Conditions and Problems to Be Aware of When Integrating Solar Combisystems in Buildings

Solar Combisystem

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1 Background

As the objective of the Altener Combisystems project is to demonstrate efficient combisystems, this document has been prepared to list various problems which must be considered before choosing the installation site and the correct system for the site, and when installing and monitoring the system.

According to the experience e.g. from monitoring projects, the following type of problems can be anticipated:

- Problems related to the system itself (components, system design etc.)
- Problems related to the interaction of the solar heating system with the building and the existing space heating system. According to monitoring projects on combisystems, the performance of combisystems has often been damaged if the conditions at the installation site are unfavourable or if the solar combisystem is unsuitable for the site.
- Erroneous and/or insufficient installation or maintenance

The objective of the document is to be circulated among the participants in the Altener Combisystems project and the participants of IEA task 26.

2 Problems Related to the System Itself

2.1 Solar Collector and Collector Loop

2.1.1 Wrong Orientation and Tilt, Shadows on Collector

Bad orientation and tilt angle of the collector and shadows on the collector decrease the solar gain of the system.

The following orientations and tilt angles are recommended in Central Europe. For solar domestic hot water systems, a deviation of ± 90° azimuth angle from south and for solar combisystems of ± 45° is acceptable. The tilt angle of the collectors should be the latitude of the system ± 20° for solar domestic hot water systems and a value between the latitude –15° and the latitude +30° for solar combisystems. Within this range it is generally easy to compensate with a slightly larger collector area. Facade integration of collectors is also a good solution for solar combisystems. The solar gain will be up to 20% (strong depending on ground reflection) smaller than with an optimum tilt angle but that can still be compensated with a larger collector area.

Of course, the ranges of tilt and azimuth angles that are reasonable depend on the size of the system and how much of the space heating load can be covered with solar energy. For example, in northern Europe a tilt angle equal to the latitude - 20° to the latitude for domestic hot water and the latitude ± 20° for combisystems is a reasonable range.

If a shadow on the collector cannot be avoided at certain times of the day, the collector circuit should be installed such that the flow line is in the sun as long as possible and the return line in the shade.

2.1.2 Overheating

Compared to SDHW-systems combisystems are overdimensioned in the summer period. Therefore, there can be problems with overheating in the summer if no special precautions are taken.

Cooling of the storage tanks at night reduces the overheating problem but decreases the overall system efficiency and is therefore not recommended.

Good solutions are
- the drainback technology.
- well designed collector circuits with good emptying behaviour as described in the following sections or cooling devices in the collector loop.
- It is also possible to install what is called a ‘discharge loop’, that is a polyethylene pipe buried in the ground under or beside the house, in which excess heat is dissipated in the summer time. The downside of this option is that it uses electricity for operating a pump.

If the collectors are allowed to boil, attention should be focused on the risk of degradation of glycol, the risk of pressure shock and noise in the collector loop, the risk of degradation of components by high temperatures etc. [1]

2.1.2.1 Pressure Shock and Noise in the Collector Loop

The risk of pressure shock and noise development depends very much on the configuration of the tubing in the collector itself and in the collector loop between collector and the store. In the following sections two configurations are shown to explain how they perform in case of stagnation.

Configuration 1: Condensation pressure shocks and noise occur, because the supply or return line is led upwards from the collector. When the collector goes in stagnation, the steam that develops inside the collector is being pushed out of the collector through liquid medium in the pipe. That causes condensation pressure shocks and vibrations in the system and is the reason for the loud noise. In addition, liquid medium from the pipe keeps flowing back into the collector where it evaporates again. This leads to larger steam volumes and therefore this configuration of tubing can cause noise development not only near the collector but also in the technical room.

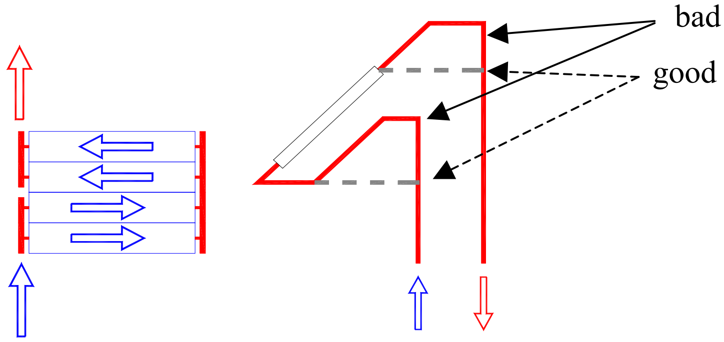

Fig. 1: Configuration 1

Configuration 2: Condensation pressure shocks and noise occur because of a bad configuration of tubing in the collector itself. Vertical absorber fins are connected so that the medium flows upwards and downwards several times. When the medium evaporates in case of stagnation, the whole collector content should be pushed out when the first evaporation occurs. That is not possible in this configuration because at the lowest part of the collector there is trapped liquid that cannot be expelled in liquid form but rather has to evaporate to be removed. This leads to condensation pressure shocks and noise development. The evaporation process over a long period of time leads to more steam development and can therefore cause noise development in the technical room.

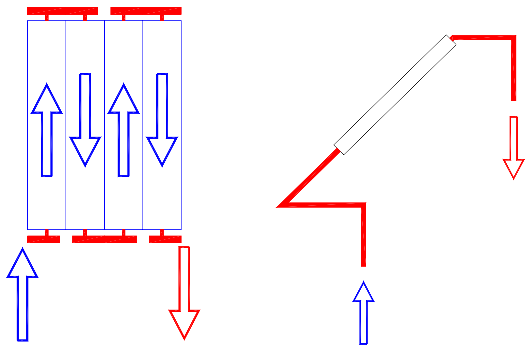

Fig. 2: Configuration 2

2.1.2.2 Degradation of Components

Leakage

High temperatures in the collector loop (up to 210°C at stagnation) can cause leaks at packings (hemp or bonding agents). To avoid this, there should be no ball or other valves with plastic parts close to the collector in the collector loop. Only soldered joints with high temperature stability should be used.

Leaks at soldered joints in the collector loop are usually caused by bad handling or use of incorrect solder material. Thorough cleaning of the parts to be soldered is important because dirty surfaces decrease the capillarity of the solder (responsible for equal distribution of the solder) and therefore cause leaks. It can also happen that a joint was overlooked when soldering the system. Before filling the system all solder joints should be checked for leaks. Typically this is done with compressed air. Don’t use water because it can freeze if the system is not filled with antifreeze directly after the test.

Leaks often occur at the connections of heat exchangers if hemp packings are used because of high temperatures at the connection. Sealing paste with high temperature stability (e.g. 160°C and 6 bars) is available from specialised dealers.

Stretching of piping in the collector array (because of high temperature differences up to 250 °C) is often not accounted for at installation of the system. This stretching can cause leaks in solder joints or even pipe fractures. Pipe stretching should be accounted for already in the planning phase by providing expansion loops and movable bearings.

Control Valves

Control valves with a viewing glass might not withstand the temperatures and pressure that can occur when the collector is stagnating and the heat carrier evaporates. In the worst case, the results can be leaks or even breaking of the viewing glass. Therefore, special care with regard to quality and area of application (pressure and temperature) has to be taken when choosing fittings for the collector loop.

Air Removers

If air removers are used in the collector loop, automatic air removers must be avoided. Automatic air removers evacuate steam as well as air in case of stagnation and steam development. The system would therefore loose heat carrier and the system might not operate properly anymore. In addition, automatic air removers are mostly not suitable for very high temperatures and get damaged after some time.

For removing of air from the collector loop, manual air removers with a small air separator vessel work well. If the collector pipes are designed such that the fluid velocity is between 0.4 and 1 m/s air is pushed through the pipe to the deaerator even if the air remover is not at the highest point of the circuit.

After the system is filled for the first time, the air separator should be opened manually several times in short intervals. After that, the intervals can become longer. Removing of air should be done when the system is hot (but NOT in stagnation), because at high temperatures less air can be dissolved in water and therefore more air can be removed from the system.

Membrane Expansion Vessel

A typical problem is that the membrane expansion vessel gets defective before the expected lifetime of the device. There are several possible reasons for that:

The size of the membrane expansion vessel is not appropriate for the system (usually too small). It should be large enough to take up not only the change in volume of the heat carrier due to the increasing temperature but also the content of the collector and part of the piping (evaporation of the entire collector content at stagnation).

Another problem is the relation of system pressure and preset pressure of the membrane expansion vessel. Membrane expansion vessels are often delivered with a preset pressure that is not suitable for collector loops. Or the preset pressure at delivery is not actually what is marked on the vessel. In any case, the preset pressure of expansion vessels should be carefully calculated for each system and checked and corrected, if necessary, before installation.

The preset pressure of the expansion vessel should be checked at annual intervals as the filling valve may become defective or leak slowly (same type as in a car tyre).

High temperatures at the membrane can also damage the expansion vessel. To protect the membrane against high temperatures it is important how the components are arranged in the technical room. A good example is shown in the following figure.

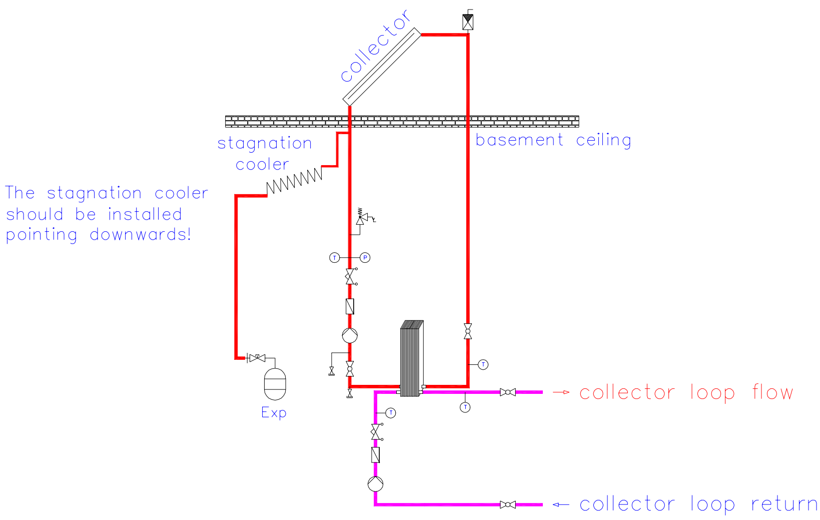

Fig. 3: Placing of the membrane expansion vessel to avoid high temperatures at the membrane

The stagnation cooler as shown in figure 3 should be installed in the technical room as high up as possible in order to avoid burning risks. At stagnation it protects the membrane expansion vessel and all other components below against very high temperatures because steam cannot reach a lower level than the stagnation cooler. The excess energy is dissipated with natural convection. The stagnation cooler must have a large heat transfer surface. For example, a baseboard heater as it is used for space heating works well for this purpose.

2.1.3 Position of Collector Temperature Sensor

A bad position of the collector temperature sensor inside the collector can lead to substantial losses in solar gain. If the sensor is not located where the collector temperature is highest, the solar loop is turned on later and also turned off earlier than with a temperature sensor that is positioned correctly. This means that less energy is transferred to the store.

A location on the absorber pipe inside the last collector at the array outlet is preferable. A mounting location from the outside of the collector is also possible if the sensor can be inserted deep into the outlet pipe so that it is sensing the temperature inside the collector absorber anyway.

2.1.4 Degradation of Components

When choosing insulation material for the collector loop piping, attention has to be directed to both high pipe temperatures and the outdoor climate influence like UV radiation, wind, rain and freezing. These factors can degrade the piping insulation outdoors and close to the collector. Sometimes also animals like birds may destroy insulating materials or electrical wires outdoors.

2.2 Heat Losses

2.2.1 Heat Losses From Tanks

2.2.1.1 Tank Losses

This issue is especially important for combisystems. Combisystems usually operate with larger tanks and in most cases, have several piping connections. A well insulated tank is not sufficient if full attention is not paid to the number of piping connections and the insulation of these. Bad insulation or poorly installed insulation leads to high system losses and a low efficiency of the whole heating system.

Furthermore, there should be as few breaks through the insulation as possible for piping connections. It is best to use a storage tank that has connections that go down inside the insulation and only exit the insulation at the bottom. Another solution is to do all connections at the bottom of the store and use pipes inside the storage tank and stratifying tubes to determine the outlet and inlet heights. If a storage tank without this type of piping connections is used, see section 2.2.1.2.1 for a method to prevent natural convection at the connections.

2.2.1.2 Pipe Connections to the Storage Tank

2.2.1.2.1 Natural Convection

Attention should also be paid to the risk of self-circulation in the connecting pipes or even circulation through the entire space heating loop. To prevent self-circulation, piping connections have to bend downwards (so-called thermosiphon) and often a check valve has to be included. An example of connections that prevents self-circulation is shown in Fig. 4.

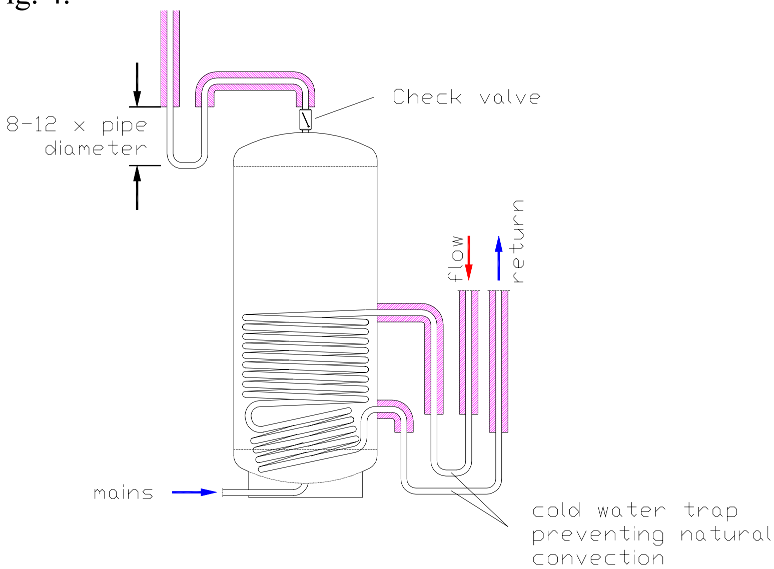

Fig. 4: Thermosiphon pipe connections to a storage tank

A special thermosiphon break has been constructed in Germany. That's a factory-made pipe that contains such an arrangement that the flow has to bend slightly downwards.

Some old systems rely on self-circulation in the radiator loop. In this case, it is important to match requirements for low losses with those for sufficient thermal driving force.

2.2.1.2.2 Flow Rates into the Storage Tank

In most storage tanks, stratification will be damaged if the inlet flow rate to the tank is too high. This is also the case if special devices have been installed to prevent mixing (although the tolerable flow will be higher).

Danish studies indicate that the inlet must be placed so that water enters the tank horizontally with a velocity not exceeding 0.03 m/s. In large Swedish district heating tanks a horizontal velocity less than 0.04 cm/s is used since many years, often created by the inlet at the centre between two disks with enough diameter to reduce the speed below 0.04 m/s at the periphery. Measurements taken at the Solvis stratifying tube showed that a flow velocity up to approximately 0.15 m/s at the outlet of the stratifying tubes did not destroy the stratification in the tank [7] (but in this case the fluid has almost the same temperature as the outlet level, already)

With regard to traditional flow and piping dimensions in relation to solar water storage tanks, the tolerable velocity can easily be exceeded if the piping is connected directly to the tank with no precautions. Possible precautions could be to reduce the maximal obtainable flow by installation of regulation valves etc. or to introduce special inlet arrangements to increase the inlet aperture.

Especially in combination with manually fired biomass boilers, it was experienced that when people realised that the fire had gone out, the building had a lower temperature than the radiator thermostats indicated. This meant that the thermostats were wide open and the flow rate at maximum. In most cases, this damaged stratification and furthermore prolonged the time the building needed to reach the desired temperature, since the boiler first had to heat the whole tank (since stratification was damaged).

2.2.1.2.3 Fault Currents

It should be the goal to separate all hydraulic loops in the system. There should be separate connections to the storage tank for each loop. If a connection to the tank is used by different loops, a part of the piping will be kept at a high temperature by another loop which leads to fault currents by natural convection and therefore to high system losses. It has been shown in monitoring projects that if a pump in one loop was running, there was also flow in different loops. Fig. 5 shows an extreme example on the right hand side where there is only one pair of connections to the storage tank for collector, DHW, space heating and auxiliary boiler loop.

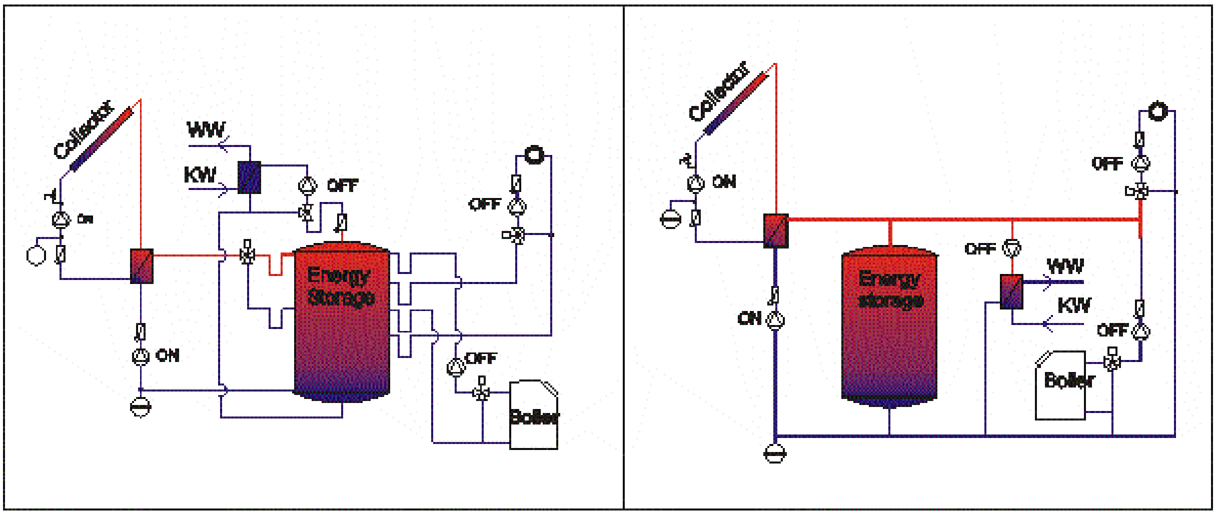

Fig. 5: Example of different hydraulic layouts (Left is a good solution concerning system heat losses by fault currents)

2.2.2 Pipe Losses

Another reason for high system losses can be poorly insulated or missing insulation of pipework. In general, all pipes, valves and other components should be well insulated. Sometimes badly manufactured insulation shows a gap between pipe and insulation. This has to be avoided to prevent to loose energy by natural convection inside this gap. To minimise pipe losses, each pipe should be insulated depending on the pipe diameters. The following insulation thickness is recommended for indoor piping by AEE-INTEC, Austria:

- for pipes DN 15: 20 mm

- for pipes DN 20: 30 mm
- for pipes DN 25: 30 mm
- for pipes DN 32: 40 mm
- for pipes DN 40: 40 mm
- for pipes DN 50: 50 mm

These values should be observed for mineral wool insulation as well as for other types of insulation.

For outdoor piping (with foamed plastics insulation, e.g. Aeroflex):

- for pipes DN 20: 40 mm
- for pipes DN 25: 40 mm
- for pipes DN 32: 40 mm
- for pipes DN 40: 50 mm
- for pipes DN 50: 60 mm

Inadequate or lacking insulation in the collector loop was a common observation during the inspection of 60 plants which SP carried out in 1995 (see ref. [4]).

2.2.3 Circulation Losses

Circulation piping for domestic hot water can generate high heat loss rates. Because the temperatures are high or because the losses are higher than expected, it can be difficult to cover this energy loss by means of solar energy even during summer, when the additional heat supply should be turned off.

Additional savings from turning off the burner during the summer might therefore not be achieved.

Care should also be taken so that this circulating flow will not mix the tank by too high return flow velocities into the tank.

2.2.4 Heat Losses From the Expansion Tank

Expansion tanks should always be connected to a cold part of the system like the bottom of the storage tank or the return pipe of the space heating loop. In addition, the expansion tank should always face downwards as shown in Fig. 6. Otherwise, the heat rises into the expansion vessel and causes significant store losses.
Bad examples include expansion tanks that face upwards as shown in the figure below and expansion tanks that are connected to the upper connection of the storage tank like it is common in Sweden for manually-fired wood boilers.

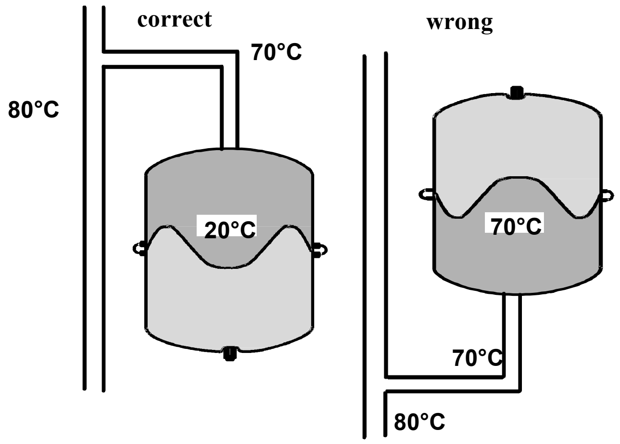

Fig. 6: Installation of expansion vessel. The option on the left is recommended !

2.3 System Design

2.3.1 Stratification of the Storage Tank

It is very important that the storage tank is well stratified. This can be done with special stratification devices, low inlet velocities and well designed inlet heights for the different loops.

The collector loop should first charge the top portion of the storage tank to the set temperature and therefore prevent the auxiliary boiler from turning on. If the store is not stratified, the collector loop has to charge the whole store and therefore, even on a sunny day, the set-temperature is reached much later. Therefore, the auxiliary boiler has to turn on to heat the top portion of the tank to the set-temperature.

2.3.2 Height of Connections to Storage Tanks

For the system performance, it is important how the storage tank is divided into sections of different temperature level. Connecting the collector, space heating, domestic hot water and auxiliary boiler loop at the correct height is important to ensure high solar gains and low system losses.

Collector loop

A common problem is that the collector loop is not operated under optimum conditions. The return line going to the collectors is sometimes connected to the upper part of the store which leads to a reduced volume that can be charged by the collector loop. In addition, return temperatures are fairly high and therefore the collector efficiency is reduced. The return line of the collector loop should always be connected to the bottom of the storage tank.

Auxiliary boiler

Sometimes the auxiliary boiler is connected to the store so that a large portion or even the entire store is kept at the set-point temperature. This leads to unnecessary store losses and also to high return temperatures to the collector loop and therefore lower collector efficiencies.

At the end of the combustion process in wood boilers, the flow temperature decreases. Therefore, the flow line of such boilers should not be connected to the very top of the storage tank. Otherwise the stratification will be destroyed.

As an example, two possible solutions for good hydraulic concepts are shown in Fig. 7 and Fig. 8.

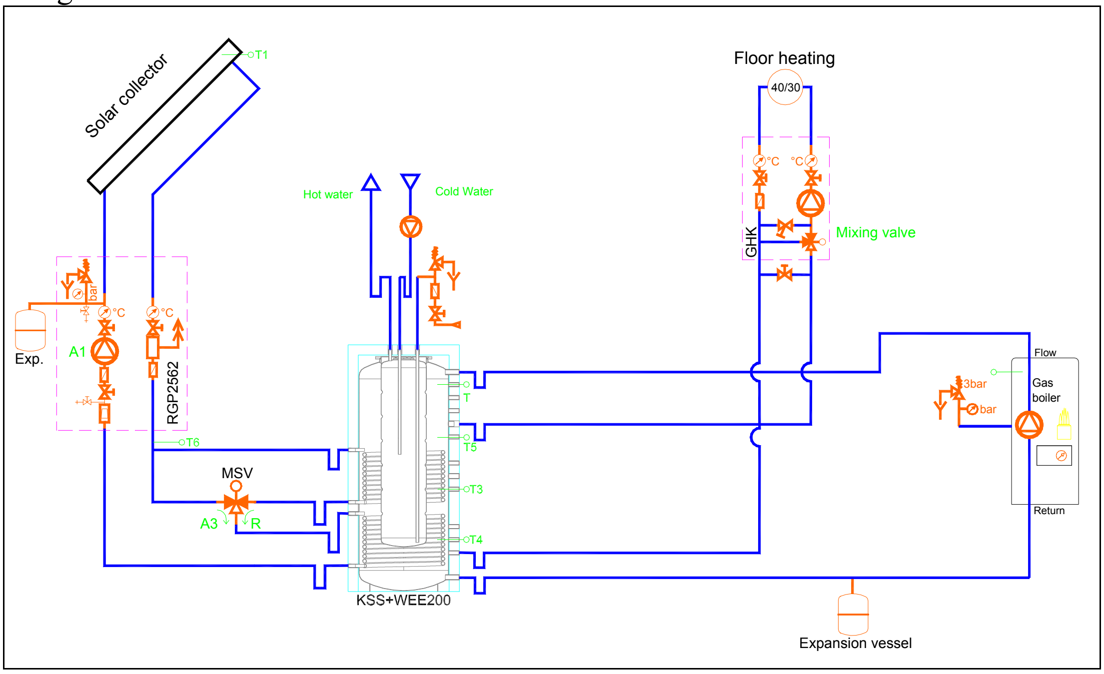

Fig. 7: hydraulic concept with tank-in-tank store

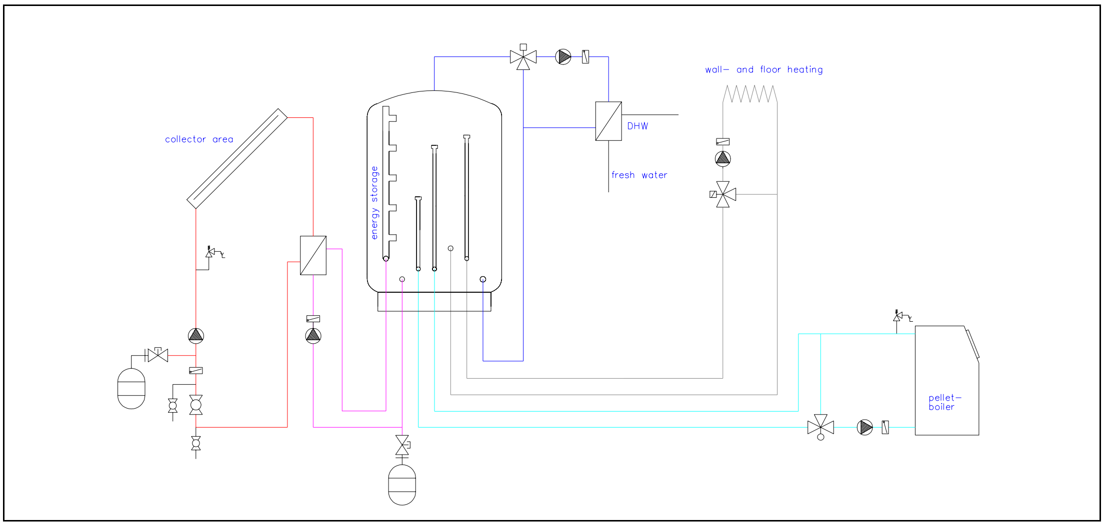

Fig. 8: hydraulic concept with wood/pellets boiler

2.3.3 Wood Boilers

Wood chip and pellet boilers are designed for long running times and therefore typically charge the entire store. This would decrease the solar yield because of increased return

temperatures to the collector. Therefore, the boiler should be optimised for solar heating systems. The most important aspect is that the storage tank has to be large enough and that it is well stratified so that there is always a cold layer at the bottom of the storage tank to feed the return line of the collector loop.
The same is true for manually-fired wood boilers. But in addition, the operator has to consider that the firing should be done in periods when there is little or no solar yield (for example, in the evening).

2.4 Control Strategy

In the following sections typical problems with control strategies that decrease system performance are documented.

2.4.1 Control of Space Heating Loop

If the space heating pump is running although there is no heat demand from the building, the reason could be one of the following bad control strategies:

- The space heating loop pump runs all year.
- The space heating loop pump runs as soon as the ambient temperature drops below a certain temperature (e.g. 18°C). That means, even in summer the pump runs most of the time.
- The space heating loop pump is turned on if the temperature in the storage tank reaches a certain temperature to prevent overheating of the collectors.
- A shunt is placed in the space heating loop that causes flow even if the radiator thermostats are closed.

2.4.2 Control of collector loop

If, by mistake, the collector loop pump is turned on at night in wintertime, the water on the secondary side of the heat exchanger can freeze and damage the heat exchanger.

2.4.3 Integration of Auxiliary boiler

A common mistake is that the boiler loop pump is operated depending on the ambient temperature parallel to the space heating pump. That means that if the boiler is not running because the temperature in the store is high enough, the boiler loop pump can still run if the ambient temperature is below a certain limit. Like this energy is taken from the store and dissipated to the ambient through the boiler or pipe losses.

2.4.4 Boiler Heat Capacity Losses

A control strategy of the boiler that causes a lot of starts and stops, together with a large heat capacity in the boiler circuit might spoil the resulting efficiency of the boiler especially in summer if it is not turned off.

Also the stand still losses of the boiler are important to consider, an automatic “valve” in exhaust outlet of the boiler or the lower part of the chimney to prevents self circulation of heat into the chimney from the boiler. This can save a lot of energy (even more than the solar heating system produces).

3 Problems Related to the Interaction of the Solar Heating System with the Building Energy Demands and the Existing Space Heating System

3.1 Building Energy Demand

When planning a solar combisystem, it is important to get an accurate estimate of the domestic hot water and space heating loads. For example, the number of inhabitants and if the washing machine or dishwasher are operated with hot water and if circulation of hot water is used, is important to determine the domestic hot water load. This way, the system can be sized correctly. If the energy demand is smaller than expected, the system is oversized which leads to very high storage temperatures and stagnation of the collector in the summer and therefore causes high system losses.

When an old building is retrofit with a new energy efficient combisystem, it has to be kept in mind that the old boiler might have been heating the whole cellar of the house because of high heat losses. With the new efficient boiler moisture and even freezing problems might occur in the cellar if no additional radiators are installed.

3.2 Interaction with Central Heating Loop

3.2.1 Flow Temperature

To get a good overall system efficiency low temperatures in the space heating loop are important. It reduces piping and store losses, increases the efficiency especially of condensing boilers and can increase the running time of the boiler because of lower set-temperatures in the store.

A common solution for reducing the flow temperature is a controller, which monitors the ambient or the room temperature (or both) and controls the flow temperature by a mixing valve or in certain cases the set-temperature in the store . Even better is a controller that switches off the heating loop pump if the room temperature is above the set-point value.

3.2.2 Return Temperature

Low return temperatures from the space heating loop are desirable in solar heating systems to ensure high efficiencies of the collectors. According to a Danish study on combisystems, an average increase in the return temperature from radiators of 10 K will require a 25 to 40% larger solar collector area in order to deliver the same performance (of course depending on the system and the collector efficiency).

Consequently, according to the Danish study it is just as important to address the possibility of reducing the return temperature as it is to optimise the solar heating system.

The return temperature of the space heating loop can be reduced by using large heat emitter surfaces.

Furthermore, it makes a difference if the heating loop has one pipe or two pipes.

One pipe systems usually have higher return temperatures than two pipe systems. With a one pipe system, it can be difficult to reduce return temperatures and it is very important to adjust the flow in the circuit correctly and to reduce the flow temperature as much as possible. Therefore this type of space heating loop is not recommended for solar heating systems.

Another way of ensuring low return temperatures is to place thermostatic valves in the return piping at the outlet of each flat.

Theoretically, the return temperature from radiators controlled by thermostatic valves at the inlet of the radiators will not be higher if the flow temperature is high in two pipe systems.
However, it is still important to correctly adjust all thermostats and to choose carefully the size of the radiators in each room. If the space heating loop is not well balanced or if temperatures in one room (e.g. an open window) cause the thermostat to be wide open, return temperatures will increase especially if flow temperatures are high. In some buildings, it has been necessary to mount a shunt at a distant place. That will also cause high return temperatures.

Manifolds are often not thermally separated. They act like a heat exchanger between the flow and return lines. This also leads to higher return temperatures. In solar heating systems, manifolds should always be thermally separated.

4 Erroneous and/or Insufficient Installation

4.1 Collector Loop

Collector loops that are badly balanced can lead to significantly decreased solar gains. The mass flow rates have to be adjusted according to the layout of the collector array.

The correct fraction of glycol in the heat carrier has to be provided. There has to be enough anti-freeze in the system to provide frost protection down to approx. –25°C in Central Europe. Note that the anti-freeze is degrading with time. Therefore it should be checked at least once in autumn if there is still enough frost protection to prevent serious damages of the collectors.
If there is heat carrier missing in the system it must not be filled with plain water but with the correct water anti-freeze mixture to ensure sufficient frost protection.

4.2 Space Heating Loop

Radiators should be well adjusted so that the flow and return temperatures meet the design values. At full load there should be a temperature difference of 20 – 25 K between the inlet and the outlet of each radiator. If that's not the case, the flow rate through the radiator has to be adjusted.

If the space heating loop operates at higher temperatures than designed, the solar collectors will have a lower efficiency and therefore a lower solar gain.

4.3 General Plumbing Installation

- correct (not reversal) connections in collector loop
- correct safety valves
- correct expansion vessels and preset pressure
- insulation thickness and quality of material and mounting (esp. outdoors).
- sufficient air-removers with manual (not automatic) valves
- Correct pipe sizing especially in the collector loop. (0.4-1.0 m/s is recommended for deaeration (lower limit)and corrosion and pressure drop (upper limit)).
- correct system pressure
- correct mass flow rates
- sufficient number of check valves and correct function
  Check valves that are not installed correctly can cause fault currents or even completely block a pipe.
- Correct installation of temperature sensors
  Bad position or badly installed temperature sensors lead to an inferior system performance. For example, if the heat transfer from the store to the temperature sensors that are attached to it, is bad, the sensor measures a temperature that is lower than the actual temperature in the store. The difference can be a few degrees Kelvin. For an auxiliary boiler that means that it has to heat the store a little bit higher which then leads to more heat losses from the store.
- Correct installation of flow and return lines at the storage tank and at heat exchangers.
  Interchanging the flow and return lines can completely destroy stratification in the storage tank or convert a counter-current heat exchanger into a co-current heat

exchanger which causes higher return temperatures. Observe flow direction through heat exchangers.
- Use appropriate mixing or reversing valves where necessary. Confusing these valves will prevent correct operation of the system.
- Check temperature setting of mixing valves

4.4 Initial operation

Malfunctioning of solar heating systems are often caused by bad parameter settings in the controller. A reason for this can be insufficient or missing operating manuals.
The controller should be adjusted to the conditions of the specific system by a professional person who should then train the system owner or operator and explain how the system works.

After mounting is finished, all controller parameters and outputs have to be checked during the initial operation of the system. For the initial operation, the controller is often operated in ‘manual mode’. Afterwards, the controller has to be set on ‘automatic mode’.

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