CombiSol project

Solar Combisystems Promotion and Standardisation

D2.3 : Guidelines for Design and Dimensioning

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Introduction

Within the IEE project CombiSol in total 70 solar combisystems in Austria, France, Germany and Sweden were qualitatively evaluated on site by experts of the project team based on an extensive evaluation form. Results of this evaluation are reported in D5.4 “Summary of the Qualitative Evaluation of Solar Combisystems” [1]. Further within CombiSol finally in total 41 solar combisystems were equipped with a monitoring system giving the possibility to measure all energy flows going in and out of the solar combisystem. Based on these measurements performance figures were calculated and some specific evaluations were done. Results of the monitoring campaign are reported in D4.4 “Comparison of results of all monitored plants” [2]. Based on experiences of these intensive evaluations of solar combisystems in four European countries “Criteria for Best Practice” [3] where elaborated with the goal to support all professionals of the solar thermal industry, manufacturers, solar companies, installers, planers and consultants to improve solar combisystems in all phases: development and design of solar combisystems by the solar industry, project specific planning by solar companies, planers and installers and finally installation and commissioning by the installer. Following up based on these documents this “Guideline for Design and Dimensioning” as D2.3 and “Guidelines for Manufacturers” as D6.3 [4] in combination with D6.2 “A simple calculation tool for manufacturers and installers” as an excel file was elaborated [6].

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.

This document mainly is thought for professionals like energy consultants, planers, system suppliers and installers who try to prepare and install the best possible solar combisystem for a specific customer and the specific boundary conditions of the house. It is NOT thought as a comprehensive planers handbook, guiding step by step through the complete procedure of planning, constructing and operation a solar combisystem. Therefore also overall dimensioning of the solar combisystem is not explained here. For that much better market available simulation programs can be used which easily give the possibility to take into account all the different boundary conditions of the specific project. This guideline is prepared based on experiences gained during the CombiSol project and tries to give assistance in specific points which came up during the project as points with high potential of improvement.

Monitoring results of 14 solar combisystems measured over a full year within the CombiSol project showed average heat losses of the overall systems (heat storage plus all piping in the technical room) of around 4000 kWh (2400 kWh as minimum and 5800 kWh/a as maximum) which is in average almost four times more than a good reference system is expected to have (but also not guaranteed in practice!!). If assumed that in average at least 2500 kWh heat losses could be avoided, this is equivalent to the solar gain of about 7 to 10 m² collector area. In other words: instead of investing around 2000 to 3000 EUR for 7 to 10 m² collector area, with the same budget a perfect insulation of heat storage and piping could lead to the same fuel savings of a good installed and proper commissioned solar combisystem. Much more, most likely the additional cost of a high quality installation would be less than 2000 to 3000 EUR. Therefore the goal must be to realize optimized solar combisystems, which have minimized system losses leading to higher solar fraction AND higher savings of auxiliary heat/fuel with the same budget or cheaper as it is actually often the case. Main reasons for high heat losses and further on bad system performance are:

- Bad insulation quality of heat storage
- Bad insulation quality of piping
- Bad system design with too big heat storages and/or inefficient multi store concepts
- Bad operation strategy and/or parameter settings of auxiliary heater resulting in too high temperatures for the auxiliary heater and the heat storage
- Bad operation strategy and/or hydraulic adjustment of space heating circuit resulting in too high temperatures for the auxiliary heater and the heat storage

Ideas and proposals how to avoid these bad characteristics for the main parts of a solar combisystem are described in the following chapters.
1 Overall System Concept

For detailed information of concepts and systems offered on the market a “State of the Art Report” (D2.4) was prepared within CombiSol, where the following six main types are described and most actual offered systems (status 2010) from various companies are presented [5]. 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 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

![Figure 1: Base categories of solar combisystems](image)

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 4, for heat storage in chapter 2 and chapter 3 and for the space heating circuit in chapter 5.
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$^2$. Figure 2 shows the distribution of the specific heat storage volume as the result of the qualitative evaluation of 70 solar combisystems done within the CombiSol project. The different labels indicate the auxiliary boiler type and it can be observed that this diagram shows a complete mix of specific heat storage volume and auxiliary boiler types without any tendency. 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.

![Specific Storage Volume - Fuel Separated](image)

**Figure 2: Specific storage volume versus number of tanks – fuel separated**

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 a) 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.

Unfortunately prepared standard configurations in standard simulation programs for solar combsysystems 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 4 and for the space heating circuit in chapter 5.

3 Heat Storage

As mentioned in the introduction 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. As Figure 3 shows some evaluation results of the CombiSol project: Only in 1/3rd of the systems 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.

![Figure 3: Unused pipe connections insulated (left) - Thermosiphon heat traps installed (right)](image)

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 4: 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 5: 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 6: 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)
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.

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.

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. Therefore in appendix A some main characteristics important for integration in a solar combisystem are mentioned:

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.
Problem of over-dimensioned auxiliary heater:
Since a solar combisystem has a relatively 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 10/60°C) or less. The boiler should have a nominal power not higher than the design space heating load, better 10% less. Worst case scenario in an extreme cold winter period is NOT that the room temperature in the house is around 0°C or less. If the actual power of the boiler is really 10% too low, the temperature difference of room temperature minus ambient temperature is 10% reduced. For example at design ambient temperature in Graz (Austria) of -14°C (as 24 hour average temperature!! 20 year average ambient temperature in January in Graz is -3°C !!) and 20°C set room temperature this means a temperature difference of 3.4°C \[= (20 - (-14)) = 34 \times 10\% \] resulting in a room temperature of 16.6°C instead of 20°C design room temperature. This might happen maybe once in 10 years for one or two days (due to climate change the risk is getting less and less). It is much more efficient for such cases to have in a store room a mobile 2 kW electric heater (investment cost of about 50 to 100 EUR) as a backup, which is switched on during these two days.

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.

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. Also the flow temperature of the boiler in this configuration should be carefully controlled in combination with an ambient temperature sensor. If the boiler is in operation in principle the boiler should be responsible for the flow temperature and the mixing valve should be fully open. This reduces the temperature of the boiler and following the heat losses of the boiler.

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.

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.

**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.

**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 than 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).

**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 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.

**Auxiliary type 1 system “auxiliary boiler as return flow increase”:**
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 litre 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.

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:

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.

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:
  o Cheap space heating system
  o 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.
  o Because of large temperature differences (flow/return) very little mass flow occurs which causes little turbulences in the heat store.

• Disadvantage:
  o 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.

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:
  o These systems in general have low return temperatures which lead to good operating conditions for the collector.
  o 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:
  o 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.
  o This type of space heating system is relatively expensive.
  o 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.

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.

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
successfully since many years as described in [5].

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.

A problem often occurs is that if a window is opened for a while or much worse somebody forgot to close it,
the thermostat valve at the radiator fully opens and heat is wasted to the ambient and the return
temperature increases dramatically. A thermostat valve in the central space heating return pipe limits the
temperature to e.g. 30°C during spring and autumn and e.g. 35°C during high space heating load periods.
With such a thermostat valve peak power space heating can be limited and reduce unwanted space heating
consumption but also keep the space heating return temperature low.

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 8). Within this range, it is generally easy to compensate with a slightly larger collector area (Weiss, 2003) [7].

![Figure 8: 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].](image)

**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 9 good quality examples of well protected pipe insulations are shown.

![Figure 9: External pipe insulation (Source: AEE INTEC / Austria): good quality of insulation and protection](image)

**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 20m² 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.

**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 configure 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 10 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 11).

![Figure 10: Right and false way for connecting an expansion vessel in a solar thermal system (left).](image)

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 Appendix B and in an extra technical report of WP6 which is comparing different methods for calculation which is available on the project webpage: [www.combisol.eu](http://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 11, 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 11, 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 12. 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 11:** Stagnation cooler, performed as a baseboard heating fitting (left) and mounted (middle) or “preposition vessel” (right)

**Figure 12:** 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 13: Collectors with bad emptying behaviour

Figure 13 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 14: Collectors with good emptying behaviour

Good emptying collectors are pictured in Figure 14. 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 12) 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 made of metal and generous
pre-filled with cold collector fluid to be mixed with. The volume should be at least two times the collector volume.

Figure 15: 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 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 bathroom.

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.)

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 so 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.

**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 us prefabricated hydraulic groups (pump, mixing valve, non-return valve, pressure relief valve, etc.) which are packed already in an insulation box. For the rest of the piping, the insulation should be easy possible because no special components are in between which need geometric adaptation of the insulation material. 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.

**Documentation of the solar combsystem:**
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.
8 Bibliography

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Appendix A – Characteristics of Auxiliary Heater

For common auxiliary heater types here some main characteristics which might be important for integration in a solar combisystem are mentioned:

1) Oil boiler
Due to high number of production units the investment costs for oil boilers are low
Due to an oil tank in the house the oil boiler is at least for a period independent on delivery
High investment costs for oil tank
Oil is a pollutant, it causes expensive security technique in the fuel storage
Oil is a fossil, not renewable energy source
Oil boilers are typically heavy constructions, therefore oil boilers are slow reacting and have high energy losses when operated in on/off mode with low average power (because stored energy in the mass of the boiler is lost when switched off).

2) Natural gas boiler
Typically no fuel store is necessary (unless liquid gas is used)
Due to high number of production units the investment costs for natural gas boilers are low
Natural gas boilers typically can modulate the power within quite a wide range
Natural gas is a fossil, not renewable energy source
No fuel store in the house leads to high dependency on the gas grid
Highest boiler efficiency is possible (if the system is installed and operated properly in order to enable highest possible condensation effect!!!)
A chimney can be used, which is mounted directly outside the wall, not on the roof
The chimney must be proof against corrosive condensate
Boiler efficiency is very strong depending on the operating conditions (low temperature level of the heat demand side, sufficient volume flow rate,...), therefore low temperature radiators or much better floor or wall heating systems are required.

3) Wood log boiler
Renewable energy source
Fuel is available in the local region and can be stored easy for long periods at different places inside/outside the house.
High return temperature possible without efficiency disadvantage
Since the fuel is not dangerous to the environment the fuel store does not need any security equipment
This boiler is not operating automatically, wood logs have to be fed manually and the ash has to be removed in regular intervals
Once the boiler is filled with a certain amount of fuel the boiler has to burn the fuel with a sufficient high power to have a high efficiency and low emissions, it can not be stopped without big disadvantages. Therefore typically a heat store is necessary to run a wood log boiler.

4) Pellet / wood chip boiler
Renewable energy source
Fully automatic operation, only the ash has to be removed a couple of times per year
Fuel is available in the local region
Since the fuel is not dangerous to the environment the fuel store does not need any security equipment
Pellet/wood chip boiler are typically heavy constructions with high water content and therefore reacting relative slow; power modulation is possible within a certain range, but typically the minimum power is higher than space heating load during most of the time, therefore the connection to a heat storage is strongly recommended.

5) Community Heating
Depending on the fuel used in the central heating plant it might be fossil or renewable energy source
Technical installation in the house requires only very little space
Only constant forward temperature is available (maybe depending on winter/summer season)
Power modulation is possible by flow rate control in full range (0 to 100%)
No fuel store in the house leads to high dependency on heating network
Fully automatic operation
There might be request of a maximum return temperature from community heating company

6) Heat Pump
Fully automatic operation is possible
Environmental heat source is required, therefore an outdoor installation is needed: ambient air unit, bore holes, etc.
Performance factor is very strong depending on the operating conditions, mainly the temperature which needs to be reached; therefore low temperature radiators or much better floor or wall heating systems are required. Hot water preparation should be done at lowest possible temperature level.
Power modulation is possible in a wide range by linear speed controlled compressor or at least by 2 or 3 step speed control.

7) Electric Direct Heating
Very low investment costs
Very compact and small heating element
Very fast reacting heater
The power can easily be modulated from 0 to 100%
but the efficiency of the electricity production amounts approximately 35 per cent.
Full automatic operating heater
No fuel store in the house leads to high dependency on electricity grid
No chimney is necessary
No local exhaust gases where electricity is used (different to the electricity production)
Very high primary energy consumption due to a long chain of energy transformation (power plant) and transport.
Electricity as a form of energy with a very high exergy value is used for a demand with very low exergy, therefore the exergetic efficiency is very bad.
Most electricity (special in winter time) is produced based on not renewable energy sources like coal, gas or oil or with dangerous (“Tschernobyl”) technologies like atomic power plants.
Appendix B – Dimensioning of Membrane Expansion Vessel

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(A report on comparison of different tools for calculation is available on the project webpage as well as some tools which can be downloaded: www.combisol.eu)

The sizing of the membrane expansion vessel is important to ensure that heat transfer fluid is not lost through the pressure relief valve in the event of stagnation conditions. The following suggests a way to calculate the minimum expansion vessel volume for safe operation.

Estimate the maximum steam power depending on the type of emptying behavior of the collector and the system (see number 22 for more information on stagnation behavior). For good emptying collectors/systems an estimate of the steam power is about 50 W/m² whilst for poor emptying collectors/systems an estimate of the steam power is about 120 W/m². These values are on the safe side and with experience with specific systems, these values can be lowered - e.g. increasing the system pressure can, depending on collector types, lower these values (/Fink et al. 2001/).

Calculate the energy removal capability of the return and flow lines. Often the horizontal parts of interconnections between collectors remain filled with liquid, so only the vertical sections should be taken into account. For pipes where the insulation thickness equals the outer tube diameter the specific heat losses will be approximately 25 W/m for a low preset pressure in the expansion vessel, (e.g. 1.5 bar) up to 31 W/m with a high preset pressure, (e.g. 3.5 bar) at the boiling point. If this length appears to be critical such that steam will reach temperature-sensitive components, then measures have to be made to limit the steam volume.

On the basis of these calculations, calculate the volume of the pipes and components outside the collector which can be filled with steam. This volume together with the collector volume gives the maximum volume of steam VS. The common procedure to calculate the nominal volume of the expansion vessel VN (/Terschüren, 1994/) has to be modified to:

\[
V_N \geq \frac{V_M * n + V_V + V_S}{N}
\]

\[
n = \frac{\rho_{\text{cold}}}{\rho_{\text{hot}}} - 1 = 0.09
\]

\[
N = \frac{P_m - P_{\text{diff}} + 1 - (P_0 + 1)/0.9}{P_{\text{sw}} - P_{\text{diff}} + 1} \leq 0.5
\]

\[
P_{\text{diff}} = H_{\text{diff}} * \rho_{\text{cold}} / 10000
\]

where pressures are above atmospheric (i.e., gage pressure) and

- VN: nominal volume of the expansion vessel [l]
- VM: entire volume of the heat transfer medium [l]
- VV: spare liquid in the expansion vessel [l]
- VS: maximum steam volume [l]
- n: expansion factor (approx. 0.09 to ~120 °C for 40% propylene glycol)
- N: maximum operational capacitance of the expansion vessel [-]
- \( \rho \): density of the heat transfer medium [kg/m³]
- \( P_m \): maximum allowable pressure = opening pressure of the safety valve – 20% [bar]
- \( P_0 \): preset pressure in the expansion vessel [bar]. The factor 0.9 in the term \((P_0+1)/0.9\) allows for temperature changes in the gas volume due to hot liquid (/Hausner et al. 2002/)
- \( H_{\text{diff}} \): if the safety valve and the expansion vessel are mounted at very different heights, this should be corrected for. \( H_{\text{diff}} = \) altitude of expansion vessel – altitude of safety valve [m]
- \( P_{\text{diff}} \): pressure difference corresponding to \( H_{\text{diff}} \) [bar].