Report on Solar Combisystems Modelled in Task 26

Appendix 1:

Generic System #2: A Solar Combisystem Based on a Heat Exchanger between the Collector Loop and Space-Heating Loop

A Report of IEA SHC - Task 26

Solar Combisystems

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Solar Heating & Cooling Programme

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by

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A technical report of Subtask C

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1 General description of the solar combisystem

1.1 Main features

This system is derived from a standard solar domestic-hot-water system, but the collector area has been oversized in order to deliver energy to an existing space heating system. The connection between the solar and the existing 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.

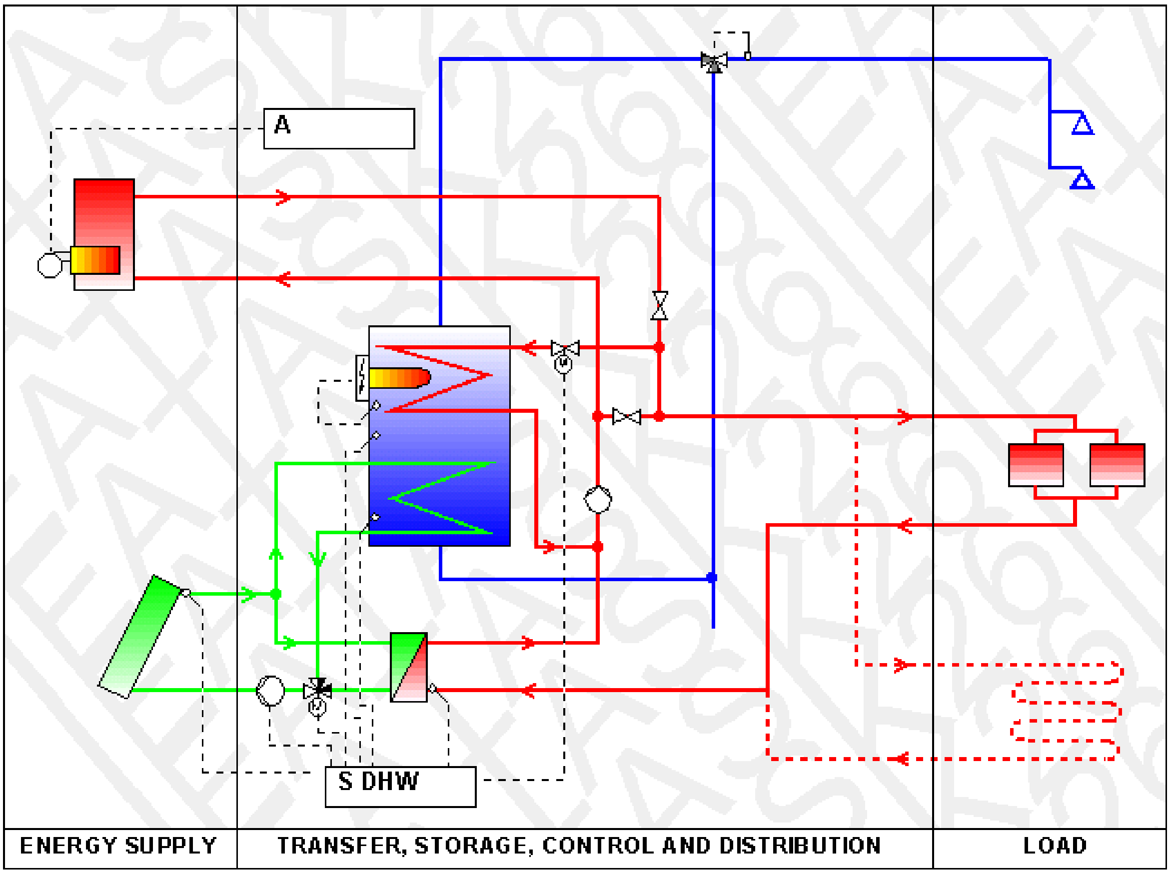


Figure 1: System Design

1.2 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.

1.3 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.

Due to the lack of store for space heating, the solar gain will be increased the more variations of indoor temperature the inhabitants tolerate. In this system, the building itself plays the role of space heating store. Therefore, the system will work better with a high-capacitance heat emission system, like heating floors. Solar-induced variations in the indoor temperature are only possible when the boiler is turned off (i.e. in summer). 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

1.4 Influence of the auxiliary energy source on system design and dimensioning

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

1.5 Cost (range)

A typical system with 7 m^2 of solar collectors and a 280 litre 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. Total cost for complete heating system with solar is 13 800 EUR, and reference cost for complete heating system without solar is 9 300 EUR.

1.6 Market distribution

This system is the most common in Denmark. Prior to year 2,000, 12 manufacturers and 400 to 800 installers all over Denmark have installed about 100,000 m^2 of solar collectors.

This report mainly deals with components from the manufacturer: Batec A/S. However conclusions will be useful for systems also delivered by other manufacturers.

2 Modelling of the system

2.1 TRNSYS model

The combisystem is modelled in TRNSYS 14.2 [1] and the model includes collectors, collector loop, storage, auxiliary boiler, building, radiator, pumps, and control systems. Figure 3 shows a diagram of the system model, and each component is described in greater detail in the next section.

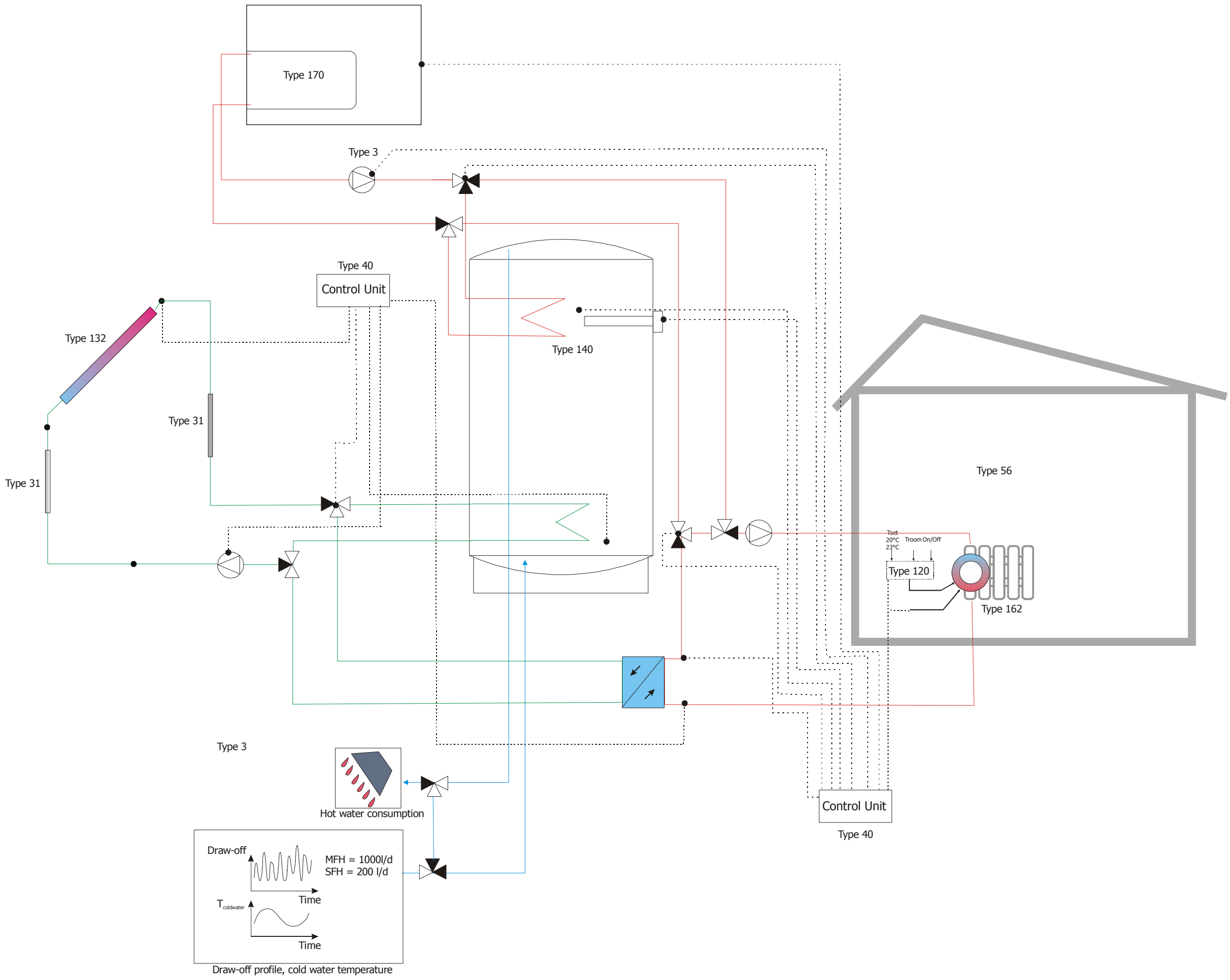


Figure 3: Diagram of System #2 modelled in TRNSYS 14.2

2.2 Definition of the components included in the system and standard input data

The first analysis is performed on a "base case" system, with a specific collector area, tank volume, insulation thickness, heat exchanger size etc. In the following subsections, the most important model components and parameters of the base case system are described.

2.2.1 Collector

For the later comparison of different combisystem concepts, it is an advantage if all the systems are modelled with similar collectors. Therefore, the combisystem is modelled with a standard flat plate collector with a reference efficiency expression as described in table 1 (as defined in [7]). The base case system has a collector area of 15 m² and, as the system is not a low flow system, a specific mass flow rate through the collectors is 72 l/m²/h. The collector is modelled with the non-standard TRNSYS Type 132.

Table 1: Collector data (as defined in [7]).

Collector	η_0	0.8 -
	a_1	3.5 W/m²-K
	a_2	0.015 W/m²-K²
	inc. angle modifier (50°)	0.9
	Area	7 m²
	Specific mass flow	72 l/m²h

2.2.2 Pipes between Collector and Storage

The geometry and insulation thickness of the pipes between collector and tank is given in table 2. For the heat loss calculations, a surrounding temperature of 15 °C is given. The pipes in the collector loop are modelled with TRNSYS Type 31.

Table 2: Collector loop data (as defined in [7]).

Collector loop	Length, tank to collector (cold side)	15 m
	Length, tank to collector (hot side)	15 m
	Inner diameter	0.02 m
	Outer diameter	0.022 m
	Insulation thickness	0.02 m
	Insulation thermal conductivity	0.042 W/mK
	Heat transfer media	Glycol (40%)/Water

2.2.3 Storage

The storage tank is a manufactured tank with a total volume of 280 litres. The tank has been tested at Danish Solar Energy Centre and the test certificate is given in Appendix 1.

The height of the storage is 1.57 m and the diameter is 0.48 m. The store is placed in a cabinet and insulated with expanded PUR foam with a thermal conductivity of 0.028 W/mK. Insulation thickness has been measured to 0.037m, 0.052 m and 0.075 m for the bottom, sides and top of the storage (see Appendix 1)

A theoretical calculation with the above thickness gives an overall heat loss coefficient of 1.56 W/K.

In [7] is given a correction factor to the theoretical heat loss to obtain a more realistic value of the heat loss. This correction factor has not been used. Instead has been used the actual heat loss coefficient obtained by testing of the store. This coefficient is 1.9 W/K

The coefficient has been distributed between top, sides and bottom of the store taking into account that cold bridges of the store are placed in the bottom.

As shown in figure 1 the storage tank includes two internal heat exchangers: Heat exchanger no. 1 is used in the solar collector loop. It is a serpentine heat exchanger with a heat transfer coefficient found by testing to 292 W/K at a temperature in the storage of 50°C and an effect of 2 kW. It is placed in the lowest part of the storage tank.

Heat exchanger no. 2 is used in the auxiliary heating loop. It is also a serpentine heat exchanger with an estimated heat transfer coefficient of 360 W/K and it is placed in the top part of the storage tank.

The storage tank is modelled with TRNSYS Type 140 (version 1.95) and the storage data are summarised in table 3.

Table 3: Storage tank data. [1)]Relative height: Storage bottom = 0, Storage top = 1.

Storage tank	Total volume	0.28 m^3
	Height	1.57 m
	Diameter	0.48 m
	Auxiliary volume	0.07 m^3
	Heat loss coefficient, top	0.118 W/K
	Heat loss coefficient, sides	1.416 W/K
	Heat loss coefficient, bottom	0.366 W/K
	Thermal conductivity of insulation material	0.028 W/mK
	Vertical thermal conductivity	1.225 W/mK
	Solar HX inlet [1)]	0.3
	Solar HX outlet [1)]	0.02
	Auxiliary HX inlet [1)]	0.75
	Auxiliary HX outlet [1)]	1
	Solar HX heat transfer capacity	292 W/K
	Auxiliary HX heat transfer capacity	360 W/K
	Cold water inlet [1)]	0

	Hot water outlet [1)]	1
	Position of collector control temperature sensor [1)]	0.02
	Position of auxiliary heat temperature sensor [1)]	0.82
	Number of nodes	30
	Charging and discharging	Non-stratified

2.2.4 Boiler

The burner in the system is a modulating condensing gas boiler. The boiler has a nominal power of 15 kW modulates in the range of 25%-100%. For the heat loss calculations, a surrounding temperature of 15 °C is used.

The gas boiler is modelled with TRNSYS non-standard Type 170 (version 3.00) [3]. The boiler data are summarized in table 4.

Table 4: Boiler data as defined in [7]. [2)] See [3] for details.

Boiler	Nominal power	15 kW
	Set supply temperature for domestic hot water	65°C
	Fuel type[2)]	Natural gas, high
	Ambient temperature in the boiler house	15°C
	Operation standby temperature of the boiler	30°C
	Hysteresis temperature difference for standby temperature	5 K
	Maximum main water temperature of the boiler	90°C
	Air surplus number (λ) [2)]	1.2
	Modulation range	25%-100%
	Mass of the boiler water	7.5 kg
	Temperature difference between flue gas and return temperature in the heat exchanger[2)]	10 K
	Maximum losses through radiation related to the maximum heat performance[2)]	3.5 %
	Standby losses related to the maximum heat performance[2)]	1.5 %
	Mode[2)]	10
	Minimum running time	1 min
	Minimum stand still time	1 min

2.2.5 Building

The combisystem will be modelled together with a full single-family house with either a low, a medium, or a high space heating demand. The three houses have the same geometry but different building physics data were defined in a way that the specific yearly space heat demand for Zurich climate amounts to 30, 60 and 100 kWh/m² per year.

The building is modelled with TRNSYS type 56 and an overview of the building properties is given in table 5. The properties of the building are defined in [7].

Table 5: Building properties as defined in [7].

Building	Specific space heating demand for Zurich climate	30 kWh/m² per year
	Area	140 m²
	Total window area	23 m²
	Window U-value	0.4 W/m²K
	Window g-value	0.408
	External walls, U-value	0.135 W/m²K
	Roof, U-value	0.107 W/m²K
	Ground floor, U-value	0.118 W/m²K
Building	Specific space heating demand for Zurich climate	60 kWh/m² per year
	Area	140 m²
	Total window area	23 m²
	Window U-value	1.4 W/m²K
	Window g-value	0.589
	External walls, U-value	0.342 W/m²K
	Roof, U-value	0.227 W/m²K
	Ground floor, U-value	0.196 W/m²K
Building	Specific space heating demand for Zurich climate	100 kWh/m² per year
	Area	140 m²
	Total window area	23 m²
	Window U-value	2.8 W/m²K
	Window g-value	0.755
	External walls, U-value	0.508 W/m²K
	Roof, U-value	0.494 W/m²K
	Ground floor, U-value	0.546 W/m²K

2.2.6 Heat distribution

The space heat distribution system is defined as an ambient temperature controlled radiator system with thermostatic valves adjusting the mass flow according to variable inner heat loads.

The radiator is modelled with TRNSYS non-standard Type 162 and it is controlled with a PID-controller, TRNSYS non-standard type 120.

Table 6 lists the design temperatures and the nominal power for the radiator system for the different buildings and climates.

Table 6: Radiator data, see also [7].

Climate	Building	Nom. Power [W]	Design flow temperature [°C]	Design return temperature [°C]	Design ambient temperature [°C]
Stockholm	30 kWh/m^2/year	3480	35	30	-17
	60 kWh/m^2/year	6160	40	35	-17
	100 kWh/m^2/year	9050	60	50	-17
Zurich	30 kWh/m^2/year	2830	35	30	-10
	60 kWh/m^2/year	4950	40	35	-10
	100 kWh/m^2/year	7290	60	50	-10
Carpentras	30 kWh/m^2/year	2460	35	30	-6
	60 kWh/m^2/year	4260	40	35	-6
	100 kWh/m^2/year	6320	60	50	-6

2.2.7 Control strategy

In reality 3 controllers control the system. One controls the pump and the 3-way valve in the collector loop. Another controls the boiler and the deliverance of heat and supply temperature from the boiler to either space heating or to the hot water store, and the last controls the immersed electric heater, which is used in summer for back up of the hot water.

In the model the two last controllers are modelled in the same type 40 controller.

Furthermore a type 120 (PID controller) regulates the heat delivery of the radiator.

In the following is described the control strategy of the system:

<u>Control of collector loop:</u>

The control strategy of the collector loop is in brief:

1. If the collector is warmer than the bottom of store, heat is delivered to the store.

2. If the store reaches a certain set temperature e.g. 50 °C, the 3-way valve is shifted to deliver heat to space heating.

3. 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.

4. 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.

The control is managed by comparing the following 4 temperatures:

T_{coll}: Temperature in collector (at outlet)
$T_{store,b}$: Temperature in bottom of store
$T_{space,1}$: Temperature in space heating circuit before solar heat exchanger (return temperature)
T_{set}: Set temperature for storage

The detailed control strategy is seen in appendix 2.

Control of boiler and space heating circuit

The boiler and the central heating circuit are controlled after the following principles:

1. When the temperature in the top of the solar hot water storage gets below the needed set temperature e.g. 50-55 ^{o}C auxiliary heat will be supplied from the boiler to the storage tank. I.e. the valves in the central loop will be shifted to direct the flow from the boiler to the spiral heat exchanger in the top of the tank and to direct the flow from the radiators in a separate circuit (see figure 3). Furthermore the boiler will be operated at the maximum set temperature of the boiler, which is 60°C.

2. If the temperature in the top of the tank is above the needed temperature the valves will be shifted so that the flow from the boiler goes to the radiators and passes the solar heat exchanger before returning to the boiler. When this happens the supply temperature will be regulated to the minimum required temperature depending on the weather conditions.

3. Additional to the control of the supply temperature as a function of the weather conditions the of the radiator is furthermore controlled by a thermostat that regulates the heat delivery as a function of the actual indoor temperature of the house, which is intended to be 20 ^{o}C.

4. The controller furthermore has an input that tells if the period can be considered as summer or winter period.

   In the summer period the boiler is turned off and the valves are shifted so the radiators only will get heat from the solar collectors. In the summer period, if the temperature in the hot water tank gets below the set temperature, the controller will turn on the electric immersion heater to keep the top of the tank at the needed temperature.

   The criterion for the summer period is in the model that no heat has been supplied to space heating within the latest 48 hours.

Table 7: describes the different controllers:

Collector control	Model (on/off controller)	Type 40
	Start temperature difference	4 K
	Stop temperature difference	2 K
Space heating control	Model (PID controller)	Type 120
	Width of PID-band	3 K
	Proportional gain in PID-band	0.8
	Integral gain in PID-band	0.05
	Differential gain	0
DHW priority control	Model (on/off controller)	Type 40
	Set temperature of hot water	50°C
	Hysteresis	+- 1 K
Burner running time control	Model	Type 40
	Minimum running time	1 min
	Minimum stand still time	1 min

2.3 Validation of model

The model has not been validated with monitored data. Even though the system is very common in Denmark detailed monitoring results exist only in very few cases.

However the storage has been tested at the Solar Testing Laboratory in Denmark. (See appendix 1)

3 Simulations for testing the library and the accuracy.

TRNSYS is an open source code where the user can modify sub-models and compile them into a user specific dynamic link called TRNLIB.DLL. In the Task 26 subtask C work, all users from all countries had to use similar TRNLIB.DLL in order to minimise the risk of introducing differences in results as a result of using different program code.
Therefore a TRNLIB.DLL comparison with a reference DLL file had to be performed. This comparison is described in the following section.

3.1 Results of the TRNLIB.DLL check

All the calculations in this report are performed with the same TRNLIB.DLL as was compiled and used at The Technical University [4].

Calculating the energy use of the three single-family reference buildings for all three climates performed the check of the TRNLIB.DLL. The results are compared with the results of the reference calculations as given in [7], and which were performed with a reference TRNLIB.DLL.

Table 8 shows the results.

Q_{sh}: space heating demand
Q_{dhw}: energy demand for domestic hot water
$E_{boiler,ref}$: final energy consumption of the natural gas boiler
$E_{total,ref}$: combined total energy consumption of the reference building(=gross gas consumption + gross electrical energy consumption)
Q_{pen}: penalty (see [5] for details)

It is seen that except for the penalties there is very good agreement with the results calculated with the two DLL's. The differences on the penalties are furthermore minor and within acceptable tolerances.

3.2 Results of accuracy and time step check

As decided in the task a time step of 1 minute is used in the calculations.

The accuracy of the calculations was evaluated by varying the convergence and integral tolerances from 0.2 to 0.005. It was decided that the necessary accuracy was obtained when the differences in $f_{sav,\ therm}$ (f_s) between actual run and previous run was below 0.01 (relatively)

As seen in table 9 this was not possible since the model would not run with tolerances of 0.005.

Instead tolerances of 0.01 were used.

Furthermore the energy balance of the calculation is checked. The result at tolerances 0.01 is seen in table 10.

Since the result of the energy balance is small it is the evaluation that the calculations using the tolerances 0.01 are acceptable for and tolerances 0.01 are used in the further work.

Table 8: Top Table: Reference building results calculated with the reference TRNLIB.DLL [7], Middle Table: Reference building results calculated with the local TRNLIB.DLL. Bottom Table: The differences in percent.

Results : Milestones report [5]

	Q_{sh} /kWh			Q_{dhw} /kWh	$E_{boiler,ref}$ /kWh			$E_{total,ref}$ /kWh			Q_{pen} /kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	1565	3587	6925	2723	5802	8180	12107	6738	9342	13521	27338	31807	28129
Zürich	4319	8569	14283	3040	9414	14415	21137	10802	15909	22743	7101	6208	3766
Stockholm	6264	12227	19773	3122	11800	18784	27693	13313	20438	29444	6247	5091	2453

Results Reference Building - Klaus Ellehauge

	Q_{sh} /kWh			Q_{dhw} /kWh	$E_{boiler,ref}$ /kWh			$E_{total,ref}$ /kWh			Q_{pen} /kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	1567	3588	6915	2723	5804	8182	12100	6738	9333	13510	27560	32040	28390
Zürich	4314	8562	14270	3040	9409	14410	21120	10800	15900	22720	7191	6288	3830
Stockholm	6256	12200	19750	3120	11790	18770	27670	13300	20420	29420	6337	5171	2512

Difference

	Q_{sh} /kWh			Q_{dhw} /kWh	$E_{boiler,ref}$ /kWh			$E_{total,ref}$ /kWh			Q_{pen} /kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	0.13%	0.03%	-0.14%	0.00%	0.03%	0.02%	-0.06%	0.00%	-0.10%	-0.08%	0.81%	0.73%	0.93%
Zürich	-0.12%	-0.08%	-0.09%	0.00%	-0.05%	-0.03%	-0.08%	-0.02%	-0.06%	-0.10%	1.27%	1.29%	1.70%
Stockholm	-0.13%	-0.22%	-0.12%	-0.06%	-0.08%	-0.07%	-0.08%	-0.10%	-0.09%	-0.08%	1.44%	1.57%	2.41%

Table 9 Influence of the TRNSYS convergence and integral tolerances

	Parameter			Results		
Run no [i]	Convergence Tolerance [-]	Integral Tolerance [-]	Time Step [h]	Simulation Runs	$f_{save,therm}$ [-]	$\varepsilon = (f_s(i)-f_s(i-1))/f_s(i-1)$ [-]
1	0.1	0.1	1/60	yes	0.478	
2	0.05	0.05	1/60	yes	0.481	0.005
3	0.01	0.01	1/60	yes	0.484	0.006
4	0.005	0.005	1/60	no	-	-

Table 10 Energy Balance

Energy supplied form gas boiler to heating media	9,346	kWh
Energy supplied from collector loop to storage	2,284	kWh
Energy supplied from collector loop to space heating loop	413	kWh
Energy in	12,043	kWh
Space heating consumption	-8,515	kWh
DHW consumption	-2,993	kWh
Heta losses tank	-454	kWh
Energy out	-11,962	kWh
Diifference (in-out)	81	kWh
Relative difference	0.7%	

4 Sensitivity analyses and optimisation

In order to optimise the system type sensitivity analyses of the system are performed.
The analyses are performed on basis of the system as described in the previous section (base case). The analyses are performed with the single-family house with space heating demand of 60 kWh/m2 year as defined in [7]. The analyses are performed under Zurich weather conditions and with a collector facing south and with a slope of 45°.

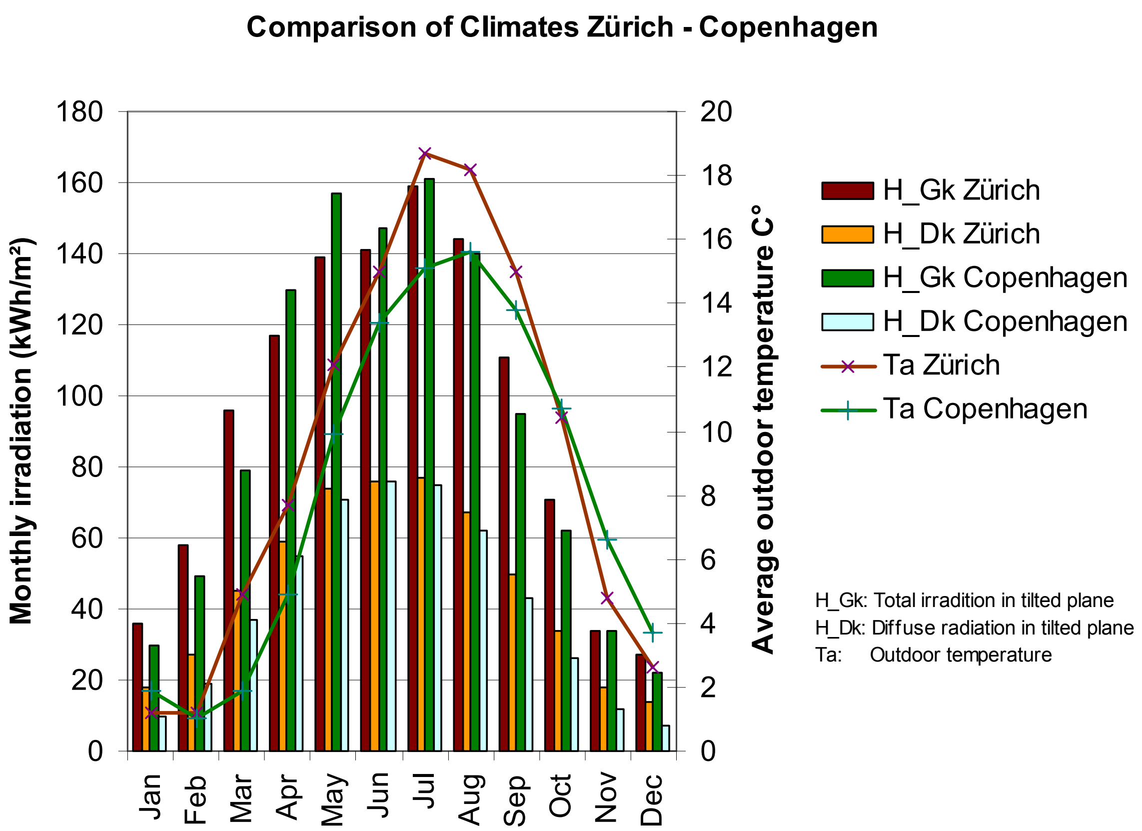


Figure 4 Weather data: Zurich - Copenhagen, from [5]

As seen on figure 4, which gives rough weather data of Zurich and Copenhagen, the difference between Zurich and Copenhagen is not very big. It is therefore the expectation that optimisation under Zurich conditions to some extent also will be valid for Danish conditions.

Parameters are varied in order to investigate the influence and in order to suggest improvements of the system. It is clear that improvements with respect to performances also must be evaluated with respect to economy.

An economical evaluation has only been performed with respect to solar collector area.

As expression of the performances the following indicators are used:

(Fractional thermal energy savings)

$$f_{sav,therm} = 1 - \frac{\frac{Q_{boiler}}{\eta_{boiler}} + \frac{Q_{el.heater}}{\eta_{el.heater}}}{\frac{Q_{boiler,ref}}{\eta_{boiler,ref}}} = 1 - \frac{E_{aux}}{E_{ref}}$$

with:

$\eta_{el.heater}$ = 40% for systems that do **not** apply solely renewable energy sources

$\eta_{el.heater}$ = 90% for systems that apply solely renewable electrical energy sources

(Extended fractional energy savings)

$$f_{sav,ext} = 1 - \frac{\frac{Q_{boiler}}{\eta_{boiler}} + \frac{Q_{el.hetaer}}{\eta_{el.heater}} + \frac{W_{par}}{\eta_{el}}}{\frac{Q_{boiler,ref}}{\eta_{boiler,ref}} + \frac{W_{par,ref}}{\eta_{el}}} = 1 - \frac{E_{total}}{E_{total,ref}}$$

with:

$\eta_{el.heater}$ = 40% for systems that do **not** apply solely renewable energy sources

$\eta_{el.heater}$ = 90% for systems that apply solely renewable electrical energy sources

η_{el} = 40% for all systems

(Fractional savings indicator)

$$f_{si} = 1 - \frac{E_{total} + Q_{penalty,red}}{E_{total,ref}}$$

Using the following nomenclature:

Q	thermal energy
W	electrical energy
E	final or primary energy
η	mean annual efficiency
el	electrical devices
ref	conventional reference system

$f_{sav,therm}$ expresses the ratio of saved energy in a house with solar heating system compared to a reference house without solar heating system.

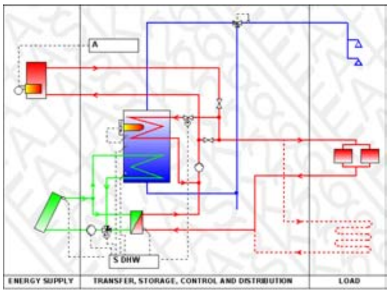
$f_{sav, ext}$ expresses the ratio of saved energy in a house with solar heating system compared to a reference house without solar heating system. However in addition to $f_{sav,therm}$ the electricity use to run the heating devices (pumps, controls etc.) is also taken into account.

$F_{sav,therm}$ expresses the same ration ratio as $f_{sav, ext}$. However a penalty, which is defined in [7] is taken into account. The penalty function adds penalty to systems that do not completely fulfil the comfort demand with respect to room temperature and availability of domestic hot water.

4.1 Sensitivity analyses

An overview of base case system parameters is given in the following table 11:

Table 11: Main parameters for Base Case system



#2 Heat Exchanger between Collector Loop and Space-Heating Loop

Main parameters (optimised):			
Building:	*SFH 60 kWh/m²a*	Storage Volume:	*0.28 m³**
Climate:	*Zurich*	Storage height	*1.6 m*
Collectors area:	*7 m²*	Auxiliary storage volume	*0.07 m³**
Collector type:	*Standard Flat Plate*	Position of in/outlets	*Bottom/top*
Specific flow rate (Collector)	*72 kg/m²h*	Overall heat loss coefficient storage	*1.9 W/K**
Collector azimuth/tilt angle	*0 / 45°*	Nominal auxiliary heating rate	*15 kW*
Collector upper/lower dead band	*4 K/2 K*	Heat Exchanger storage tank:	*151 W/K**
		Heat Exchanger space heating loop:	*151 W/K**
Simulation parameter:		Storage nodes	*30*
Time step	*1 min*	Tolerances Integration Convergence	*0.01 / 0.01*

It should be noticed that the storage has been tested at the Solar Energy Testing Laboratory in Demark. Storage parameters marked with *) are taken from test report.

Table 12: Summary of sensitivity parameters

Summary of Sensitivity Parameters			
Parameter	**Page**	**Variation**	**Variation in $f_{sav, ext}$**
Base Case	20		17.8 %
Auxiliary storage volume Top Heat exchanger capacity Set temperature top of tank	20	0.070- 0.126 m³ 151 – 500 W/K 50 – 56 °C	17.8 – 14.4 %
Modified Base Case (to meet comfort demand)			16.5 %
Boiler running all year (Collector area)	22	4- 15 m²	12.6 – 20.3 %
Collector area (fixed storage 280 litres)	23	4- 15 m²	11.1 – 20.9 %
Collector area (storage 0.040 m³/m²)	23	4- 15 m² 0.160 –0. 600 m³	11.1 – 20.9 %
Storage volume	24	0.160 –0. 600 m³	12.5 – 18.2 %
Storage Temperature for shift Collector Loop	25	20- 75 °C	14.3 – 16.7 %
New control strategy for Solar collector loop: (Collector Area)	26	4 – 15 m²	11.7 – 20.0 %
Temperature difference for shift from space heating loop to Store	27	25- 55 °C	15.9 – 16.9 %
Set temperature radiator summer (Heat capacity (thermal mass) of heat delivery system (radiator) 1.150 kJ/K)	28	20 – 24 °C	16.5 – 15.3 %
Set temperature radiator summer (Heat capacity (thermal mass) of heat delivery system (radiator) 11.500 kJ/K)	28	20 – 24 °C	15.3 –16.3 %
Heat capacity (thermal mass) of heat delivery system (radiator) - Collector area 5 m²	30	1,150 – 12,000 kJ/K	12.1 – 12.3 %
Heat capacity (thermal mass) of heat delivery system (radiator) - Collector area 15 m²	30	1,150 – 12,000 kJ/K	21.8 – 23.6 %
New control strategy for Solar collector loop: Heat capacity (thermal mass) of heat delivery system (radiator) - Collector area 5 m²	31	1,150 – 12,000 kJ/K	11.7 – 11.8 %
New control strategy for Solar collector loop: Heat capacity (thermal mass) of heat delivery system (radiator) - Collector area 15 m²	31	1,150 – 12,000 kJ/K	17.6 – 18.1 %

Sensitivity parameter:	Auxiliary storage volume	0.070 – 0.126 m³
	Capacity of auxiliary HX	151 – 500 W/K
	Set temperature auxiliary volume	50 – 56 °C

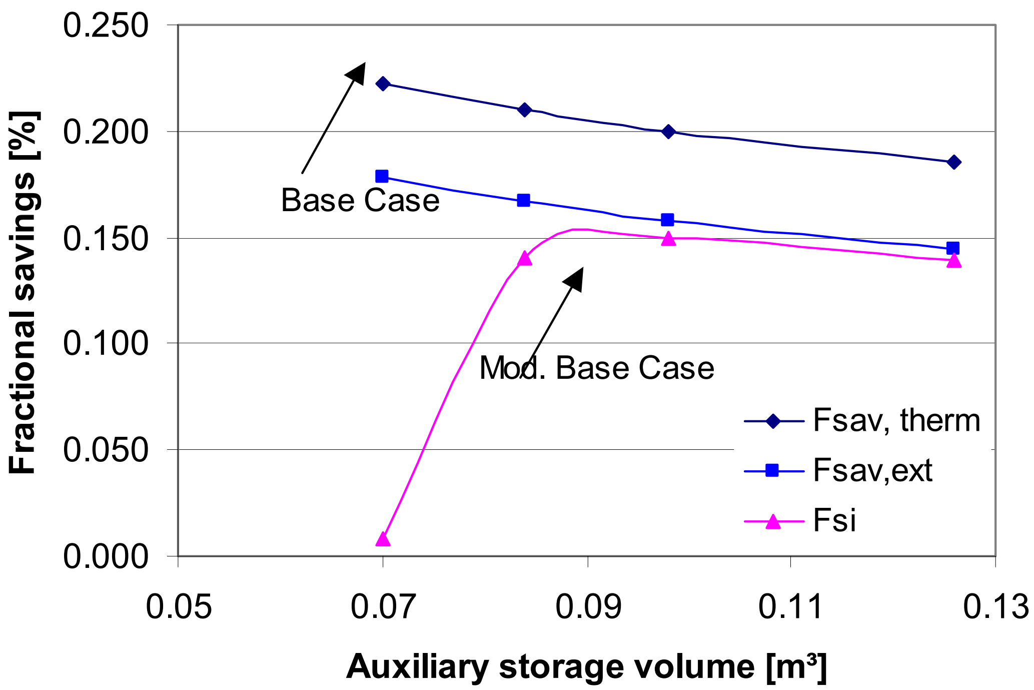


Figure 5: Variation of Auxiliary volume, capacity of auxiliary HX, set temperature auxiliary volume.

Difference from base case
It is seen that in the base case the F_{si} is very low, which means that the system does not meet the required comfort of the task with respect to domestic hot water temperature and therefore has been given a penalty.

The first sensitivity analyses are therefore to determine a design that fulfils the requirements of the task.

Determining for the ability of the system always to be able to deliver the specified hot water volume at the needed temperature are the 3 parameters:

Auxiliary storage volume:	The top volume of the store that is always heated by the auxiliary heating device (boiler or electric immersed heater)
Capacity of auxiliary HX:	The capacity of the heat exchanger in the auxiliary volume delivering heat from boiler
Set temperature auxiliary volume:	The temperature that the auxiliary volume is controlled to be heated to.

Increasing the capacity of the auxiliary HX will increase the cost of the system, while increasing the other parameters will increase the comfort, but also decrease the f_{sav}

Results:
In the sensitivity analyses the 3 parameters have been varied at the same time and it is seen from the figure that an optimum f_{si} is obtained with an auxiliary volume of 0.090 m³. The corresponding values of the other parameters are:

Capacity of auxiliary HX:	290 W/K
Set temperature auxiliary volume:	52.3 °C

In order to obtain a comfort comparable with the comfort obtained from other systems in the task the above parameters are used in following simulations as a modified base case.

Comments
It is a discussion if the new parameters are recommendable for actual practice in Denmark. The system is very common in Denmark and the manufacturers have response on how the system fulfils the comfort at the customers. It is the estimation that the average hot water consumption in Denmark is lower that the 200 litres/day used in the simulations, and the system might therefore very well fulfil most Danish comfort criteria even though this is also possible to obtain solely by increasing the set temperature of the auxiliary volume.

Sensitivity parameter: Control Strategy: Boiler running all year	Collector area	4 - 15 m²

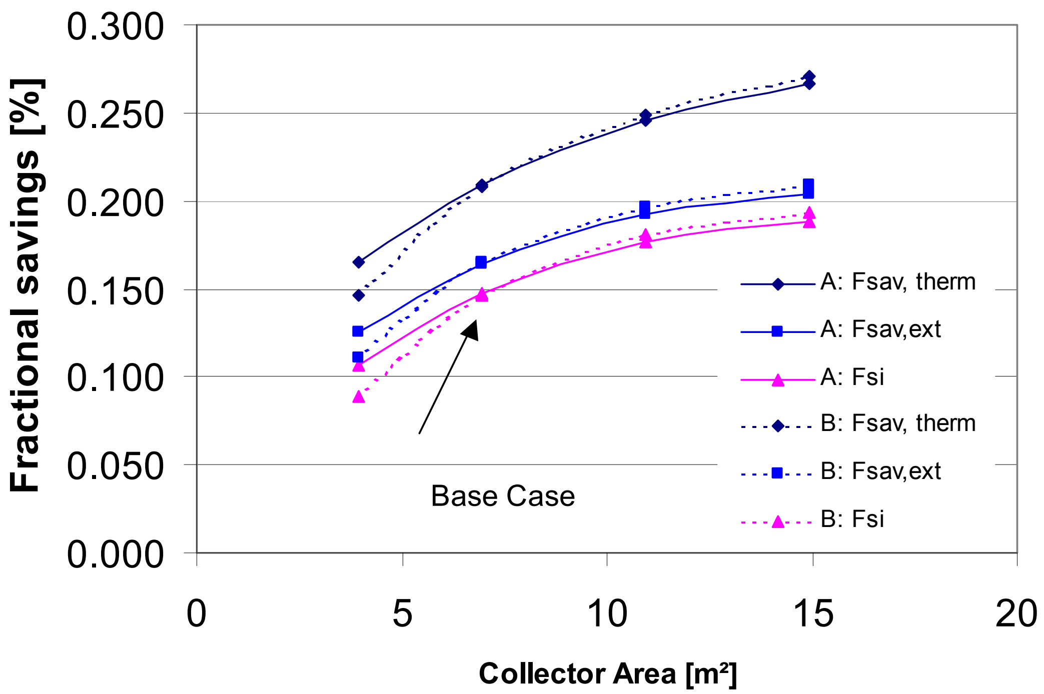


Figure 6: Control strategy A: Boiler running all year, B: Electric immersion heater used in summer

Difference from base case

In the analyses the electrical energy is included in the $f_{sav,\ ext}$ by multiplying with 1/0.4, since this reflects the overall energy efficiency of producing electricity. It furthermore also very well in Denmark reflects the typical relation between the price of gas/oil and electricity.

In the analyses the system is run with the boiler turned off in summer and auxiliary energy from an immersed electric heater.

In the analysis shown in figure 6 the performance for the system with the boiler running all year is also given.

Results:

It is seen on the figure that for collector areas above 7 m² it is most advantageous to turn off the boiler in summer.

Comments

None.

Sensitivity parameter:	Collector area	4 - 15 m²
	Storage volume (and height and heat loss etc.)	0.160 – 0.600 m³

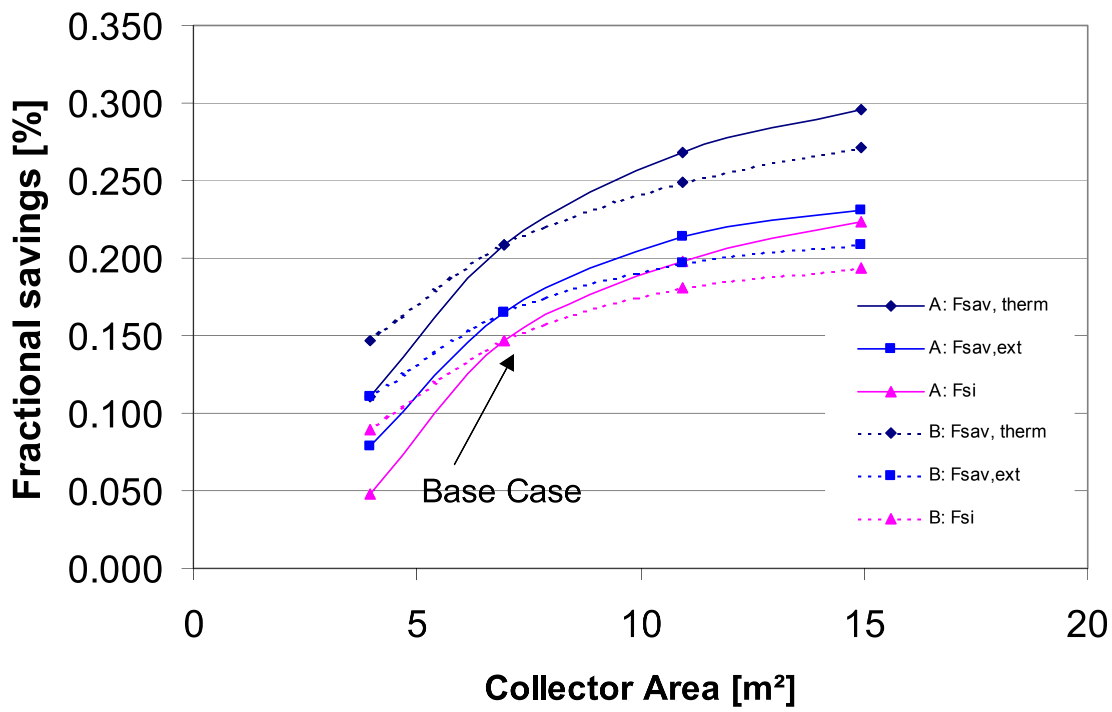


Figure 7: Variation of collector area and storage volume, A: Collector area and storage volume varied, B: collector area varied but constant storage volume of 280 litres

Difference from base case

Figure 7 shows the results of two analyses:

In A both the collector area and the storage size is varied. In B only the collector size is varied while the storage is kept on 280 litres.

Results

The results show an increasing performance with the collector area. Furthermore it is seen that for areas over 7 m² the performance is best in case A, i.e. when the storage volume also is increased.

Comments

A larger storage is expected to be relatively more expensive and it is therefore not certain if a larger store will increase the cost effectiveness.

Sensitivity parameter:	Storage volume (and height and heat loss etc.)	0.160 – 0.600 m³

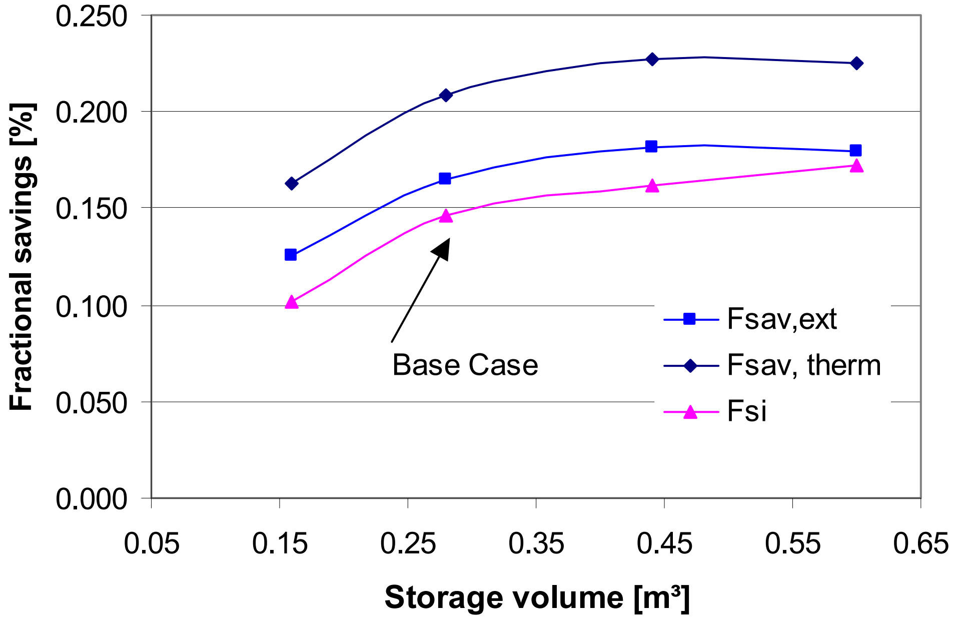


Figure 8: Variation of storage volume

Difference from base case

In figure 8 is seen the result of varying the storage volume with a constant collector area of 7 m².

Results

It is seen that the performance decreases quite much if the store is less than 280 litres. When increasing the volume the performance can also be increased.

Comments

The idea of the concept is to use a standard solar hot water storage, which fits into a standard ground module of 0.6 x 0.6 meters. It is therefore the estimation that for 7 m² of collector the storage volume of 280 litres is sufficient and probably the most cost-efficient.

Sensitivity parameter:	Storage Temperature for shift Collector Loop	20- 75 °C

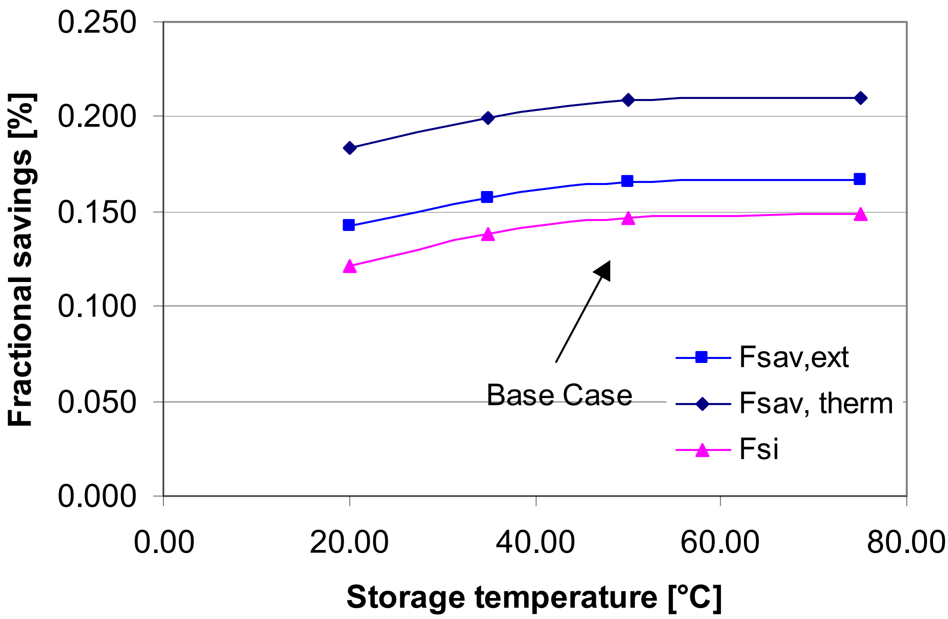


Figure 9: Variation of Storage Temperature for shift in collector loop

Difference from base case

As explained in paragraph 2.2.7 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.

It is not obvious which temperature will give the best performance.

Results

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

Comments

The figure shows surprisingly that the best performance is secured with a high set temperature. This means that the effect of storing solar energy to fulfil the hot water demand is better than always running the system at the lowest possible temperature.

Sensitivity parameter:	New control strategy for Solar collector loop: Collector Area	4 – 15 m²

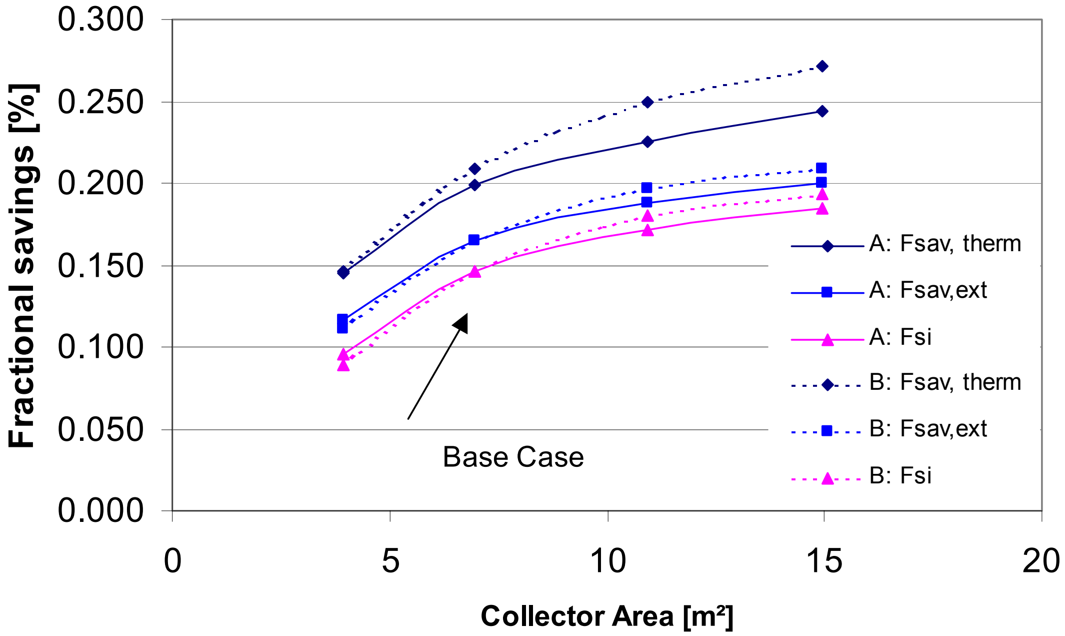


Figure 10: New control strategy that always have collector to run at lowest temperature. A: New strategy, B: Base case Strategy

Difference from base case

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 as described in paragraph 2.2.7 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.

Results

The results are seen on figure 10 and it is seen that this new strategy however not gives a better performance, but actually a worse.

Comments

The result is surprising but in agreement with the results obtained in the previous analysis, where a high set temperature for the shift had the best performance.

Sensitivity parameter:	Temperature difference for shift from space heating loop to Store	25- 55 °C

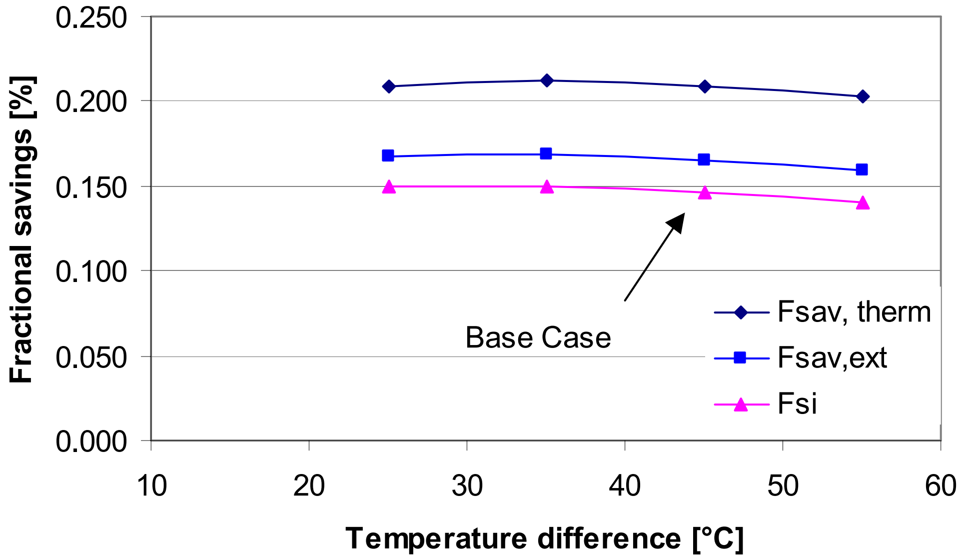


Figure 11: Variation of temperature difference between collector and space heating loop

Difference from base case
As explained in paragraph 2.2.7 the control, of the collector loop is so, that when the collector loop is shifted to deliver heat to the space heating loop, it is tested, if there actually is flow in the space heating loop and that it therefore is possible to deliver heat. This test can be performed by a flow switch, but can also be performed by a temperature sensor. If the temperature difference between the temperature in the space heating loop and the collector gets too big it is an indication of that there is no or only little flow in the space heating loop.

Results
The simulations show which temperature difference gives the best performance.

Comments
The optimum is very flat showing no big influence of the temperature difference.

Sensitivity parameter:	Set temperature radiator summer	20 – 24 °C
	Heat capacity (thermal mass) of heat delivery system (radiator)	1,150 – 11,500 kJ/K

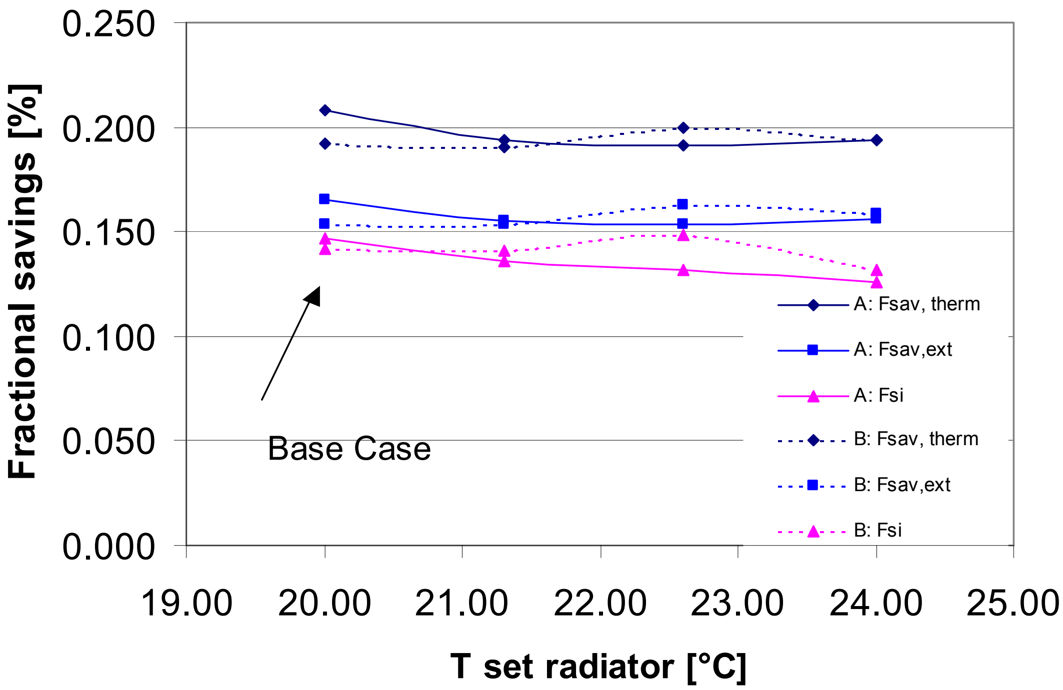


Figure 12: Variation of Set temperature radiator thermostat summer. A: Radiator thermal mass 1,150 kJ/K, B: Radiator thermal mass 11,500 kJ/K

Difference from base case
In Denmark it has been the opinion that System #2 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. This is also the principle of Systems #1 and #3 in the task.

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.

Results

The figure gives the results of varying the set temperature of the radiators when the boiler is not running. The analyses are performed with a thermal mass of 1,150 KJ/K (A:), which could be typical for a normal radiator system, and which is used generally in the task, and a thermal mass of 11,500 kJ/K, which could be obtained by floor heating in part of the house. (However one should notice that the simulations with respect to heat delivery capacity and other thermal properties are not realistic for a floor heating system).

It is seen that a set temperature of approximately 23 °C will be suitable.

Comments

It is surprising that a set temperature greater than 23 °C will not increase the fractional savings further.

It is furthermore not understood why a set temperature higher than 20 °C decreases the performance with little thermal mass of the radiator.

Sensitivity parameter:	Collector Area	5 – 15 m²
	Heat capacity (thermal mass) of heat delivery system (radiator)	1,150 – 11,500 kJ/K

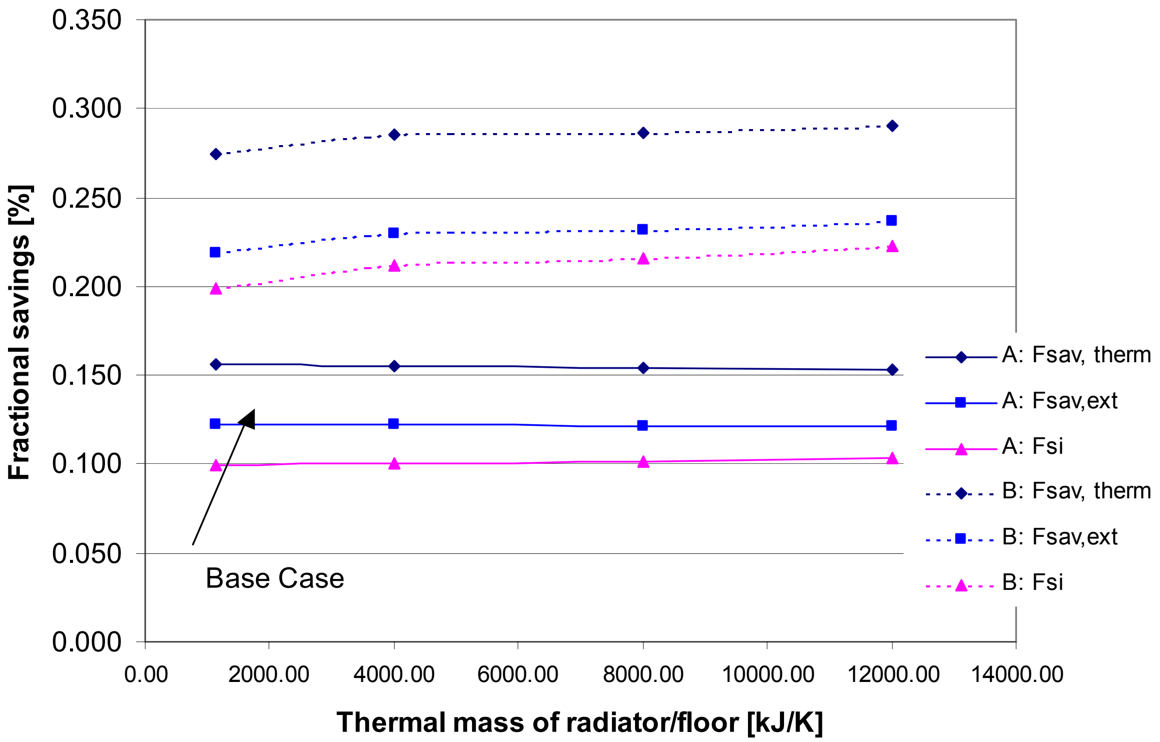


Figure 13: Variation of Radiator Thermal mass. A: 5 m² Solar Collector B: 15 m² solar collector

Difference from base case
With the set temperature of 23 °C for the radiator in summer the thermal mass of the radiator/floor has been varied for the collector areas of 5 m² and 15 m².

Results
For the 15 m² system the thermal mass increase the performance, while this is not the case for the 5 m² system.

Comments
It is only the larger collector areas that can make use of the thermal mass. The results are not fully understood since another study [6] indicated that the effect of the thermal mass would be larger.

Sensitivity parameter:	New control strategy for Solar collector loop:	
	Collector Area	5 – 15 m²
	Heat capacity (thermal mass) of heat delivery system (radiator)	1,150 – 11,500 kJ/K

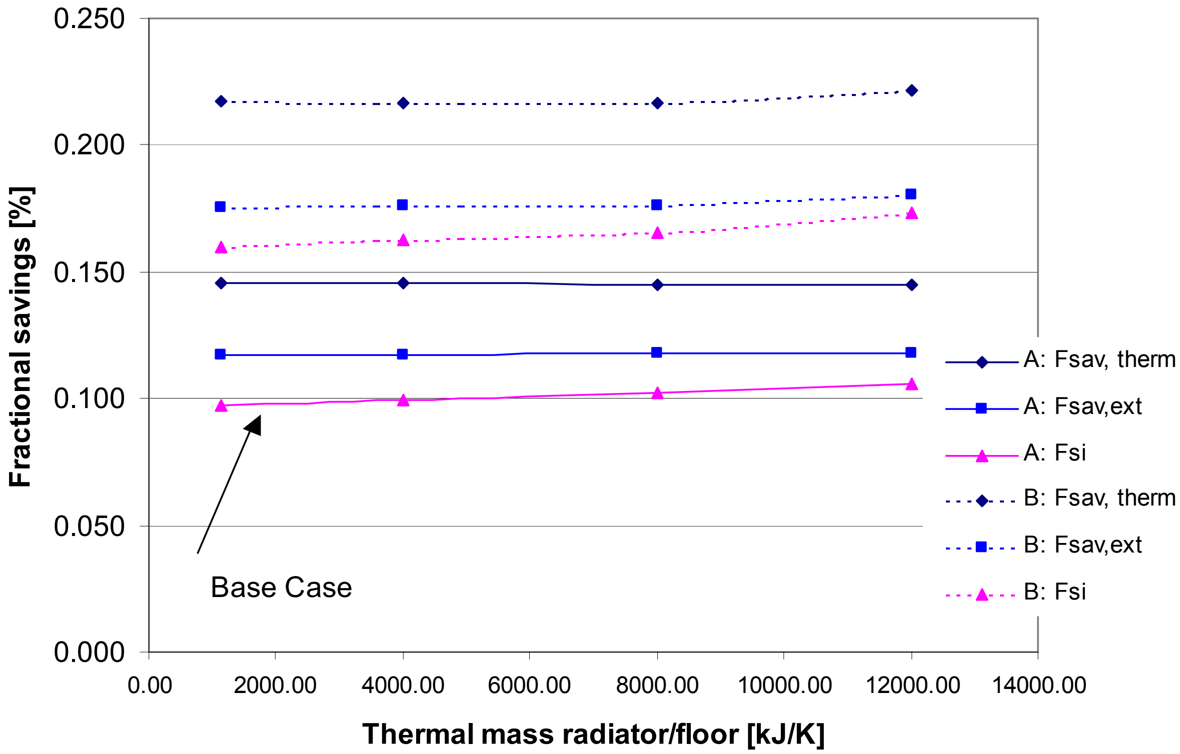


Figure 14: Variation of Radiator Thermal mass. A: 5 m² Solar Collector B: 15 m² solar collector

Difference from base case

It was estimated that the new control strategy investigated on page 26, was not advantageous because of that there was no storage of the space heat. It is therefore interesting to test if the strategy could be advantageous with larger thermal mass in the radiators.

Results

The new strategy is applied for collector areas of 5 m² as in the previous analysis.

Comments

Compared to the previous analysis it is seen that also in this case the new strategy is not advantageous

4.2 Further sensitivity analyses

It is obvious that further analyses of parameters relevant for the performance could have been performed, e.g. the heat loss of the storage tank is an important parameter.

Since the effect of the heat loss is well understood the focus in this report has not been on this parameter.

In a simulation with a collector area of 10 m² the heat loss from the tank has been calculated to 450 kWh/year.

5 Optimised system

The summary of the sensitivity analyses given in the previous is:

- With a relation between the cost of gas and electrical energy of 0.4 it is most advantageous to turn off the boiler in summer (excepted are areas below 7 m²)

- Better performances can be obtained by enlarging the storage volume especially at larger collector areas. However it is uncertain if this is economically advantageous since the used tank is a standard tank and therefore relatively not as expensive as a larger tank will be.

- The set temperature for the hot water tank before the collector shifts to the space-heating loop should be above 50 °C.

- Another control strategy always having the collector to work on the lowest temperature (either the bottom of the storage tank or the space heating look) had a worse performance than the control strategy of heating the hot water tank to a certain temperature (above 50°C) before shifting to space heating.

- The optimum setting of the temperature difference between the space heating loop and the collector before the collector loop shifts back to heat the store (if no heat can be delivered to space heating) is about 35°C.

- 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. The performance of this system compared to the (modified) base case is seen on figure 15.

  However it is seen in the figure that for 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 study [6] 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.

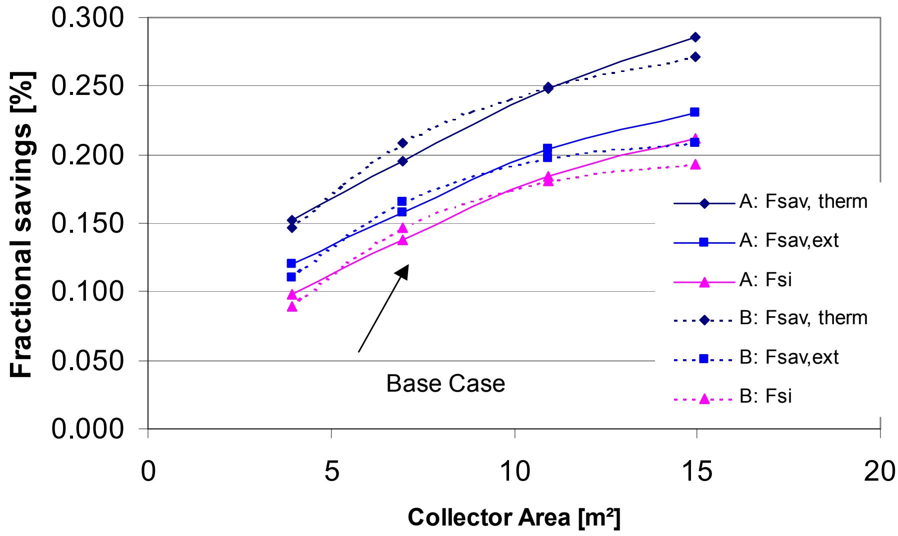


Figure 15: A: System using floor/radiator as buffer, B: Base case

5.1 Economic optimisation

For the use of the comparison of systems given in [7] 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 [7]:

Additional price System #2: 2565 + 287 * Collector Area (Euro)

In table 13 the cost and savings are shown. In the annual savings used electricity 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 13: 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 16 showing a very flat optimum for the collector area of the system if the collector area is above 7 m².

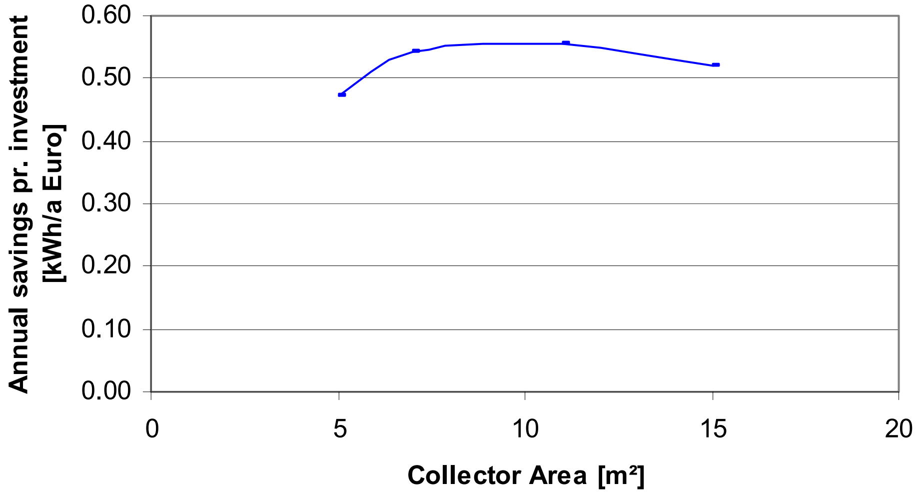


Figure 16: Annual savings per investment cost

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

5.2 FSC analyses

To compare fractional savings of different systems under different climates and loads the FSC method has been developed in the task. The method is described in detail in [7]

In the method the fractional savings are plotted as a function of the **Fractional Solar Consumption.** (FSC).

The FSC represents the proportion of energy consumptions for space heating and DHW which is "in phase" with the available solar energy on the collector plane. FSC can be considered as the maximum theoretical Fractional Energy Savings, which could be reached if the SCS had no losses.

$$FSC = Q_{solar,usable} / E_{ref}$$

$Q_{solar,usable}$ is calculated on a monthly basis in a simple way, using the solar collector area **A** (m²), the monthly irradiation in the collector plane **H** (kWh/m²) and the monthly reference consumption without solar combisystem $\mathbf{E_{ref,month}}$ (kWh), and taking for each month the minimum of this total consumption and of the available irradiation :

$$Q_{solar,\ usable} = \sum_{1}^{12} \min(E_{ref,month} , A.H)$$

The yearly reference consumption $\mathbf{E_{ref}}$ is the sum of the monthly reference consumptions $\mathbf{E_{ref,month}}$:

$$E_{ref} = \sum_{1}^{12} E_{ref,month}$$

The quantities of the FSC are illustrated on the figure 17 [7]
FSC is area 2 divided by (area 1 + area 2).

The FSC curves for System #2 is given in figure 18.

The FSC curve is based on calculations of

- 3 collectors sizes 5, 10 and 15 m°
- 3 reference houses (30, 60 and 100 kWh/m² year)
- 3 climates (Carpentras, Zurich, Stockholm)

The results shows quite big scattering and it has been suggested especially for the System #2 to skip the result using the low energy house (30 kWh/m² year).

If this is done the curve looks as in figure 19.

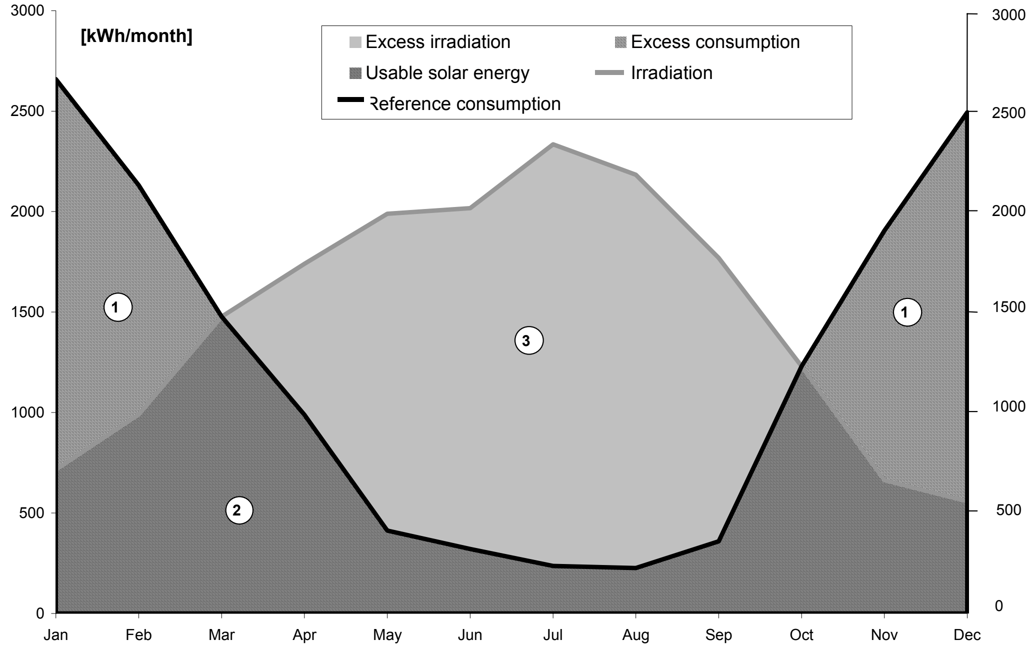


Figure 17: The FSC quantities

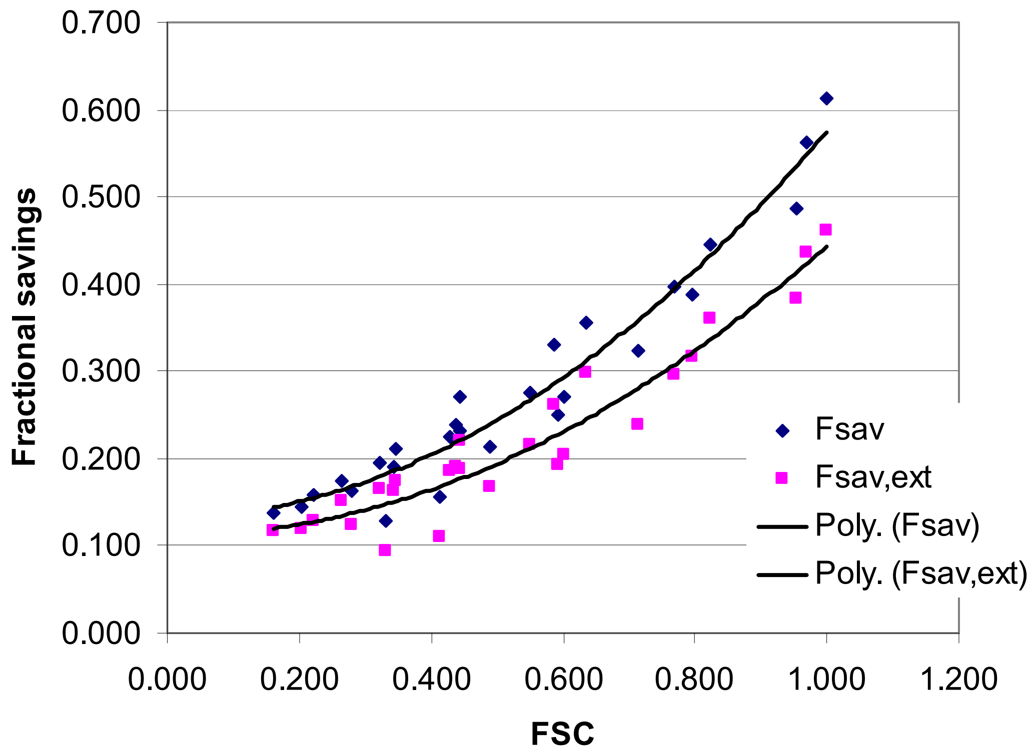


Figure 18: FSC curves for all loads and climates

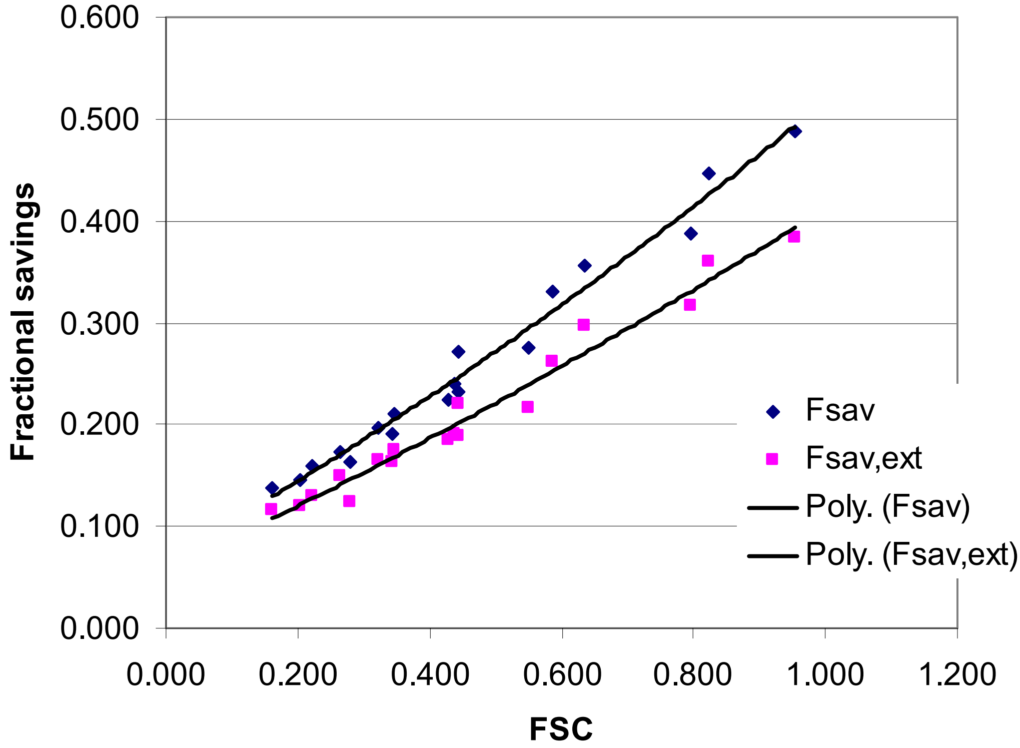


Figure 19: FSC curves for all climates, but excluding low energy houses

For the comparison with the other systems analysed in the task is referred to [7].

However it can be mentioned that the system has relatively low performances, but that this to some extent is compensated by the inexpensive design.

5.3 Material demand

The material demand of a number of systems has bee analysed in the task.

The System #2 has the following material demand

Table 14: Material demand and energy use of system with 9 m² collector

System		#2		#2
collector area (aperture)	[m²]	9	[m²]	9
store volume	[m³]	0.28	[m³]	0.28
comment		without burner and collector-tubes		without burner and collector-tubes
Material			AEE	
	unit		[MJ/unit]	MJ
aluminium, 27.6% recycling material	kg	26.16	151.7	3968
steel high alloyed	kg	6.00	96.55	579
steel un- and low alloyed	kg	171.00	33.85	5788
sheet steal, galvanized	kg		58	0
copper/brass/zinc	kg	29.2	96.59	2822
glass (flat shape) without coating	kg	91.2	13.3	1213
glass and mineral wool	kg	7.20	18.6	134
EPDM rubber, PUR hard foam polypropylene, diff. polystyrol types polyethylene diff. densities and other polymers	kg	18.0	93.59	1682
PVC, hard quality	kg		81.8	0
propylene glycol	kg		48.87	0
bitumen, PVC sealing strip	kg		49.82	0
wood (raw)	kg		1.4	0
wood (fibreboards, …)	kg		7.4	0
others				0
Burner + Pumps + controller (average of 85 MJ/kg+A22 with steel, alu., copper, plastic…)	kg	11.5711	85	984
				0
Selective coating	m²	8.73	44.53	389
Electronic	kg		293.69	0
Total	**kg**	**360.3**	**MJ per system**	**17560**
Without burner				

The table also gives the energy used to produce the materials (AEE).

The energy payback time has furthermore been calculated to between 1.9 and 2.5 years under the different climates and with the 60 kWh/m² year single-family house.

6 Conclusion

The most common Danish solar combisystem is theoretically investigated in the report.

The principle in the system is that in a normal solar hot water system a heat exchanger is added to deliver solar energy from the collector loop directly to the space heating loop.

In this way solar energy for space heating is not stored which is expected to decrease the performance. On the other hand the system is relatively inexpensive, which can compensate for a reduced performance.

A TRNSYS model of the system is developed and sensitivity analyses of parameters are performed by simulation.

The analyses show no major improvements of the system.

Special emphasis has been put on investigating the control strategy and to investigate if the thermal mass of radiators or floor could act as buffer for the solar energy delivered to space heating and in this way improve the performance.

The analyses show that this is possible and has advantages at larger collector areas. However the improvements are not as large as expected.

An economic optimisation gives an optimum solar collector area of approximately 10 m^2. However the optimum curve is quite flat for areas above 7 m^2, and collector areas up to 15 m^2 are also feasible.

The calculated performances have been the basis for comparisons with the other systems modelled in the task 26.

The comparison shows that the performance is not among the best, but however probably not as bad as expected. Furthermore the inexpensive design compensates to some extent for the lower performance.

Furthermore the material use of the system and the energy used to produce the materials has been estimated. The energy demand is in a range that gives energy pay back times of 1.9 – 2.5 years.

7 References

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[3] Bales, Chris TRNSYS Type 170 Gas/Oil/Biomass boiler module. Version 3.00. Högskolan Dalarna, Solar Energy Research Center – SERC, EKOS. S-78188 Borlänge

[4] Shah, L.J. Report on Solar Combisystems Modelled in Task 26 (system description, modelling, sensitivity, optimisation), Appendix 3: Generic system #4, Technical Report, IEA SHC Task 26 Solar Combisystems, http://www.iea-shc.org, 2003

[5] Remund, J., Lang, R., Kunz, S. Meteonorm Version 4, Nov. 1999, Meteotest, Bern

[6] Ellehauge, K. Aktive solvarmeanlæg med større dækning af husets samlede varmebehov, Udredning og skitseprojekter, DTI, November 1999.

[7] Weiss, W. (ed.) Solar heated houses – A design handbook for solar combisystems, IEA SHC Task 26, Solar Combisystems, James & James Science Publishers, 2003.

Appendix 1 Data of Storage (in Danish)

Datablad for solvarmebeholder, rev. DANAK Reg.nr. 300	*D3100*
Fabrikat: Batec A/S, Danmarksvej 8, 4681 Herfølge	Type: **Batec 280**
Rekvirent: -	VA-godk.nr.: 3.21/DK 9674

Data for solvarmebeholder - fabrikant oplysn.

Udformning:

Cylindrisk stålbeholder med to varmevekslere, en bundspiral til solvarme og en topspiral til suppleringsvarme. Beholderen er isoleret med hårdt CFC frit polyurethanskum og er indbygget i et kabinet af stål. Pumpe, ekspansionsbeholder mm. placeres i kabinettet under beholder.

Tomvægt incl. kappe/spiral : ca. 170 kg

Varmtvandsbeholder:

Type	: Cylinder m. hvælvede endebunde
Diameter x højde	: ø496 x 1581 mm
Volumen	: 280 liter
Materiale	: R st 37-2
Korrosionsbeskyttelse	: Emalje og anode

Solvarme veksler

Dimensioner Spiral, længde	:16000 mm.
Materiale	: R st 37-2
Væskeindhold	: 5,9 liter
Opvarmet volumen af veksler	: 280 liter
Vol. fra beh.bund til veksl.top	: 107 liter

Suppleringsvarme veksler

Dimensioner Spiral	: ø 27 mm, l= 8500 mm
Materiale	: R st 37-2
Væskeindhold	: 3,1 liter
Opvarmet volumen af veksler	: 70 liter

El-patron

Type	: Stav
Effekt	: 1 kW / 230V 3 kW / 400V
Opvarmet volumen af el-patron	: 80 liter

Isolering:

CFC-frit PUR skum

Bund	: 37 mm
Sider	: 52 mm
Top	: 75 mm

Prøvningsforhold:

Rumtemperatur	: ca. 21°C
Væske i solfangerkreds	: Vand/propylenglycol 60/40
Benyttet væskestrøm	: ca. 3 liter/minut

Resultater:

Målt brugsvandsvolumen	: 264 liter ± 5%
Varmekapacitet	: 1184 kJ/K ± 2%
Varmetabskoefficient i drift v. 60°C	: 1,9 W/K ± 5%
Varmetabskoefficient i hvile	: 1,7 W/K ± 5%

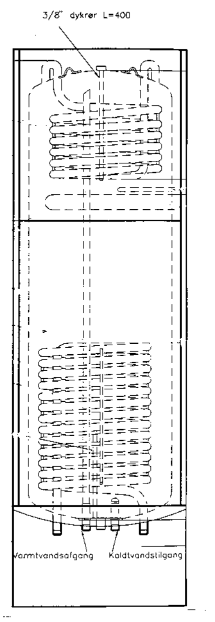
Varmeoverføringsevne, UA, fra solfangerkreds til beholder:

UA ved T beh.= 50°C, og effekt på 2 kW: 292 W/K ± 7%

Udtryk for UA : 167,5 + 2,5 • T beh. [W/K]

Principskitse af solvarmebeholder:

Beholder set fra front



Bemærkninger til prøvning:

Pumpe, ekspansionsbeholder, fittings mm var **ikke** monteret under prøvningen.

Dato:

Prøvestationens underskrift:

Appendix 2 Details on control strategy

The control strategy of the multicontroller that operates the collector loop is given in the table below.
There are 12 modes.

1: Logic expression true
0: Logic expression false

Mode	Tcoll> Tstore,b	Tcoll> Tspace,1	Tcoll> Tspace,1	Tstore> Tset(e.g 50)	Tstore,b> 97		Pump	Valve
1	0	0	0	0	0		off	space h.
2a	0	0	0	1	0		off	space h.
2b	0	0	0	1	1		off	space h.
3	0	1	0	0	0		1	store
4a	0	1	0	1	0		1	store
4b	0	1	0	1	1		1	store
5	0	1	1	0	0		off	space h.
6a	0	1	1	1	0		off	space h.
6b	0	1	1	1	1		off	space h.
7	1	0	0	1	1		off	space h.
8a	1	0	0	0	0		1	space h.
8b	1	0	0	1	0		1	space h.
9	1	1	0	0	0		1	space h.
10a	1	1	0	1	0		1	store
10b	1	1	0	1	1		1	store
11	1	1	1	1	1		off	space h.
12a	1	1	1	0	0		1	space h.
12b	1	1	1	1	0		1	space h.
Start temperature difference	4	4	45	2	2			
Stop temperature diffrce	2	2	43	1	1			

The control strategy of the multicontroller that operates the boiler, space heat circuit and electric immersed heater:
There are 8 modes.

1: Logic expression true
0: Logic expression false

	Comparisons				Output			
Mode	Tn,s> Ts,c	Summer period	Tstorage< Tset		Electric immersed heater	Valves, pumps and boiler for hot water tank	Turn off boiler	Space heat circuit not through boiler
1	0	0	0		0	0	0	1
2	0	0	1		0	1	0	1
3	0	1	0		1	0	1	1
4	0	1	1		1	1	1	1
5	1	0	0		0	0	0	0
6	1	0	1		0	1	0	1
7	1	1	0		1	0	1	1
8	1	1	1		1	1	1	1

Tn,s: Called supply temperature for space heating
Ts,c: Actual temperature in space heat circuit before boiler