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Drain back systems in laboratory and in practice

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Abstract

Drain Back systems with ETC collectors are tested and analyzed in a Danish - Chinese cooperation project. Experiences from early work at DTU, with drain back, low flow systems, was used to design two systems:

1) One laboratory system at DTU. 2) One demonstration system in a single family house in Sorø Denmark. Detailed monitoring and modelling/validation of the system in the DTU lab is done, to be able to generalize the results, to other climates and loads by simulation and to make design optimizations. The advantage with drain back, low flow systems, is that the system can be made more simple with less components and that the performance can be enhanced. Also problems with long term degradation of glycol collector loops are totally avoided. A combination of the drain back and system expansion vessel was tested successfully. It is very important to achieve a continuous slope for the pipes in the collector loop to have a safe reliable operation. The components should also be designed and marked so that only one correct mounting option is possible, like forward and return pipes to/from the collector of slightly different sizes or color. Adapted installer education and training is a very important step to have success with drain back systems. Practices used in glycol systems may give serious failures.

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Keywords: Drain back, solar combi system, low flow, ETC collectors

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1. Introduction

This paper gives a status from an ongoing Danish – Chinese cooperation project with the aim to improve and promote drain back solar combi systems. Drain back systems have been tried and used for a very long period. Even the first MIT solar house from 1939 did apply drain back [14]. One of the first scientific publications is from 1981. This ISES paper demonstrates the advantages of drain back systems by both simulation and experiments at CSU.

Also economic advantages are stated [11]. The drain back system type has been very successful on some special markets, like in the Netherlands, due to special restrictions for antifreeze solutions in solar collector loops heating domestic hot water [2]. Also low flow in the collector loop applied here is well known and studied in detail at DTU in combination with drain back [1, 3]. An overview on the low flow principle is given in [13]. The early work at DTU showed that all barriers for safe operation of drain back systems, can be overcome if the system is properly designed and installed.

One of the most important findings from previous DTU work is that only one air volume should be present in the solar collector loop, as otherwise fluid can be pressed up to, or sucked into the collector and then freeze during cold nights, see figure 1.

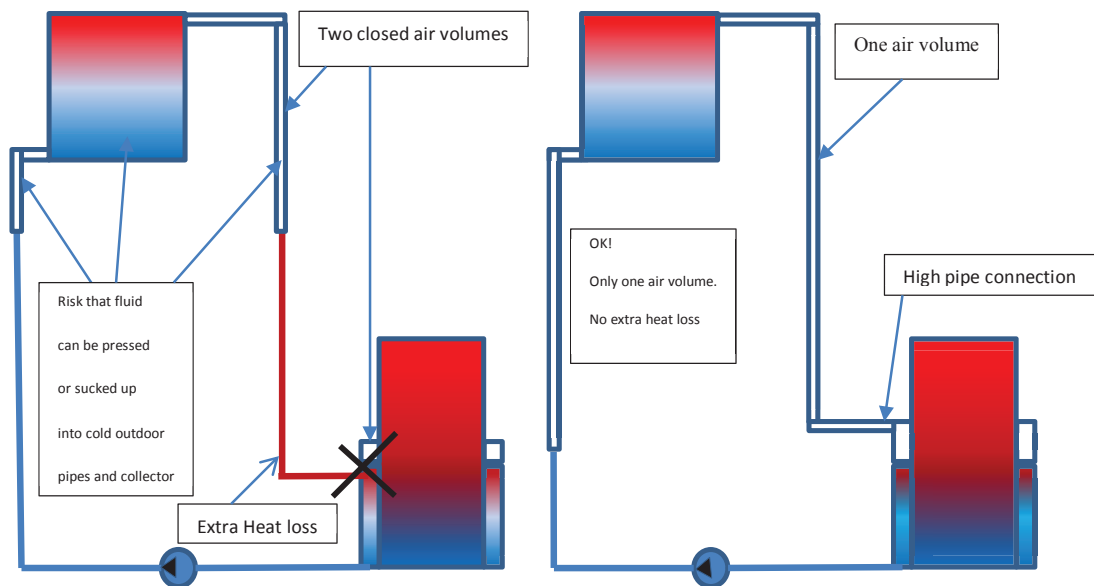


Fig.1. Left figure shows a “dangerous” design where two air volumes can be created in the collector loop. The right system has only one air volume possible and is a much safer drain back design.

In the DTU work also the very common advice to have a continuous slope in the whole collector loop was verified and with perfect mounting of straight pipes the slope can be almost zero and still drain. The required speed of the fluid to fill the system was also investigated. A speed of around 0.3-0.5 m/s gives a margin to flush the system at startup. Smaller pipes need lower speed. Also the risk of fluid freezing during startup in cold outdoor pipes was shown to be more of an academic problem, if the pipes are not extremely long and outdoor temperatures very low. Fast filling/startup is advantageous, that also fits to quickly get siphon operation with no air left. This also reduces the pumping power. The DTU reports [1,2,3] (in Danish) contain a lot of measurable advice that can be used for advanced system design.

In this project the combination of drain back and low flow in the solar collector loop, for a solar combi system, is studied experimentally and by simulation [6]. In parallel to this project recent market investigations and experimental work has been done at Kassel University [4,5] showing that there is a significant market and that the system operation can be made safer, more efficient and more cost effective, with new knowledge and adapted components. Also experiences from a long period of Swedish research and development [7, 8, 9] have been integrated into the project, in a second phase, when the first experimental experiences were available and small improvements were possible. One experience is that the fluid level in the system should be very easy to check and adjust by the user. Overfilling the system by the user could be one trivial cause of failure.

2. System design

Early laboratory investigations and experiences from low flow drain back systems at DTU [1] and [3] were used as basis for the design of the solar combi systems tested in this project. Figure 2 and 3 shows the lab solar combi system layout. Note in figure 3 the special single module accelerated test system, to the far right in the first picture. There the same ETC collector was tested with frequent extreme stagnation cycles. This is sometimes told as a problem for drain back systems using ETC collectors as the collector manifold is “dry” between the operating periods and also during stagnation. No problems were found after hundreds of cycles.

Figure 4, 5 and 6 shows the demonstration solar combi system. Sunda Seido 5 heat pipe Evacuated Tubular Collectors (ETC) are used as solar collectors on both systems.

Special fabric stratifiers are also used in the heat storages for the solar collector loop return in the tank and at heating loop return, to establish thermal stratification and to minimize thermal mixing of the tank. The lab system is well instrumented for scientific level evaluation and model validation and the demo system is equipped with energy meters to get energy flows and circulated fluid volumes in the different loops.

In the laboratory system a traditional drain back tank is used and placed on the forward flow going down from the collector to the tank. Flexible stainless steel pipes with very large diameter (22 mm outer diameter) were also used. This created unexpected air/water pockets both indoor and outdoor that made the filling and draining less reliable due to small extra pressure drop. Also the level indicator in this system was not reliable after some time and a risk of overfilling was obvious. This is not acceptable in a commercial system as the system will most likely freeze then in winter. The collector aperture area was 6.1 m². The orientation was 15° west and with 45° tilt. The tank volume was 500 liter with a 100 liter immersed DHW tank inside. The tank was insulated with 100 mm mineral wool except for the bottom. The backup energy was supplied with an immersed direct electric heater at ¾ of the tank height.

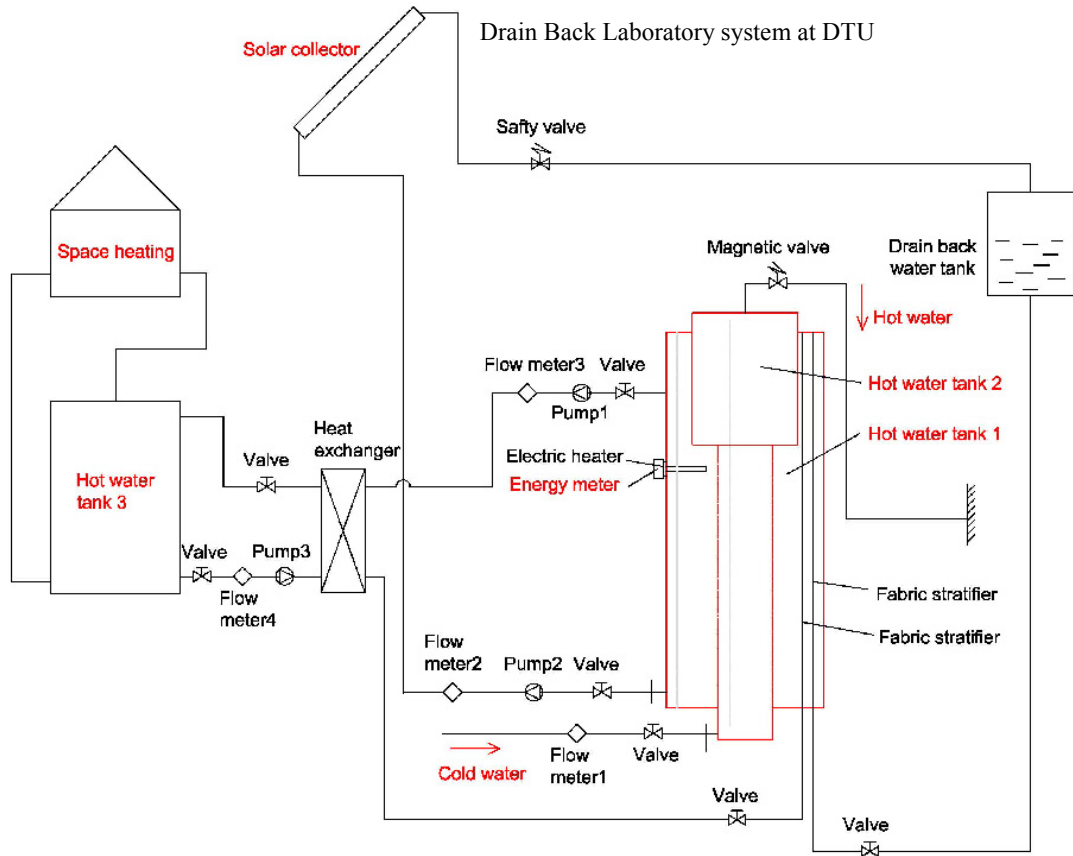


Fig. 2. Principal drawing of the drain back low flow **laboratory solar combi system** under test at DTU. Note that the same fluid (water) is used in the storage tank all loops except for domestic hot water where it would cause corrosion and also too high pressure resistance requirements.



Fig. 3. **Lab system** at DTU: ETC solar collectors on the roof, storage tank, controller, auxiliary heater and drain back vessel. Note the special single module system to the far right in the first picture. There the same ETC collector was tested with frequent stagnation cycles. This is sometimes told as a problem for drain back systems using ETC collectors. No problems were found after hundreds of cycles.

In the demo system a combined drain back and expansion tank arrangement was tried and it has worked after some minor modifications needed, as a normal solar pump unit was used by the installer that had check valves with too high pressure drop. The check valves and pump unit are not needed in a later commercial system. In the demo system half rigid smaller diameter (12mm outer diameter) pipes were used to avoid the problem with air/water pockets. The fluid level indication for the system was made with a traditional overflow pipe that is probably safer, as an installer recognizes this from other system types. The collector aperture area was 12.2 m². The orientation was 60° west and with 27° tilt. The tank volume 750 liter with an immersed DHW tank of 150 liter. The tank was insulated with mineral woll inside a square box around the tank in a corner of the garage. The backup energy was coming from an existing district heating connection to the house. The space heating loop used floor heating. The demo system is installed in a 225 m² one family house with 3-5 inhabitants. The house was built in 2006 and has a yearly heat demand of about 20000 kWh. Heat is supplied to the house from a district heating system by means of a floor heating system.



Fig. 4. Sunda Seido 5, Vacuum tube solar collectors, in the **demo system**. (The PV system to the far left only interacts with the electric grid.)

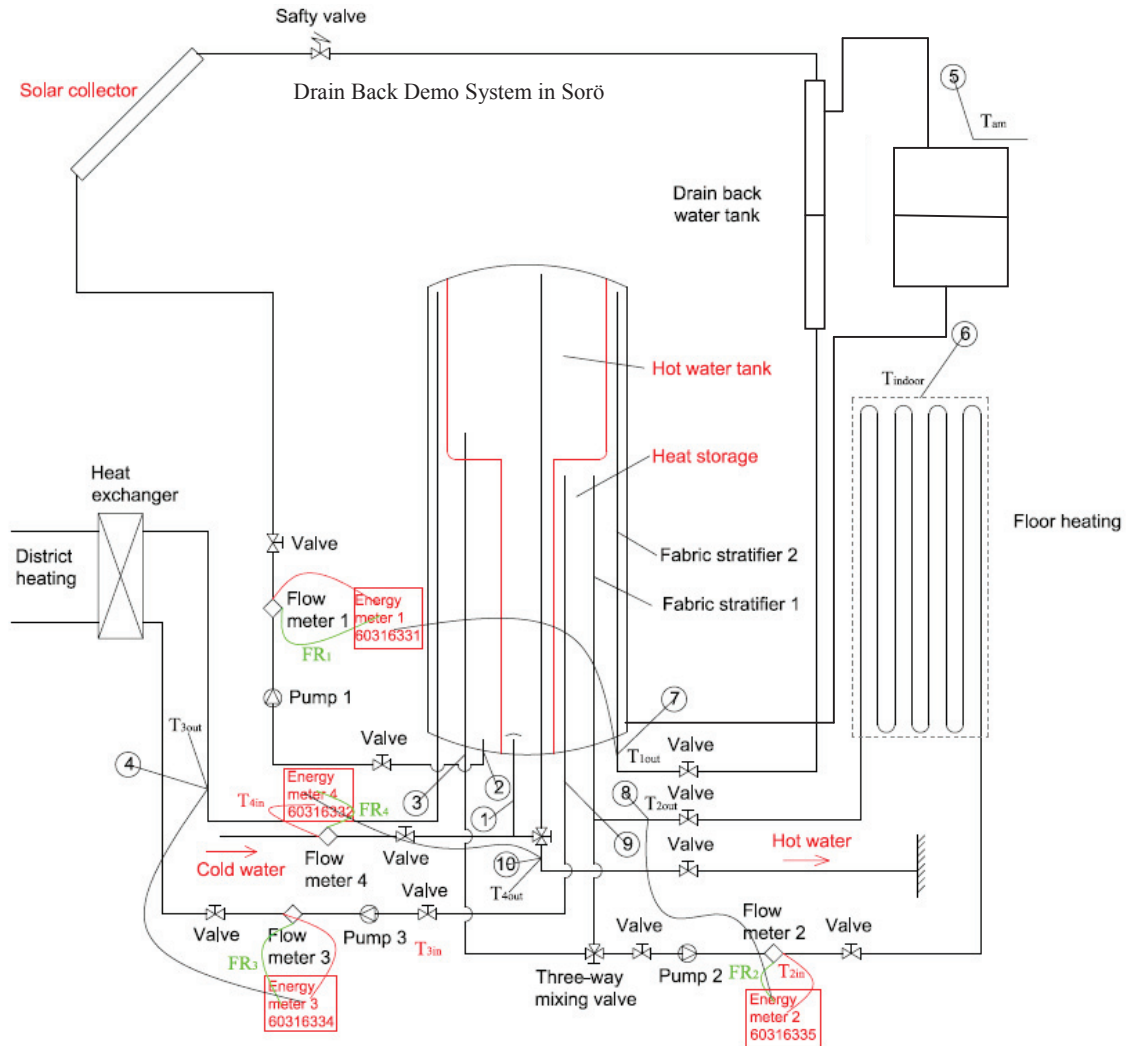


Fig. 5. **Demonstration system** inclusive energy meters in Sorö, Denmark. Note the combined drain back and expansion tank in the upper right corner of the drawing. The expansion tank is connected to the bottom of the tank, to reduce the heat losses from the tank when fluid is pressed out of the tank during heating.



Fig. 6. Top drawing showing the principle for the combination of a drain back and expansion vessel to reduce heat losses. Lower part some more pictures from the **demonstration system** in Sorø, Denmark. The left picture is before insulation of the storage tank. Note in the middle picture the small drain back vessels (white) and the combined expansion tank (red). Note in the right picture, the pump unit that was convenient to use for the installer, but gave extra pressure drop and malfunction of the combined expansion vessel in the beginning.

3. Experiences from operation

The overall operational results are very positive for the drain back low flow combi systems. The main problem is to get all drain back and low flow details properly designed and installed. Some adapted components like special drain back low flow pumps would help. The main findings from the experiments are listed below:

-Flexible stainless steel pipes were used in the lab system collector loop. The pipes were hanging down between too distant supports here and there. This was creating small air/water pockets and thereby freezing and unreliable draining and startup in winter. See example in fig 7. (This may be a general problem in malfunctioning drain back systems)

-Too large diameter pipes for low flow in the collector loop in the lab system. This prevents reliable “flushing” of the system at startup. Siphon draining is then also less reliable and water can stay in pockets and freeze.

-Misleading or malfunctioning fluid level indicator in the drain back vessel. It is very important in a commercial system that the system water level is easy to see and adjust by the user. (This will immediately show if there are small leaks too). Over- or under filling the system may cause malfunction and even freezing damage in worst case. It should be as visible and reliable as a tank meter in a car.

-Loose or wrongly located temperature sensor at the collector outlet. This will cause too late startup of collector loop and even boiling at start up. (This is a problem in conventional glycol systems too.)

-Air bubbles can enter the storage tank from the collector loop, due to too high flow and not enough air separation in the drain back tank. The air is then collected in the top of the tank. This creates a very unsafe situation, with two air volumes. This can press fluid into the collector in freezing cold nights. The ultimate solution to this problem is to have the drain back air volume in the tank top. But also a thin air connection between the storage tank top and drain back vessel can be a possible solution.

-Clogging of fabric stratifier from small dirt and rust particles means that the tank will get less thermal stratification.

-Not intended and not necessary components were installed in the demo system, like check valves and a standard “glycol” pump unit. This gave extra pressure drop in the collector loop and was disturbing drain back operation.

- The steel tank in tank design is heavier than normal and may be problematic to install without special equipment, or several persons to help.

- Manufacturing of specially adapted components and installation of test systems can take a lot of extra time.

All these problems mentioned above are possible to avoid, if considered at the design and installation phase, of a new drain back system. As a positive outcome the stagnation testing showed no damage to the ETC collectors.

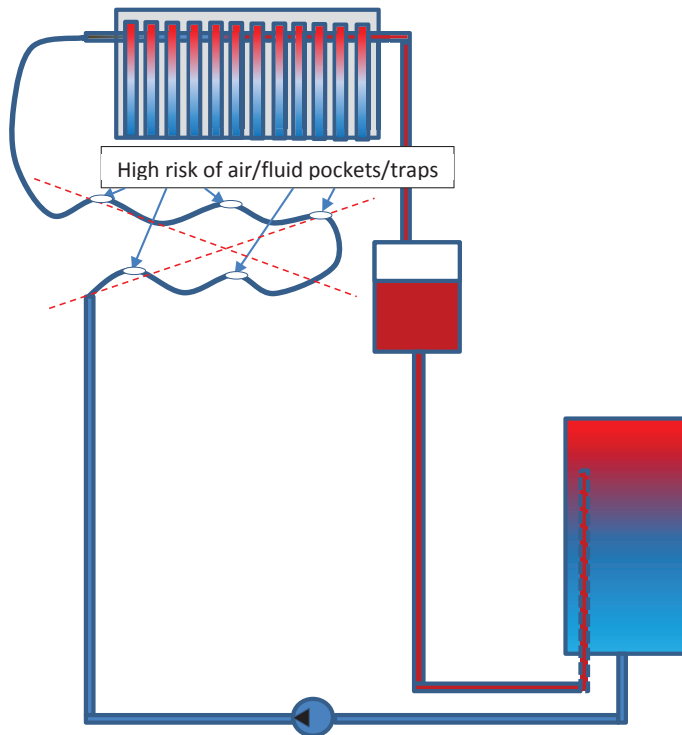


Fig. 7. This picture shows a probably very common mistake to have a slight wave formed up and down slope on the collector loop pipes. This can give unpredictable air and fluid pockets/traps and extra flow resistance. This can also delay or even prevent both draining and startup. This was experienced in the lab system at DTU. Only the cold side has wrong installation here, but the same problem can occur on the hot side of the collector creating even worse operating problems.

4. Performance and model validation for the laboratory system

The test system was operated in systematic way to give as good validation data over a long period. The domestic hot water draw off was controlled to be 100 l per day and evenly distributed at 07:00 12:00 and 19:00. This is an average Danish consumption, but can of course vary from house to house depending on the number of persons and their habits. The heating load was specially adapted to give a good validation data base and not according to a normal space heating profile dependent on outdoor temperature and wind for example. Therefore most of the tank energy content below the heating loop outlet was discharged by a timer every night to get a large temperature swing in the tank frequently. This gives more stress to the modelling.

The idea was that after model validation the TRNSYS model could be used to simulate almost any similar drain back system design, different loads and climate situations that can be of interest to study and optimize. This later step is not done yet in the project.

A TRNSYS system layout is shown in figure 8. Note that the drain back tank is simulated as an extra pipe at the outlet of the collector, located before the tank. This simulates the extra time delay and higher heat losses due to this vessel. In the demo system this loss was minimized by combining the drain back and expansion volumes into one vessel, see figure 5.

After collecting enough data in the lab at DTU a simulation model in TRNSYS was validated using the lab system measurements.

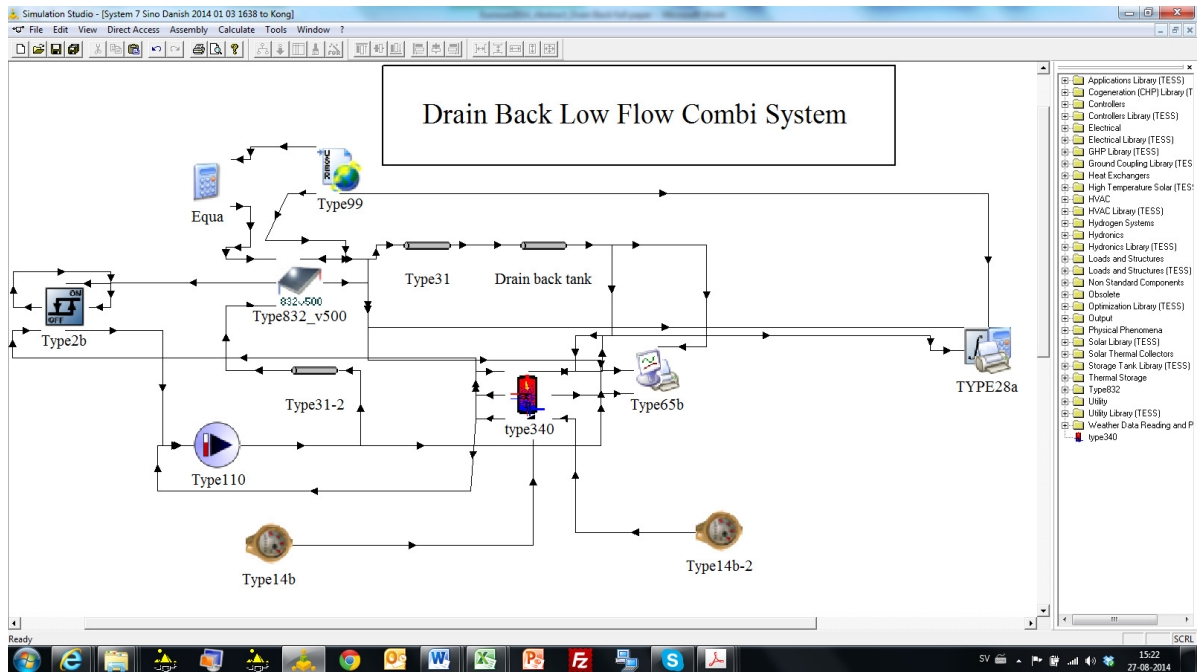


Fig. 8. TRNSYS system layout. Note that the drain back tank is simulated as an extra pipe at the outlet side of the collector located before the tank. This simulates the extra time delay and heat losses due to this tank.

An overview of the TRNSYS simulation model validation results, is given in table 1 below indicating a good match between measurements and simulation almost within the measurement uncertainty of the variables, for the two week period October 5 - October 19, 2013. The bottom line shows the ratio between TRNSYS simulation and measurement results. It should be pointed out that the Auxiliary input, Space heating and Hot water loads, are also simulated according to controller settings and consumption patterns and are not input to TRNSYS as measured values. So it is a more complete model validation and not only of the solar part of the system.

Table 1. TRNSYS model validation results for a 2 week period for October 5-19 2013 for the lab drain back system at DTU.

Energy Flow =>	Total Solar Radiation in Coll plane	Energy from solar collector	Ecoll into tank	Espace heating	E hot water draw off	Eauxiliary to the tank	Heat loss from tank	Net Utilized Solar Energy
Unit =>	kWh/m ²	kWh	kWh	kWh	kWh	kWh	kWh	kWh
Measured	31	112	77	79	44	57	12	66
TRNSYS	31	106	79	85	42	58	10	69
TRNSYS/Measure	1.00	0.95	1.02	1.08	0.95	1.02	0.84	1.05

5. Measurements from the demo plant

In the demo plant only energy meters were installed to derive long term performances. Therefore no detailed information can be derived.

In figure 9 the main energy flows in the demo system are shown. The tank was not insulated in the first months. There is domestic hot water (DHW) circulation in some periods about 5 hours each evening with a timer. The hot

water consumption shown includes this circulation heat loss. Therefore the total DHW value shown varies more than the hot water consumption itself. A point measurement in September 2014 indicates a circulation pipe heat loss of about 1 kW or 5 kWh per day when operated 5 hours each evening. This is almost the same energy as 100 liter hot water consumption. Hot water circulation saves water and it improves the comfort very much, when hot water pipes are very long as in this case. A timer on the DHW circulation pump was used to limit this circulation to maximum 5 hours each evening. Further checks will be done to elucidate the DHW energy balance and if further energy saving measures can be done.

The net utilized solar energy, defined as domestic hot water consumption inclusive circulation pipe heat loss + space heating - heat supply from district heating, gets negative in winter when the solar contribution is very small. It is because the heat losses are not included in this definition.

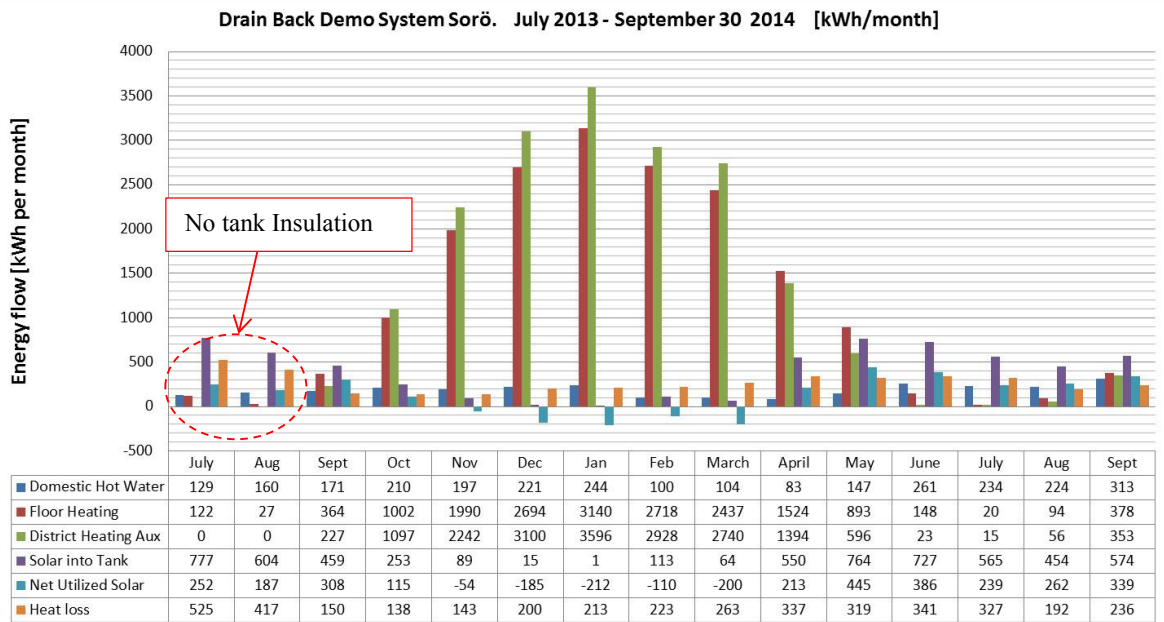


Fig. 9. The main monthly energy flows and energy balance in the drain back demo system in Sorö.

As can be seen the solar combi system is oversized for the normal summer load. This is normally reduced to the domestic hot water consumption. Some comfort floor heating is used in summer as the extra solar energy use is almost free. Cold unheated ceramic or stone covered floors are avoided then. This is increasing the comfort in summer. An annual energy- and volume balance for September 2013 to August 2014 is given in table 2.

Table 2. Heat demands and thermal performance for one year operation.

Hot Water	Hot Water	Floor Heating	Floor Heating	District Heating	District Heating	Collector into Tank	Collector loop	Net Utilized Solar	Heat Losses
[kWh]	[m3]	[kWh]	[m3]	[kWh]	[m3]	[kWh]	[m3]	[kWh]	[kWh]
2338	130	17038	2514	18139	1073	4168	274	1237	2931

The net utilized solar energy of 1237 kWh/year, corresponding to 101 kWh/m² collector per year is only one third of the energy delivered to the tank by the solar collectors. The main difference is the tank heat losses that are not taken into account in the net utilized solar energy calculation. Part of these losses would have been covered by auxiliary energy, if not solar energy was present in the system. The tank heat losses are larger than the tap water

consumption including circulation pipe heat loss in this case. This is due to the less well insulated storage tank. Also some shorter connecting pipes were still uninsulated and add up to the relatively large heat losses.

The solar energy delivered into the tank corresponds to 341 kWh per m² collector. The collectors have too little load during summer and operate at very high temperatures then. Therefore the output is reduced. The collectors can of course not produce more energy than the load plus tank heat losses.

6. Conclusions and recommendations

After some minor initial installation problem, the systems have been in continuous operation with only minor problems. The following conclusions and recommendation can be given:

- 1) Continuous slope of pipes above the drain back level is very essential. The use of stainless steel flexible pipes in the collector loop should be avoided, unless mounted very carefully to avoid water pockets.
- 2) Only one, closed air volume should exist in the system, to make the drain back function 100% reliably and to avoid oxygen coming in and thereby avoid corrosion inside the system.
- 3) The combination of a drain back vessel (a pipe in this case) and system expansion tank, can be a good solution, see fig 5. In an extreme design the drain back vessel can be integrated into the top of the tank.
- 4) It is possible to avoid all heat exchangers in the system and use the same fluid (water) everywhere, except for domestic hot water. For domestic hot water, a tank in tank system solution is recommended, see fig 5 and 5.
- 5) A standard pump can be used in the collector loop, if the drain back tank is placed high enough, but still indoors.
- 6) An adapted control system is desirable. It should increase the flow in the collector loop during startup and thereby flush it. Then the pumping power can go down by siphon action in the forward pipe down to the tank and drain back vessel. Also blocking of start at extremely cold outdoor temperatures could be one controller feature.
- 7) The mounting of the collector temperature sensor is important to have good thermal contact to the true collector absorber temperature during startup and to the outlet fluid temperature during operation.
- 8) Installer education and training is very important (like for normal glycol systems.)
- 9) A TRNSYS model has been developed for the system type and validated with reasonable accuracy against measured data.

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