SOLAR COMBISYSTEMS WITH HEAT EXCHANGER BETWEEN COLLECTOR LOOP AND SPACE-HEATING LOOP

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Abstract – This paper describes some of the modelling work performed as part of the Danish participation of the IEA SHC task 26 about solar combisystems. One of the 2 Danish simulated systems is a system that delivers solar heat directly to the space-heating loop via a heat exchanger in the collector circuit. The system is very popular in Denmark, and it is estimated that about 30% or up to 10.000 systems of the design are installed in Denmark. The simulations show that the normal practice with respect to control strategy is quite optimal. Furthermore the simulations shows that the system is not one of the best performing systems compared to other combisystems. However the system is relatively inexpensive and comes out with a cost efficiency that is comparable to the other systems. Furthermore comparison with a French system that was also modelled in the task, indicates that if floor heating had been taken into account maybe performances could have been improved substantially.

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1. INTRODUCTION

In Denmark it is estimated that about 33% of all solar heating systems are combisystems and nearly all of these are designed according to the same principle. I.e. solar heat is delivered either to the hot water storage or to the space-heating loop via a heat exchanger between the collector loop and the space-heating loop. Unlike most other solar combisystem designs there is no storage of the solar heat used for space heating.

Since it is estimated that about 30.000 solar heating systems are in stalled in Denmark during the last 20 years this means that up to 10.000 combisystems of the above type are in operation in Denmark.

In spite of the big number of installations in operation the performance of the systems is only poorly investigated. Only very few systems have been monitored, and none of these were monitored in detail. The monitoring took place in the start of the 90ies and today one system is monitored as part of the Altener project Solar combisystems.

Furthermore only little work has earlier been performed to simulate the system in detail. A study performed in 1999 used the simulation programme EMGP3 for simulating and comparing the system design with other combisystem designs.

I was therefore evident that the system type was one of the Danish system types that were analysed in the work performed under The International Energy Agency's (IEA) Solar Heating and Cooling Task 26 on solar combisystems, which started in 1998 with 8 participating countries.

2. MAIN FEATURES OF THE SYSTEM TYPE

A simplified diagram of the system type is seen on figure 1.

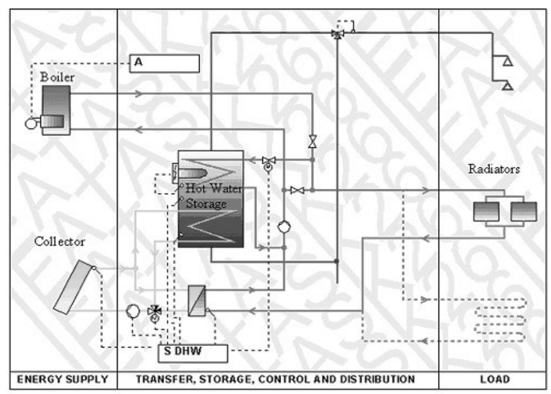

Figure 1: System Design

The system is derived from a standard solar domestic-hot-water system, but the collector area is often oversized in order to deliver energy to an existing space heating system. The connection between the solar heating system and the heat delivery system is made through a heat exchanger included in the return pipe of the space-heating loop. The store is only devoted to DHW preparation, with two immersed heat exchangers: the solar one in the bottom of the tank, and the auxiliary one at the top. A three-way valve directs the antifreeze fluid coming from the collector either to the DHW heat exchanger, or to the space-heating heat exchanger.

In summer an immersed electric heater can supply additional heat to the hot water allowing the boiler to be turned off.

2.1 Heat management philosophy

The controller doesn't manage the auxiliary part of the system. As long as the temperature at the collector outlet is higher than either the return temperature from the space-heating loop or the temperature at the bottom of the tank, the pump of the collector loop operates. The three-way valve is managed so as to deliver solar energy to the space-heating loop, i.e. when the temperature at the collector outlet is lower than the temperature at the bottom of the tank, or when the storage is warm enough (temperature at the top of the store higher than the set-point temperature). When the domestic-hot-water temperature is too low, auxiliary heat is delivered to the tank through the two-way valve.

2.2 Specific aspects

The system uses a standard solar domestic hot water tank with all components of the system integrated in the same cabinet as the tank. The dimensions of the cabinet are furthermore modular 0.6 x 0.6 m, so that it easily fits into the utility room.

The system could be controlled so that it delivers heat to the space-heating loop independently of any space heating needs if there is a risk of overheating in the system.

Figure 2: Storage tank and other components integrated in cabinet

The system can work with any auxiliary energy source (gas, fuel, wood, district heating). It could be also used with separated electric radiators.

As for all solar heating systems in Denmark it is most common that the system is installed in existing houses and not in new building.

2.3 Cost (range)

A typical system with 7 m^2 of solar collectors and a 0.280 m³ store costs about 5 200 EUR. This amount only includes the solar part (collectors, storage device, controller and heat exchanger, installation), since the auxiliary part (boiler, radiator circuit) already exists. In new building where the system substitute a usual hot water tank the additional cost for the solar heating system amounts to about 4500 EUR.

3. MODELLING

As part of the IEA task 26 work the system has been modelled with the TRNSYS simulation programme, using the boundary conditions on climate and installation site (i.e. house design including space heating delivery system and hot water demand) that was set up in the task.

Furthermore it was decided in the task to use a solar collector with the same efficiency, and for solar heating systems were the space heating delivery system and the auxiliary energy system was not part of the solar heating system common specifications for this was agreed.

The boundary conditions have been explained in detail in the technical reports elaborated in the IEA task 26. The main specifications are given below:

Climate:	Zurich
Building	
Area:	140 m²
Heat demand:	60 kWh/m² per year (8400 kWh/year)
Hot water demand:	Average 0.200 m^3/day at 45 °C
Auxiliary energy:	Modulating condensing gas burner on 15 kW with ambient temperature controller for the heat delivery temperature.
Heat delivery system:	Radiators with thermostatic valves.

The sensitivity analyses have been performed on the bases of a base case system with specifications in accordance with the most common practice in Denmark.

The main specifications of the base case solar heating system is given below:

Collector area	7 m²
Specific flow rate in collector circuit:	72 kg/m²h
Collector azimuth/tilt angle	0/45°
Storage volume:	0.28 m³
Auxiliary storage volume:	0.07 m³
Heat exchanger storage tank:	151 W/K
Heat exchanger space heating loop:	151 W/K

In the IEA task 26 work was furthermore set up comfort criteria with respect to indoor temperatures and hot water temperature. To meet these criteria it was found necessary to increase the auxiliary storage volume from 0.07 m³ to 0.09 m³ and to have a capacity of the auxiliary heat exchanger on 290 W/K together with a set temperature of the tank on 52.5 °C.

As part of the modelling work a number of sensitivity analyses of the performance dependency of different parameters have been carried out. The focus in the analyses has been put on the control strategy since it was the impression that it was not obvious how the optimal control strategy should be.

Normally the control, strategy of the solar heating system can be described as follows:

Control of collector loop: The control strategy of the collector loop is in brief:

- If the collector is warmer than the bottom of store, heat is delivered to the store.
- If the store reaches a certain set temperature e.g. 50°C, the 3-way valve is shifted to deliver heat to space heating.
- If there is no need for space heating the 3-way valve will be shifted back and heat will be delivered to the store to raise the temperature further. If there is no need for space heating this is detected by that the temperature difference between the collector and the space heat circuit will increase since the flow (and thereby the ability of the space heating circuit to receive heat) has stopped.
- If the store reaches 99°C the flow of the collector loop is stopped.

The philosophy of the strategy is that it is important to secure a certain temperature in the hot water store before solar heat is delivered to space heating.

As explained earlier it is often so that the controller is designed to supply excess heat to the space-heating loop in case of overheating of the storage. This feature was not implemented in the model

Control of auxiliary energy. The supply of auxiliary energy to the top of the storage is controlled with a temperature thermostat that start the supply of auxiliary energy if the temperature drops below a certain set temperature, which in the calculations is set to 52.5 °C.

It is common that the system has an immersed electric heater which is used in the summer period whiled the boiler is turned off. A thermostat also controls this electric heater.

3.1 Sensitivity analyses

In the following are given a number of conclusions derived from the sensitivity analyses.

Turn off of immersed electric heater in summer.

- For collector areas larger than 7 m² it is advantageous to turn off the boiler in the summer period and to use the electric immersed heater as back up. This conclusion is based on a natural gas condensing boiler and will turn out different with other boilers.

Collector size and storage volume

Variations of the collector area using either a constant storage volume of 0.280 m³ or a variable storage volume of 0.04 m³/m² collector area show:

- From a performance point of view it is advantageous for collector areas below 7 m² to use the storage of 0.28 m³, while for collector areas larger than 7 m³ is advantageous to use the variable storage volume, which results in volumes larger than 0.280 m³. However since the storage with the volume of 0.280 m³ is a standard tank and furthermore fits in a standard module of 0.6 x 0.6 meters it is estimated that this tank is the most cost efficient for a larger range of collector areas..

Set storage temperature for shift in collector loop.

As explained earlier the control of the system is so, that when the collectors are operating, first a certain set temperature is secured in the domestic hot water store before heat is delivered to the space-heating loop. For most systems manufactured in Denmark this set temperature can be adjusted by the customer, while some systems have a fixed set temperature.

In the analyses this set temperature is varied between 20 and 75 °C.

- The conclusion is (surprisingly) that the best performance is secured with a set temperature above 50°C.

Control strategy always to run the collectors at lowest possible temperature:

Since it is not obvious which control strategy of the collector loop is most advantageous, manufacturers in Denmark all have their own variations on the strategy. Instead of running the collector always to secure a certain set temperature in the storage one could argue that it should instead always deliver heat to the lowest temperature; either the bottom temperature of the storage or the inlet temperature to the heat exchanger in the space heating loop.

Therefore the control strategy is modified, so that the bottom temperature of the store is compared with the temperature of the space-heating loop, and if the collector temperature is higher than one of these, the solar energy is delivered to the recipient with the lowest temperature.

- The conclusion is (surprisingly) that this new strategy does not give a better performance, but actually a worse.

Set temperature of radiator in summer and thermal mass of heat delivery system

In Denmark it has been the opinion that system design is especially advantageous in houses with floor heating, since the thermal mass in the floor could function as a buffer store for the solar energy delivered to space heating.

On second thoughts this is of course only the case if the temperature in the floor is allowed to vary in accordance with the content of solar energy. For the normal control of the system this will not happen in winter, when the boiler is adding additional energy to the space-heating loop, since the boiler control and the radiator thermostat only take into account the need of energy in the house and therefore determine the supply temperature.

However in summer when the boiler is turned of it is possible to use the floor as storage. If the radiator thermostat is set to a higher temperature than 20 °C the floor will be heated to this temperature, when the collector loop is running and will cool down to room temperature after a while.

It is of course of interest to investigate this effect. It has in this work not been possible to implement a floor-heating element in the TRNSYS model. However it has been possible to do analyses with increased heat capacity (thermal mass) of the radiators. It is expected that this also could give good indications of the effect. Anyhow the system is in Denmark very often installed in houses with both radiators and floor heating e.g. floor heating in the bathroom and radiators in the rest of the house.

For the analyses a new control strategy of boiler and radiator has been designed.

The control is so that every time the boiler is not delivering heat to the space heat circuit and therefore not controls the supply temperature, then the set temperature of the radiator thermostat is increased some degrees in order to supply heat into the thermal mass of the heat emitter.

This occurs in the following cases:

1. The boiler delivers additional heat to the domestic hot water storage.
2. There is no space heat demand during the day in winter, spring and autumn.
3. The boiler is turned off in summer.

It is expected that if the set temperature of the radiator in summer is too high this will in periods increase the room temperature above comfort level and therefore increase the penalty.

A number of parameter variations have been performed to analyse the effect.

- Conclusions are that for larger collector areas it is an advantage if the solar energy delivered for space heating can be buffered in the thermal mass of the radiators or floor. If this is the case an advantageous control strategy for radiator thermostats is to set those to a temperature of 23°C, when the boiler does not deliver heat to the space heating loop (either because it is turned off or either because it delivers heat to the hot water storage.
- However for smaller collector areas that are most common, the system using the buffer does actually not show improvements compared to the modified base case system.
- All the above conclusions are done with respect to the calculation performed on the specific reference house, hot water usage and Zurich climate. Another Danish study investigating the effect of using the thermal mass of the radiator as buffer showed a very big advantage of this. However the study was performed on a house also having a certain space heating demand in the summer as is the case for many countryside houses in Denmark.

4. ECONOMIC OPTIMISATION

For the use of the comparison of systems within the IEA task 26 a function for the cost of the system has been developed.

The cost function is developed from price information on Danish systems. However in order to get comparable prices, the price of the actual solar collector has been substituted by the price of the reference collector, which is used in the calculations.

Furthermore the price has been adjusted to a common European price level. For Denmark the price level is 125 compared to the European level of 100.

The price function reflects the additional price of the system compared to the reference house without the solar heating system, and is without VAT (and without subsidy).

The price function is:

Additional price::
2565 + 287 * Collector Area (Euro)

In the table below are shown the cost and the savings. In the annual savings electricity used is multiplied by 1/0.4.

It is calculated that the boiler efficiency of the boiler used in the simulations is 88% at a solar collector area of 10 m². For the reference house is used a boiler efficiency of 85%. A minor part of the savings given in the calculation are caused by the improvement of the efficiency of the boiler.

Table: Costs and savings

Collector area [m²]	5	7	11	15
Additional cost [Euro]	4,000	4,574	5,722	6,870
Savings (gas) [kWh/year]	3,075	3,435	3,995	4,417
Electricity for immersed electric heater [kWh/year]	350	251	164	120
Electricity for pumps etc. [kWh/year]	122	130	163	217
Resulting annual savings [kWh/year]	1,894	2,482	3,178	3,575
Annual savings pr. investment cost [kWh/year/Euro]	0.47	0.54	0.56	0.52

The yearly savings per investment cost is given in figure 3 showing a very flat optimum for the collector area of the system if the collector area is above 7 m².

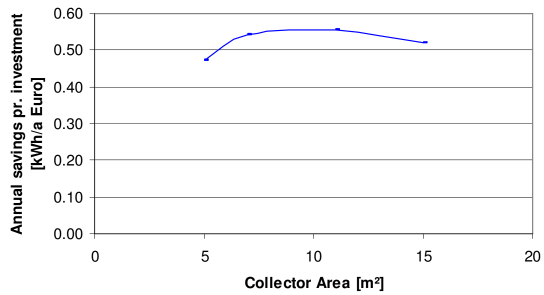

Figure 3: Annual savings per investment cost

It is the conclusion that the system is useful in a large range of collector areas.

5. COMPARRISON WITH OTHER SYSTEM DESIGNS.

The results of the modelling work are made practical available by the PC-programme CombiSun elaborated in collaboration between the EC Altener project Combisystems and the IEA SHC task 26.

Figure 4 shows the performances calculated with CombiSun of different system designs evaluated in the IEA task 26. Design #2 is the system type dealt with in this paper. The performances are calculated for the Danish climate and with a reference house of 130 m^2 with an annual space heat demand of 100 kWh/m^2, which is typical for the kind of existing houses that the system often is installed in.

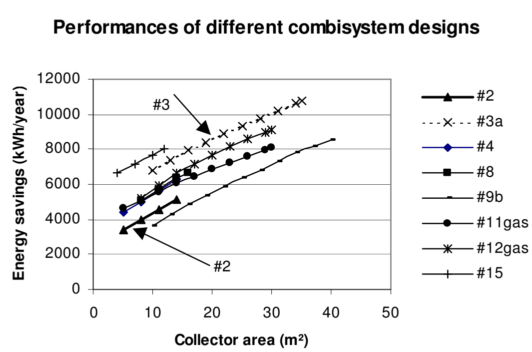

Figure 4

It is seen that the system is not one of the best with respect to performance, but since the systems is relatively inexpensive it comes out quite well in a comparison of the cost-efficiency.

On figure 4 is also shown calculations for the French system #3a. In principle this system is quite similar to the Danish system design except that the collector circuit and the space heating circuit are directly connected and not connected via a heat exchanger as in the Danish system.

Furthermore this system is always installed in connection with floor heating, which is also used in the modelling work.

It is seen that the French system has one of the very best performances and a performance much better than the Danish system.

It should therefore be an item for further studies of the Danish system to investigate the behaviour with a floor heating system to see if this would raise the performance to be comparable with the performance of the French system.

6. CONCLUSIONS

A number of sensitivity analyses especially dealing with control strategy of the system shows that the most common practices for strategy are reasonable.

Sensitivity analyses trying to detect the influence of storing solar heat in the thermal mass of the heat emitter, did not show heat substantial improved performances as was expected by comparison with the simulation results of the French combisystem design. The reason for this might be that a floor-heating model was not implemented.

REFERENCES

The paper refers to the work carried out in the IEA SHC task 26 about Solar Combisystems.

Technical reports describing background and boundary conditions for the simulations as well as the specific simulations of the Danish system design (which is design #2 in the IEA terminology) and the inter comparison with the other simulated systems will be downloadable from the IEA SHC task 26 website http://www.iea-shc.org/task26/ in summer 2003.