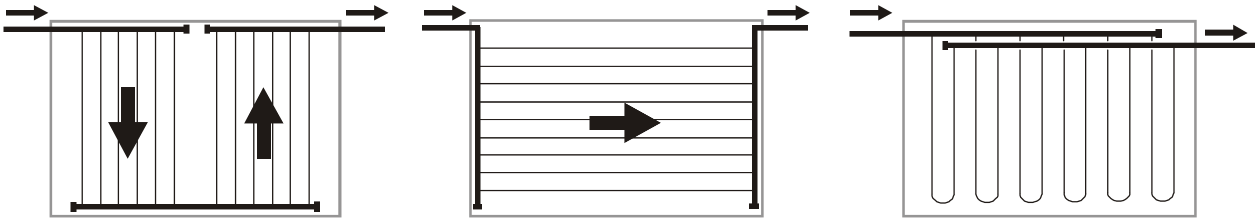


Figure 83: Collectors with bad emptying behaviour

Figure 83 shows collector types with bad emptying behaviour. In this case nearly the whole collector volume will vaporise, because in the case of stagnation the fluid cannot drain out of the collector.

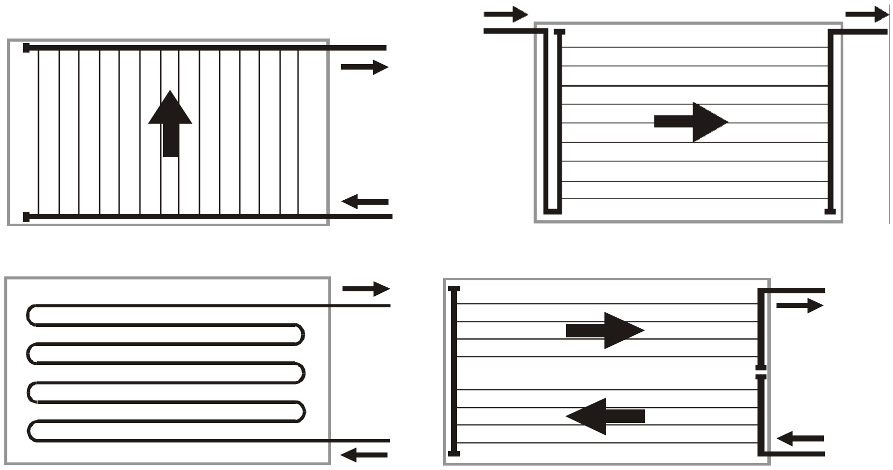


Figure 84: Collectors with good emptying behaviour

Good emptying collectors are pictured in Figure 84. In the beginning of stagnation procedure, the fluid can drain out of the collector. In this case the steam volume can be reduced to a minimum.

One step further from good emptying collectors can be to design and install so called "drain back" systems. In such systems all the liquid in the collector drains back to a vessel in the technical room and the collector is filled with air, if the solar pump is switched off. In this situation in summer time no steam production is possible and in winter time no freezing problems occur. For starting the operation in such a system the pump must be strong enough to be able to refill the collector again.

Temperature critical components which can not be protected as described before (e.g. pump in Figure 82) need to be chosen properly with high temperature resistant material. Such one is the de-aeration valve at the top of the collector loop. This MUST NOT be an automatic valve because a) it is not able to differentiate between steam during stagnation and air and b) most types of automatic valves have plastic components inside which do not withstand such high temperatures during stagnation. At the top always a manual de-aeration valve should be mounted which is used only when the collector loop is cold. If necessary, an automatic de-aeration valve can be mounted in the technical room at lowest possible point where for sure it is not reached by steam and before the heat exchanger since at high temperature most air bubbles occur.

In the case something is wrong in the system, for example the expansion vessel is broken, the pressure relief valve will be active, in worst case blowing out hot steam in case of stagnation. Therefore it is a MUST to have a drain pipe and collection tank at the outlet of the pressure relief valve in order to avoid damage of other components around in the technical room and much more to prevent any persons to be injured by the hot steam!!! The drain pipe must be high temperature resistant (steam with 150°C is possible), therefore made of metal and NO plastic is allowed. Also the collection tank should be high temperature resistant and generous pre-filled with cold collector fluid to be mixed with. The free volume should be at least two times the collector volume.

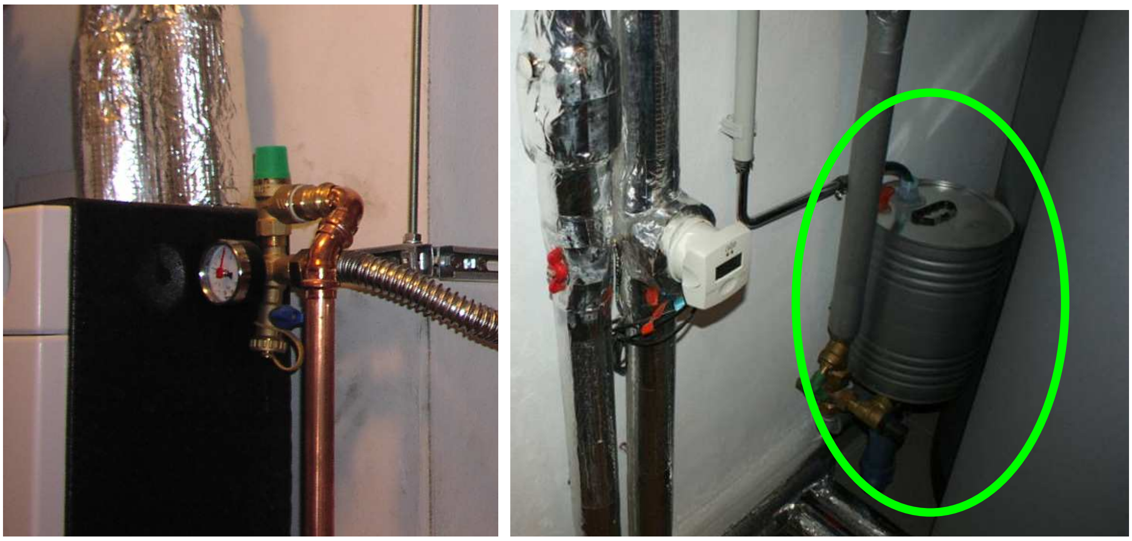


Figure 85: Drain pipe at outlet of pressure relief valve made of copper (left) and collection tank which is closed and made of metal (right)

2) Active Protection

In the first instance passive protection strategies should be used, because they are fail-save in cases of no electricity. Only if this is not enough, it is suggestive to install active overheating protection components or measures. In the following paragraphs some possibilities are described.

A part of the solar energy yield which was charged into the heat store during the day will be chilled in the night. Therefore collector loop is started during night and heat is dissipated from the heat storage to the ambient air via the collector. So the system can be protected against overheating, if the cooled heat storage is able to take over all the solar energy during the next day. In this case electric energy for the pump is necessary and very high heat losses are unavoidable.

Another possibility: the collector liquid is pumped through an external water-air heat exchanger, parallel to the heat store, if the maximum temperature in the heat storage is reached. Disadvantage of this concept is again that some additional electric energy for the pump and the ventilation is needed. If a swimming pool exists, of course this is a perfect heat sink (except in Southern Europe) which can be used to remove surplus heat of the collector.

If the temperature at the top of the heat storage reaches a critical value, a switching valve bypasses the collector loop directly through the space heating system in a specific room where overheating is not a problem, e.g. the bath room.

6.7 General Aspects

Finally some general design aspects shall be discussed, which did not fit specifically into the chapters before. (Some points might sound like peanuts but the sum of many peanuts also reduces hunger.)

6.7.1 Important thoughts before starting the installation:

It is important to think well in advance about a proper placing of the main components in the technical room and in the building in order to keep the system compact and enabling minimized pipe length (especially high temperature pipes) including thermosiphon heat traps at pipe connections at the heat storage. But also at T-piece connections and hydraulic switches pipes which are not in use all the time should be connected downwards in order to realize the thermosiphon heat trap effect (e.g. connection of an expansion vessel or a space heating loop for an extra room in the basement which is heated only occasionally).

The heat storage should be placed that domestic hot water preparation can be connected very close and much more that domestic hot water distribution pipes can be kept as short as possible to the taps. Main goal with huge advantage is to avoid domestic hot water circulation pipes. DHW circulation heat losses can be in the same range as low heat storage heat losses, in other words catastrophically high.

Each meter avoided pipe length means:

a) two meter less pipe installation (because typically flow and return pipes are needed) reducing investment cost
b) two meter less pipe insulation reducing investment cost
c) heat losses of zero meter pipe are zero, not depending on any insulation quality
d) faster reaction of the system because water needs to pass less distance
e) pressure drop is reduced and allows smaller pumps consuming less electricity the next 50 years or smaller diameter can be used reducing investment cost.

Often in a hydraulic loop a mixing valve is used which means that the flow temperature before the mixing valve is high and after the mixing valve is low. Therefore it should be the goal to minimize the hot part which means that the mixing valve always should be as close as possible to the heat source (heat storage, boiler), even if the pump is on a different place this is possible.
Also a flat plate heat exchanger has a high temperature primary loop and a low temperature secondary loop where the length of high temperature loop should be minimized if possible.

6.7.2 Heat loss never is useful:

Sometimes people argue that heat losses anyway can be used for heating the house. This is only true partially and often to a very low percentage. Often the technical room needs to have an opening to the outside for getting in combustion air for the boiler which is cooling the room. Heat losses can not be controlled like a radiator with a thermostat valve, therefore heat losses occur all the year round and can not be stopped if passive solar or internal gains lead to sufficient temperature; consequently overheated rooms are cooled by opening windows and heat losses are wasted again. Finally for controlled heating an expensive space heating distribution and control system is installed which should be used what it is thought for.

In general pipe insulation shall be done properly. For that it is advantageous to use prefabricated hydraulic groups (pump, mixing valve, non-return valve, pressure relief valve, etc.) which are packed already in a insulation box. For the rest of the piping insulation should than be easy possible. The qualitative evaluation within the CombiSol project unfortunately showed very often that pump groups were nice insulated with pre-fabricated insulation boxes but not the pipes around.
If cost shall be saved, inside the technical room a high quality protection of the insulation by metal or plastic sheets extra around the insulation is avoidable.

6.7.3 Documentation of the solar combisystem:

Last but not least for later maintenance or repair it is very important to have a good documentation on site AND as copy in the files of the installer for some assistance by phone if necessary. This means:

- Hydraulic scheme as it fits to the really installed system, not a standard scheme copied from a standard technical catalogue
- Clear named components in the hydraulic scheme, at least those which are used by the controller (sensors) or which are controlled (pumps, valves, boiler, etc.). The same names should be written on the components themselves as well.
- Controller settings as they are set during commissioning and not only the factory settings.

- Instruction manual what can/shall be changed by the resident to adapt the system to the own needs; this is mainly the domestic hot water tap temperature, room set temperature, heating curve depending on ambient temperature, time schedules for space heating, heating of the domestic hot water auxiliary volume and domestic hot water circulation pump
- Maintenance manual explaining what shall be done by the resident himself in which time interval and what the resident shall as an installer to do within specific time intervals.

7 Tools

Main Author : Jan-Erik Nielsen

A simple tool "COMBI-EN" for calculating the savings of a solar combisystems has been developed. The advantages of the tool are:

- Easy to use: Spread sheet type; input in one sheet; output in another. Can be used by manufacturers, planners/architects, installers and users.
- Simple: Calculations are based on simple explicit equations (monthly basis) → instant results.
- Compatible with European Standards: Calculations of the solar output are done according to the EN 15316-4-3 specifying how to calculate output and savings from a solar heating system in a building. The En15316 series is used in more and more countries for calculating the "energy performance of buildings" as specified in the DIRECTIVE 2010/31/EU on the energy performance of buildings. Uses standard collector test results as input (such test results are easily available for 90 % of the collectors on the EU market from www.solarkeymar.org.
- Availability: The tool is available for free in 5 languages from CombiSol web www.combisol.eu.

As input the "COMBI-EN" needs:

- System type
- Location
- Load
- Collector data from Keymark data sheet
- Tank size and a few other specifications
- Back-up system information

Results are:

- Solar output
- Annual savings (energy. kWh)
- Annual savings (fuel: m^3 gas / litres oil / kWh electricity / kg biomass)
- Annual savings (tones of CO_2)
- Annual savings (€)

The result sheet is shown in Figure 86.

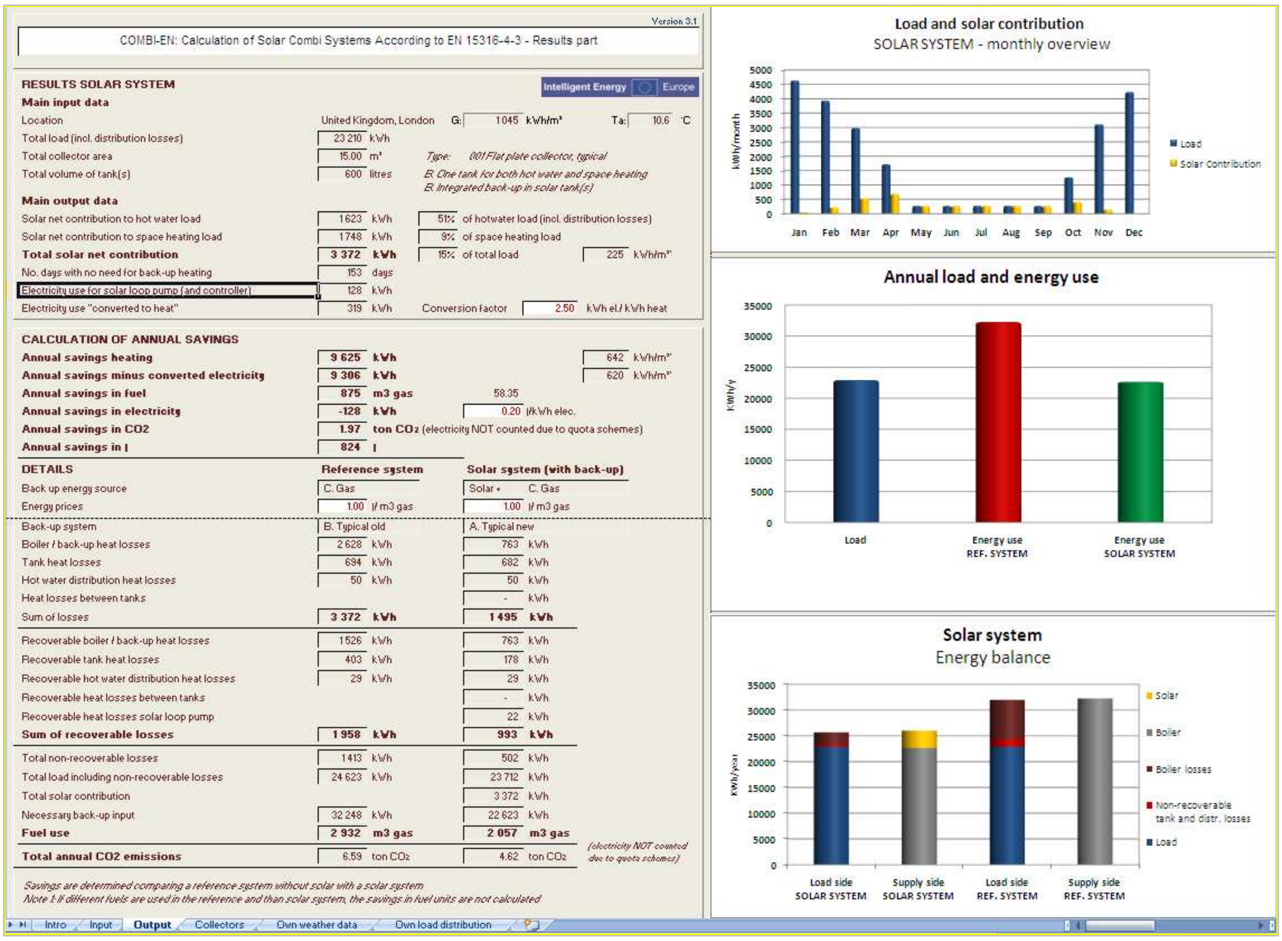


Figure 86: COMBI-EN result sheet - example

8 Training

Main Author : Chris Bales

A survey on available training material has been done: A huge amount of materials is already available in the different countries.

Instead of producing a new standard set of training material it was decided to prepare the following:

- A list of topics that should be addressed in a training session dealing with SCS
- Additional training materials based on experience gained during the project

In addition a “database” (excel work book) with information on literature concerning SCS was created by updating and revising a more general database created in a previous EU project, the NEGST Project, in the mid 2000’s. This is available on the project website and thus available to the general public. For each book/document there is information about the contents, target groups and whether it has information about 16 different categories such as materials, storage etc.

8.1 Suggested Contents for courses on SCS

A document summarizing the suggested contents for teaching about SCS in training courses has been compiled within Combisol [8]. This is split into two categories: basic information that should be taught in all courses; extra contents that could be included in a longer and more in-depth course. Information on possible sources of information on the topics is given in the report. The report is available on the project website and thus available to the general public. It is summarized here.

The contents assume that the students already have a basic understanding of solar hot water systems as well as general HVAC knowledge.

8.1.1 Essential contents of courses

Characteristics of loads (DHW and space heating)

Differences in heating rates, temperatures and flows as well as typical profiles

Differences between solar DHW and combisystems

Differences in loads, types of circuits required, heat exchangers

Types of DHW preparation

Tank in tank, immersed heat exchangers and external flat plate heat exchangers and their advantages and disadvantages.

Difference between buffer and DHW stores

Requirements for DHW store materials (fresh water), relative costs

Different thermal zones in a solar combistore

At what heights should you connect different heat sources and sinks.

Connection and types of auxiliary heaters

Auxiliary heater heating the store or being preheated by the store.

Common system designs

The six different characteristic designs of Combisol. Examples of compact systems.

Stagnation protection

Degradation of glycol at high temperatures, the basic concept of the boil-back approach (emptying the collector by boiling), stages in stagnation, how to calculate the correct system pressure, prepressure in the expansion vessel and the size of the expansion vessel as well the need for cooling.

Control, including items important in stagnation control

Starting and stopping the collector in normal operation. Protecting from overheating by night cooling of the store via collector, hindering restart of the collector with high temperatures in the collector. Charging of the store from auxiliary: two sensor and one sensor control.

Sizing of solar combisystems (collector, store, piping)

Variation of savings with collector area and store size, two store and one store systems, size of pipes, rules of thumb for store size dependent on collector size.

Dependence of savings on temperature and size of auxiliary heated volume in store

Energy saving are less for higher set temperatures for the auxiliary heated volume in the store as well as with an increase of this volume. The available DHW capacity increases as savings decrease.

Heat losses from stores and pipes and how to prevent them

Reduction of heat losses from the stores and pipes are critical to achieving a good performance in practice with solar combisystems. Thermosiphon breaks, non-return valves and good store insulation without thermal bridges are required.

Legionella and national regulations for its avoidance

Legionella growth and destruction. Methods for prevention and national regulations.

8.1.2 Possible Extra Contents for Longer Courses

This section deals with topics that are not essential for a shorter course but which can be taken up in longer courses. Which of the topics are taken into a course depends on the target group for the course. Much of the material can be found in the handbooks from IEA-SHC Tasks 26 [7] and 32 [10] as well as Combisol reports. The Viessman technical guide [11] also covers several of the topics as does the VDI guide for solar DHW systems [13]. The Combisol report D2.3 on guidelines for solar combisystems covers a lot of the material as well [12].

- Solar radiation and its variation in time and place.
- Stratification in tanks and how it is achieved.
  - Internal heat exchangers.
  - Direct connections.
  - Stratifying units.
- Comparison of low and high flow systems.
- Different types of system design.
- Integration of collectors into roof and façade.
- Collector field design and calculations.
- Test methods for solar combisystems.
- Solar combisystems for multi-family houses.
- System simulation with design tools (T-sol, Polysun etc).

- Guaranteed solar results (monitoring).
- Tendering processes for larger systems.

8.2 Training Materials for Installers Courses

The objective was to complement what already exists in terms of training materials in the participating countries, and then to translate this new material to the local languages. However, the materials were also used at a workshop run by SERC for trainers of installers in Sweden during June 2010 and in regular training courses in France by INES Education.

Some of the materials have also been used by SERC in university courses: in their one year international master's program on solar energy (ESES); as well as in a two year program for energy technicians.

The project partners have used many slides in their workshops for installers and manufacturers. These translated slides are available together with the full original English presentations are available on the project website.

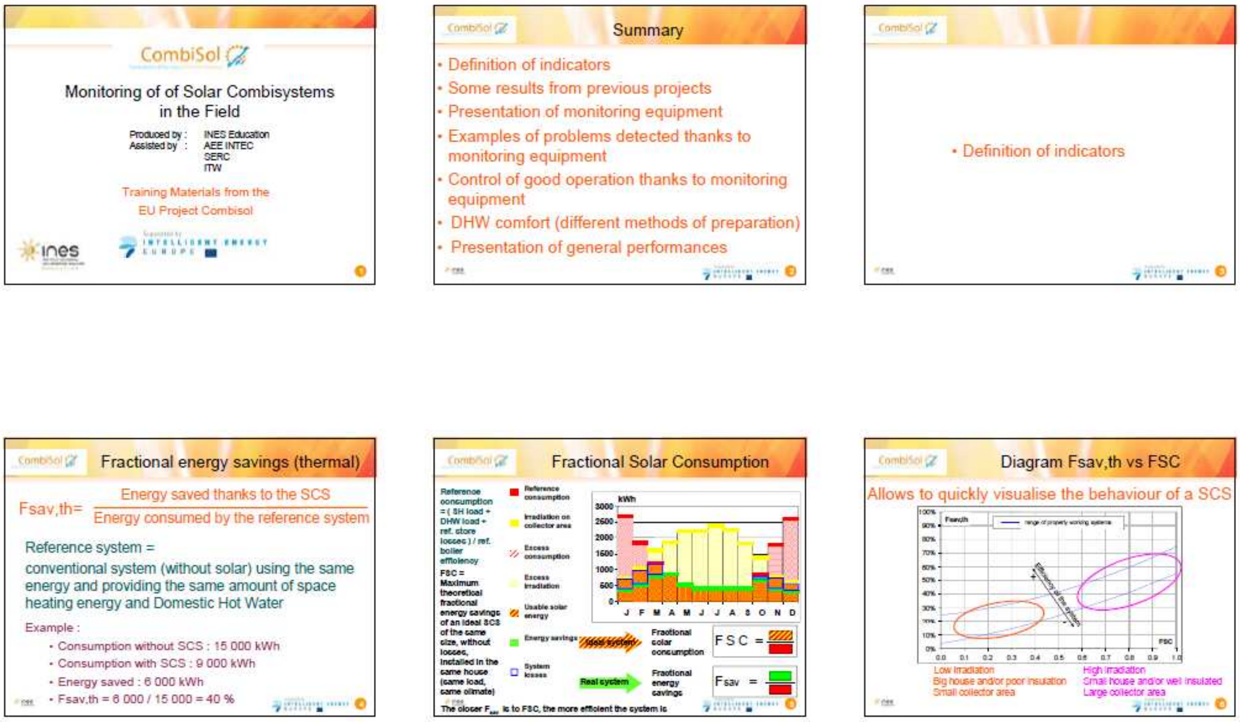


Figure 87: example OH slides from one of the training presentations.

The powerpoint presentations used a unified format and cover the following topics (see Figure 87):

State of the art for SCS

This is based on the Combisol deliverable D2.4 [14] and outlines the six different categories of solar combisystems as defined in Combisol. It also describes the advantages and disadvantages of the three different methods of preparing hot water and the two methods of connecting the auxiliary heater to the system. Examples are also given of compact solar combisystems on the market.

Testing methods and certification

This provides details of the two main testing methods developed for solar combisystems: component test and system simulation; and whole system test. It compares them and gives information on their advantages and disadvantages. It describes the current EU standards and the strongly developing certification scheme Solar Keymark.

Monitoring of SCS

The monitoring equipment and methods for analysis that were used in Combisol are described in detail, with special emphasis on the FSC method that is used to compare results of systems with very different loads, sizes and climates. The basic FSC method requires one complete year of data, but the method for extrapolating from data of less than one year is described briefly. The main part of the presentation covers the results in terms of FSC charts for the Combisol project with 42 monitored systems, and comparison with results from previous and parallel French projects. Monthly energy balances are shown, highlighting the large heat losses from many systems. Finally there is a section where the detailed, one minute resolution data, is used to show examples of both good and bad functioning of the different circuits of the SCS.

Qualitative analysis of inspected SCS

Results of qualitative analysis of 70 SCS as inspected in the field during the Combisol project are presented together with the evaluation form that was used Charts. Both good and bad features of systems are shown with many pictures from the various systems in the four countries.

Stagnation processes in solar collector circuits

This presentation describes the need for stagnation protection and the processes in the boil-back protection method.

This comprehensive training material is available from the CombiSol website: www.combisol.eu.

8.3 Comparison of tools for calculating the size of the expansion vessel

In solar combisystems there is generally a higher capacity than load during some parts of the summer. This means that the store becomes fully charged and the collector circuit pump has to be turned off to prevent boiling in the store. The collector then goes into what is called stagnation and, during periods of high solar radiation, reaches high temperatures of up to 200°C and in the case of evacuated tube collectors, even higher. The normal freeze protection used in northern Europe is to add propylene glycol to water. However, propylene glycol breaks down with time at temperatures above 140°C. Thus if nothing is done to protect the glycol, this can result in solid residues that block filters, valves and pumps. There are several methods to protect the glycol from these high temperatures, but the most common one is the “boil-back” method that is described here, where the water-glycol mixture is forced out of the collector by the vapour created during boiling. For this method, unusually large expansion vessels are required, and there have been a number of methods derived to calculate this volume.

Six different methods for determining the size of expansion vessel suitable for the “boil-back” method for stagnation protection of the heat transfer fluid have been described and compared for similar boundary conditions [9]. Due to limitations and differences in the software, the exact boundary conditions were not exactly the same, but very similar. Only two of the tools differentiate between good and poor emptying behaviour of the collector, the methods from Viessmann and AEE Intec, while only the Viessmann method determines the size of active coolers required to prevent steam reaching the expansion vessel.

The comparison shows that the methods suggest widely different expansion vessel sizes (see Figure 88). The methods also suggest a variety of different pre-pressures in the expansion vessel, although the variation is smaller for these pressures than for the size of the expansion vessel.

The basic method used by Viessmann and AEE Intec is the same, but applied slightly differently. It is based on a lot of research on many different collector field configurations and can be considered state of the art. The Viessmann tool implements the method to the full extent, but is limited to the Viessmann collectors. It is suggested that this tool be adapted to be suitable for general use. However this was not possible within the time frame of the Combisol project.

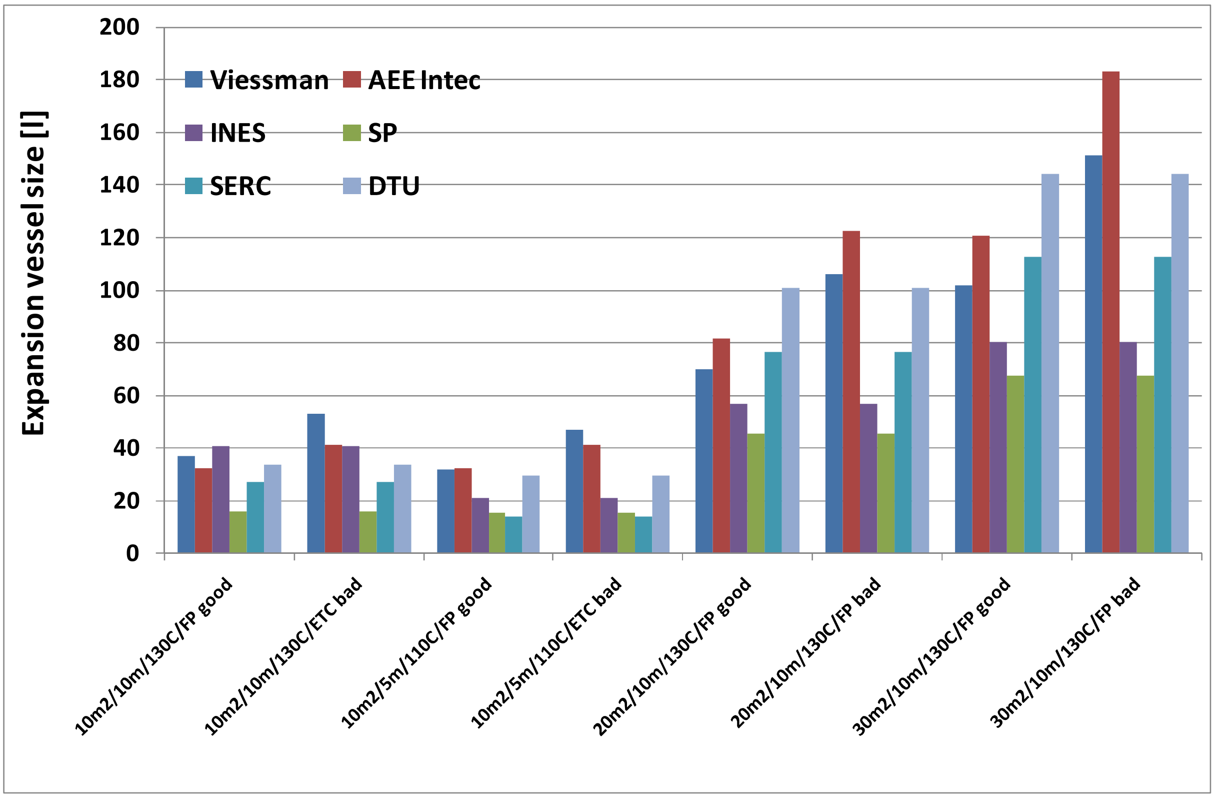


Figure 88: comparison of the suggested size of expansion vessel as calculated by six different tools [8].

9 Recommendations for subsidies scheme

Main Author : Céline Coulaud

Renewable energy technologies available for meeting heating demand in many locations currently lack cost competitiveness with conventional systems that are based on relatively cheap electricity, gas or coal. Public support is therefore necessary to ensure a growing deployment of REH (Renewable Energy Heating). Historically in most countries, renewable heating has not received comparable policy support as has renewable electricity or biofuels for transport. This disparity is, at least in part, due to a lack of legislative tools and policies to support the market development of specific heating technologies.

Policies in support of REH may be inherently different than those which address renewable electricity generation thereby reflecting the somewhat different characteristics of the electricity and heating markets. Electricity markets are clearly assigned to one or more centralized grid operator whereas, with the exception of district heating systems, heat is often the responsibility of individual producers.

Moreover, the heat generated from renewable energy sources (RES) must be utilized locally as it is not possible to feed heat back into an extensive distribution grid, as is common practice with renewable electricity. Therefore, policy instruments need to be specifically addressed to meet the unique, local characteristics of REH resources, the small-scale technologies involved, and the widely distributed demand.

Experience has shown that the status of the market greatly influences the levels of required support and degree of successful product deployment. For technologies that have reached a critical mass, comparative intensities of support lead to higher levels of deployment. Therefore in a supportive policy environment, a cycle of technology and market development becomes self-enforcing in terms of economies of scale, falling costs and public awareness ([16]; Figure 89).

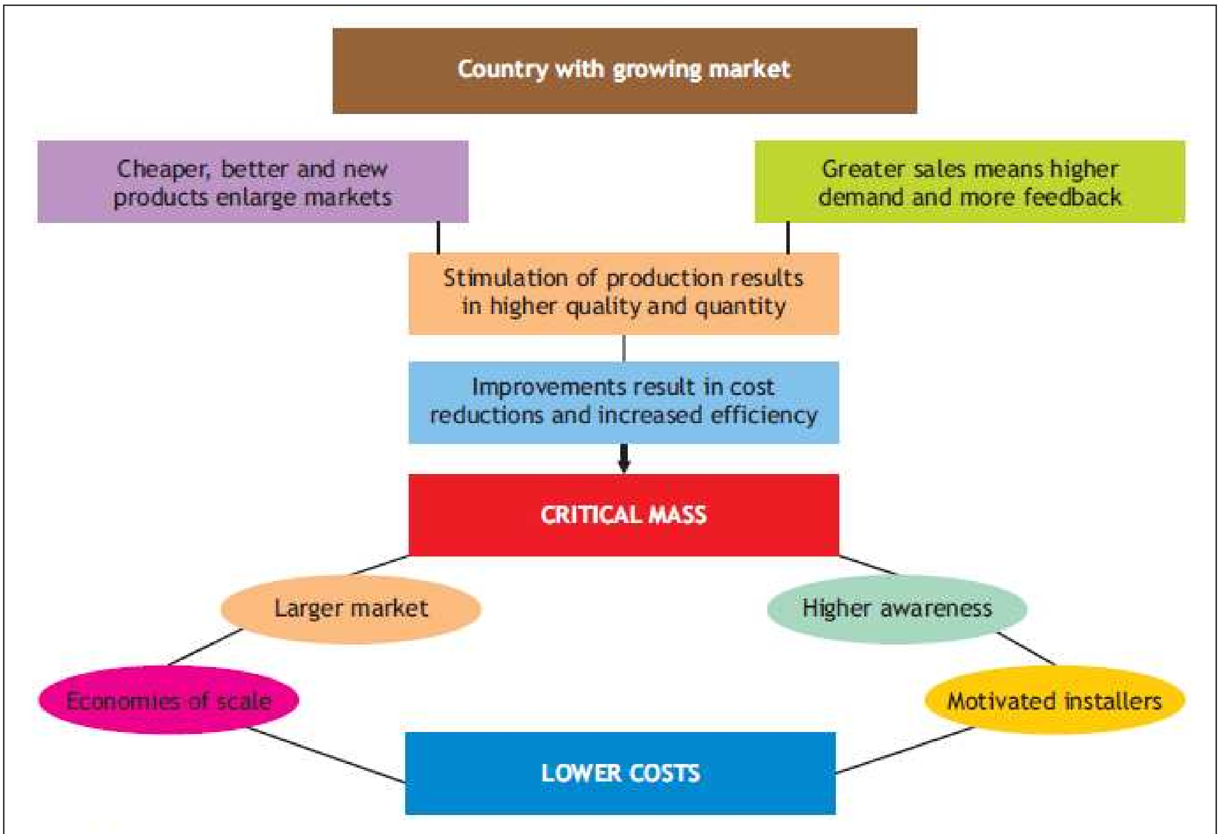


Figure 89: Technology development, industrial development and market deployment are linked to produce a market with critical mass that becomes self-sustaining [16]

Following are the policies which have been utilized to promote an increased use of renewable energy heating. The types of policy deployment instruments which have been used are introduced and grouped into categories (Figure 90):

1) Carrots - financial incentive schemes

2) Sticks - regulatory schemes, and
3) Guidance, or educationally based schemes.

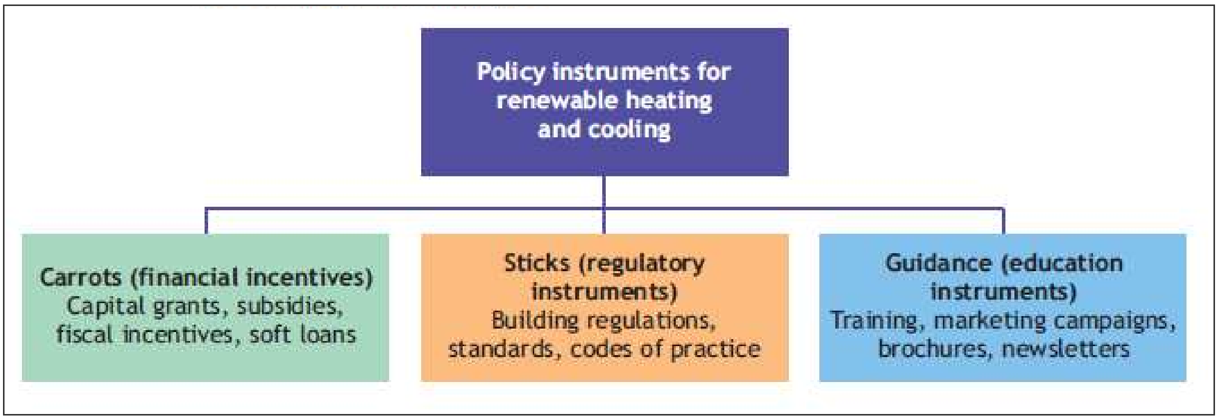


Figure 90: Policy instruments categories for renewable heating and cooling with examples [16]

9.1 Carrots: incentive schemes

Typically carrots act to entice a customer into utilizing RES to meet local heating needs and aims to address the cost gap between RETs and conventional technologies used for either direct or indirect heating. Such incentives schemes may be further categorized into:

1) financial incentives – based on direct financial support such as capital grants used to reduce the capital cost of deploying renewable energy technologies, or investment risk reduction using soft loans (IEA, 2004), and
2) fiscal incentives such as tax benefits.
Generally these types of incentive are funded out of government budgets. In order to be effective the design of these incentive schemes needs to allocate sufficient levels of funding to bridge the gap between the market price of heat energy and the costs for RETs. The incentives should be predictable and consistent over the life of the policy to provide investment confidence.

9.2 Sticks: Regulatory schemes

Generally implemented by means of regulation, governments can intervene in the market by placing requirements on specified sectors. This type of instrument forces REH deployment by directly requiring the development of specified technologies. The legal and administrative costs of political incentives are often kept to a minimum for governments, although monitoring and enforcement may be required at the local or regional level.

9.3 Guidance: education-based schemes

Education to promote REH aims to enhance the awareness of the public by information campaigns and providing training to increase installer knowledge. This type of support may take the form of technical assistance, financial advice, labelling of appliances, or information distribution. Information on resource availability, the benefits and potential of renewable energy, plant type, capacity and heat production statistics, and available government incentives, may be distributed in a variety of forms.
In addition, training programmes may be established in schools, universities, or amongst key professional groups so they consist of well-informed, skilled individuals and networks. Professionals within the supply chain for heat and cold include equipment installers, heating engineers, and architects who should be encouraged to incorporate REH systems into their designs. Information provision and knowledge-based promotion needs to work in conjunction with other political tools. A lack of information regarding renewable energy resource availability, technology development, and product availability may inhibit investment in REHC applications simply due to a lack of awareness.

9.4 Recommendations

Carrots	Sticks	Guidance
Feed-in tariff The best way to encourage the use of solar energy for DHW and heating is to implement a feed-in tariff for the renewable heat energy. For example, the Renewable Heat Incentive is an important initiative for boosting the amount of energy generated from the renewable sources in the UK. In fact it's a world first! There are two different approaches that can be used to measure the heat output of systems: metering and 'deeming' (i.e. estimating the likely heat output). For the 'deeming', the level of payment will be based on a 'deemed' output based on what the installed system would be expected to deliver if the property were well insulated.	***Regulations*** Regulations requiring solar thermal systems for hot water in new or renovated buildings have become increasingly common in recent years. Building permission could be withheld if plans do not incorporate the necessary installation. Supplying a portion hot water demand in a building using solar thermal technologies is relatively straightforward. However regulating for the supply of heat for both water and space is more difficult. ***Standards*** Standards for heating equipment as set by governments would prevent less efficient technology designs from entering the market (as has been successfully achieved with various domestic appliances and electric motors). Greater confidence in the reliability of the technology is thereby created, thus reducing investment risks. Standards may be established for performance, safety, or sitting of heating or cooling plants. A standard should be developed for SCS.	***Installers training*** A good way to improve the global quality of the SCS installations is to improve the installers training. Actually, one goal of the combisol project is to develop and collect training material. ***Dimensioning tools*** An other way can be to offer to the installers some tools in order to help them for the SCS dimensioning.

Conclusion

The main objective of Combisol project was to encourage an accelerated market deployment of SCS – hence a higher share of heat produced by solar energy - and to promote an improved quality of the systems installed.

Thanks to an intensive work on qualitative and quantitative evaluations of existing combi-systems, CombiSol project has partially achieved this main objective since the main results of these qualitative and quantitative evaluations are not up to what was expected.

Nevertheless major results were achieved that allow to be optimistic about the future of SSC provided the industrial sector and installers react quickly to provide consumers with high quality systems that achieve expected energy savings.

Through in-situ monitoring and laboratory tests, CombiSol also proved it was possible to achieve significant energy savings, provided the system is well designed and its installation is done carefully.

Finally, based on the learning and in order to encourage an accelerated market deployment of SCS and to promote an improved quality of the systems installed, CombiSol provides clear guidelines related to:

- System design dedicated to manufacturers,
- System installation for installers,
- Performance assessment of systems in labs to increase consumers' confidence,
- Training and tools to promote installers' skill,
- Recommandations for subsidies.

All the materials delivered within this project should significantly contribute to increase the share of heat produced by solar energy in the future, and thus helping to achieve the main goal of reducing our carbon footprint.

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