
System Simulation Report

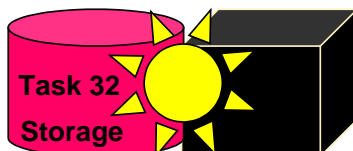
System : HEIG-VD-W and HEIG-VD-PCM

**A Report of IEA Solar Heating and Cooling programme - Task 32
Advanced storage concepts for solar and low energy buildings**

Report C6.1 of Subtask C

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Author:
Stéphane Citherlet
Jacques Bony



Report on System Simulation

C6.1: Appendix 1 of report C6

HEIG-VD-W and HEIG-VD-PCM

by

Stéphane Citherlet
Jacques Bony

A technical report of Subtask C



heig-vd

Haute Ecole d'Ingénierie et de Gestion
du Canton de Vaud

Laboratory of Solar Energetics and Building Physics (LESBAT)
University of Applied Sciences Western Switzerland (HES-SO/HEIG-VD)
Route de Cheseaux 1
CH-1400 Yverdon-les-Bains
Switzerland

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1 General description of HEIG-VD-W and HEIG-VD-PCM

Main features

This system was designed for a single family house to provide energy for the space heating and the domestic hot water (DHW). The water storage tank can contain phase change material (PCM – yellow part see figure here under), but not in the upper part of the tank to get enough power to provide the DHW. The global ratio of PCM is about 50% in volume. The solar collector loop of this installation is a drain back system. The storage tank, space heating and solar loop use water as heat transfer fluid. DHW preparation is done with an external flat plate heat exchanger. The space heating demand is fulfilled by solar energy with an auxiliary gas boiler.

Heat management philosophy

Solar loop:

When the collector temperature is higher than the bottom temperature of the storage tank, the solar pump is switched on. The solar loop uses a constant flow rate without stratification. The maximal temperature inside the storage tank depends on the PCM type. Some PCM don't support high temperature, therefore, if the storage tank temperature is too high (80°C for some PCM) or if the collector temperature is higher than 90°C the solar pump is switched off.

Auxiliary boiler:

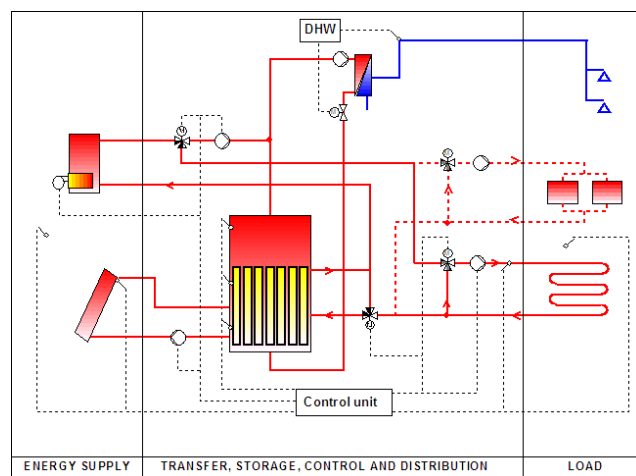
The gas boiler has a modulated burner. This gas boiler provides energy for the space heating loop without going through the storage tank. There is no heat charge in the space heating part of the tank. Thus the storage heat losses are reduced and the solar tank part is bigger.

Space heating:

If the return temperature of the space heating loop is lower than the temperature in the middle of the tank, the energy is taken from the storage tank. If the temperature level in the tank is not high enough, the gas boiler switches on. The set point temperature for the space heating loop depends on the outside temperature and the room temperature.

Preparation of DHW:

The auxiliary heat for the DHW demand is provided by the gas burner, and during this step, the space heating loop is interrupted. In the upper part (DHW) of the tank, the set point temperature is 57 °C with a dead band of ± 3 °K. The DHW temperature at the output of the external heat exchanger is regulated by a temperature control valve. Due to the instantaneous DHW preparation, there is no legionella risk.



Influence of auxiliary energy source on system design and dimensioning

As there is no buffer storage the space heating loop requires a modulated burner.. If a non modulated burner is used, there is too many start-up cycling. On the other hand, the space heating demand influences only the nominal power of the boiler.

Cost (range) and Market distribution

This kind of installation is not a commercialised combisystem. So it is difficult to give its total cost.

2 Modelling of the system

2.1 TRNSYS model

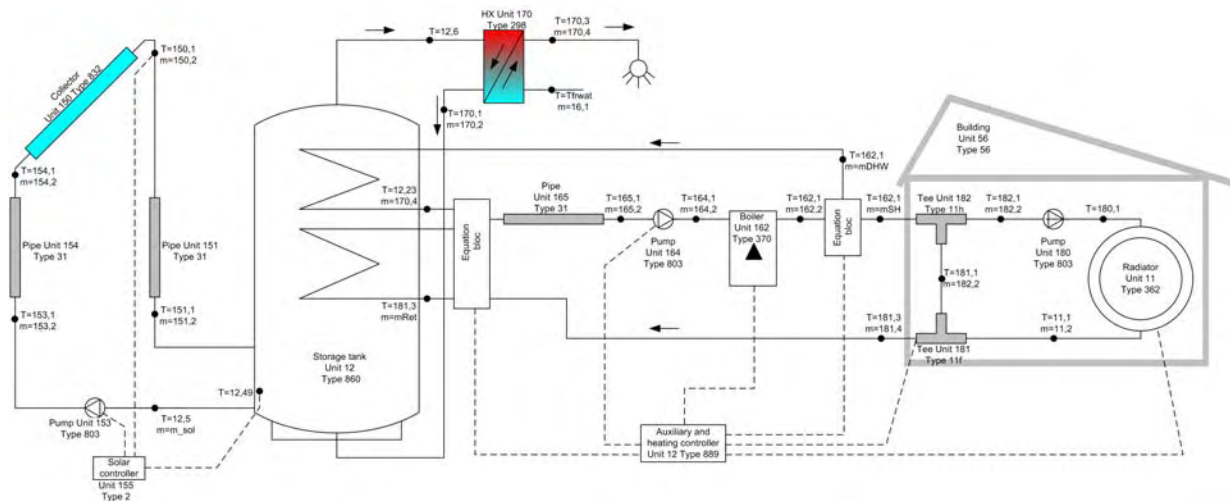


Figure 1. TRNSYS model of the HEIG-VD system, with or without PCM

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

The simulated system has no internal heat exchanger. Figure 1 shows the storage tank with two internal heat exchangers. In fact the type860 (type60+PCM) has only two double ports. To simulate other double ports, we introduce a heat exchanger with a large heat exchange area and a high conductivity coefficient (555 [W/m.K] or 2000 [kJ/hr.m.K]).

2.2.1 General Setting in the TRNEDIT template

General Settings (to be chosen by TRNEDIT):

Main

simulation timestep	1/20 hr
tolerance integration / convergence	0.003 / 0.003
length of simulation	13 months
climate	Zürich
building	SFH30

Auxiliary

Nominal Power of Auxiliary	34200 kJ/hr
Set temperature Auxiliary into store	57 °C
Auxiliary temperature rise	6 K

Collector

type	flat plate selective (ref)
aperture area	20 m ²
tilt angle	45°
azimuth (0° = south, 90° = west, 270° east)	0°

Collector (continuation)

primary loop specific mass flow rate	15 kg/hm ²
upper / lower dead band (switch on / off)	7 K / 3 K
relative height of low temperature sensor in store	0.083
cut-off temperature of collector	80 °C
boiling temperature of collector fluid	90 °C

Store

storage volume	0.83 m ³
insulation thickness ($\lambda=0.042$ W/mK)	0.15 m
correction factor for heat loss	No correction factor

2.2.2 Collector

Type: 832

Version Number: 2.06

Collector	η_0	0.8 -
	a_1	3.5 W/m ² -K
	a_2	0.015 W/m ² -K ²
	inc. angle modifier (50°)	0.9 -
	Area	20 m ²
	Specific mass flow	15 l/m ² h

2.2.3 Heat exchanger of collector loop

No heat exchanger

2.2.4 Pipes between Collector and Storage:

Model: One Type 31 for hot side and one Type 31 for cold side

Pipes: Inner diameter: 0.014 m Total Length: 30 m

INSULATION: THICKNESS 20 MM (4.275 W/M²-K) THERMAL CONDUCTIVITY: 0.042 W/M-K**2.2.5 Control of the collector loop**

Type 2

Reason	Sensor	Off-Criteria	Hyst.
Upper dead band (Udb)	Collector temperature (T-coll) and storage collector control (St-coll)	On: T-coll>st-coll + Udb	
Lower dead band (Ldb)	Collector temperature (T-coll) and storage collector control (St-coll)	Off: T-coll>st-coll + Ldb	
Collector stagnation	Collector Temperature	Boiling Temp. of fluid as defined by user (TRNEDIT)	10 K
Storage tank protection	Temperature in the uppermost Node of the store	Cut-off Temperature T_in as defined by user (TRNEDIT)	2 K

2.2.6 Storage:

Type: 860 (Specific type)

Storage tank	Total volume	0.83 m ³
	Height	1.8 m
	Store volume for auxiliary	0.0 m ³
	Number of nodes	18
	Media:	Water
	Insulation thickness, thermal conductivity	15 cm, 0.042 W/m-K
	Start $\Delta\theta$, hysteresis, Collector loop	7 K, 3 K

Relative heights of store doubleports, heat exchangers and temperature sensors

<i>Doubleport description</i>	<i>relative height</i>	<i>Dp Nr.</i>
inlet of collector loop	0.333	1
outlet of collector loop	0.0	1
inlet of DHW loop	0.0	2
outlet of DHW loop	1	2

<i>Heat exchanger description</i>	<i>relative height</i>	<i>Hx Nr.</i>
inlet of auxiliary for DHW	1	1
outlet of auxiliary for DHW	0.778	1
inlet of Space Heating loop	0.555	2
outlet of Space Heating loop	0.333	2

<i>Sensor description</i>	<i>relative height</i>
Collector control temperature	user defined (TRNEDIT)
Storage protection temperature	0.75
Auxiliary On/Off temperature	0.861

2.2.7 Auxiliary boiler:

Type 370 – Specific Type, data defined by Heimrath, Haller 2007

Nr.	Description	Value(s)
1	temperature set point for auxiliary DHW to store	$T_{aux,set}$ [°C] set by the user (TRNEDIT)
2	Fuel type	2 (natural gas high)
3	ambient temperature at location of boiler	15 [°C]
4	standby temperature	35 [°C]
5	hysteresis for standby temperature	5 [K]
6	maximum water temperature	90 [°C]
7	nominal power	set by the user (TRNEDIT)
8	air surplus (lambda) value	1.2
9	lowest modulation factor	0.12 (ELCO THISION)
10	mass of the boiler water	3.2 [kg]
11	temperature difference between flue gas and return temperature of water	10 [K]
12	radiation losses	3.5 [%]
13	standby losses as percent of nominal power	0 [%]
14	simulation mode	0 (original)
15	number of nodes in heat exchanger	10
16	exhaust gas temperature at entrance of heat exchanger	1000
17	minimum flow on water side	=MIN(800,Mdot80+200)

Type 889 – Specific type is used as auxiliary controller.

Description	Value(s)
room set temperature	19.5 [°C]
ambient design temperature	taken from dataset for location chosen by the user
set temperature for auxiliary heat supplied to store for DHW preparation with dead band	54 ±3 [°C]
nominal mass flow rate for DHW preparation	= MIN(800,Mdot80+200)

2.2.8 Building

Type56 – One Zone Model, (Geometric Data defined in defined by Heimrath, Haller 2007)

2.2.9 Heat distribution

Radiators Type 362

Nr.	Description	Value(s)
1-5	length of supply pipe and exhaust pipe respectively	not used
6	specific heat of fluid	$C_{p_{Wat}} = 4.19$ [kJ/kg.K]
7	mass flow rate of fluid	\dot{M}_{dot80}
8	radiative fraction of total emitted power	0.35
9	nominal power of radiator	$Q_{Rd,n}$
10	radiator exponent	$n_{Rd} = 1.3$
11	thermal capacitance of radiator	1150 [kJ/K]
12	initial temperature (Data defined in defined by Heimrath, Haller 2007)	55 [°C]

The mass flow in the radiators is constant.

2.2.10 Draw-Off loop

Type 805. The overall heat transfer coefficient of the heat exchanger has been set to a value which results in a return temperature of 15 °C to the store in the case of 10 °C cold water temperature, 60 °C temperature from store and a secondary mass flow rate (DHW) of 1200 kg/h.

Nr.	Description	Value(s)
1,2	specific heat capacity of primary and secondary side fluid respectively	$C_{p_{Wat}}$
3	maximum allowed flow rate on primary (hot) side	1400 [kg/h]
4	temperature set point for secondary side outlet	45 [°C]
5	overall heat transfer coefficient UA of heat exchanger	19200 [kJ/hr.K]

2.3 Validation of the system model

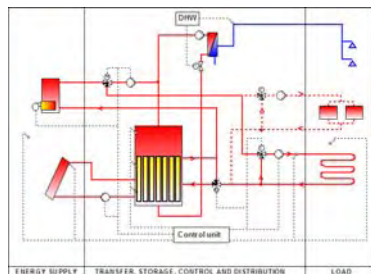
There is no measurement to validate the simulated system. The solar, DHW and heating loops keep the reference template configuration. The auxiliary, the storage tank and the controller are new systems.

3 Simulations for testing the library and the accuracy

The used simulation time step is 1/20 (or 1/30) h and the tolerances for convergence and integration are 0.003.

4 Sensitivity Analysis and Optimization

4.1 Presentation of results



PCM and water storage tank with decentralised auxiliary boiler (SCS-Switzerland)

Main parameters (optimised Base Case (BC)):			
Building:	SFH 30	Storage Volume:	0.83 m ³
Climate:	Zurich	Storage height	1.8 m
Collectors area:	15 m ²	POSITION OF AUXILIARY IN/OUTLET: DHW:	1/0.778
Collector type:	Standard Flat Plate	Relative position of in/outlets: DHW: Solar :	0/1 0.333/0
Specific flow rate (Collector)	15 kg/m ² -h	POSITION OF SPACE HEATING IN/OUTLET:	0.555/0.333
Collector azimuth/tilt angle	0 / 45°	Thermal insulation	15 cm
Collector upper/lower dead band	7 / 3 °K	Nominal auxiliary heating rate	9.5 kW
Storage medium	Water	DHW set point temperature (in storage tank) / dead band	54 °C / ± 3°
Simulation parameter:		Storage nodes	46.1 l/Node 18 nodes
Time step	1/20 h	Tolerances Integration Convergence	0.003 / 0.003

Summary of Sensitivity Parameters			
Parameter	Variation	¹ Variation in $f_{sav,ext}$	
Base Case (BC)	-	54.02%	
Collector size [m ²] (fixed store size (0.83 m ³))	10-25	48.48 – 59.53%	Figure 2
Storage medium	Water/Water+RT2 7 /Water+RT35 /Water+RT42	54.02 – 55.13%	Figure 3
Store Size [m ³] (fixed collector area of 15 m ²)	0.83 – 2.50	54.68 – 53.38%	Figure 4
Collector Azimuth [°] (fixed tilt of 45°)	-90 - 90	43.37 – 54.02%	Figure 5
Collector Tilt [°] (fixed azimuth of 0°)	15 – 90	49.05 – 54.53%	Figure 6
Specific Collector flow rate [kg/m ² -h]	15 - 45	53.44 - 54.02%	Figure 7
Collector Controller dT _{stop} [K]	1 - 5	53.93 – 54.18%	Figure 8
Collector Controller dT _{start} [K]	5– 12	53.79 – 54.02%	Figure 9
Climate (30 kWh MFH – Base Case (BC))	Bar./Mad. / Zur. / Stock.	96.3% / 89.6% / 54.0%/ 44.7%	Figure 10
DHW Heat Exch. UA [%] (variation from BC value - 5'330 W/K)	-50 - +100	52.89 – 54.27%	Figure 11
DHW thermostat temperature [°C]	50 - 60	53.05 – 54.38%	Figure 12
DHW dead band [K]	±2 - ±5	53.98 – 54.08%	Figure 13

¹ The variation if fractional savings indicated in the table does not represent the values for the extremes of the range, rather the minimum and maximum values for the range indicated.

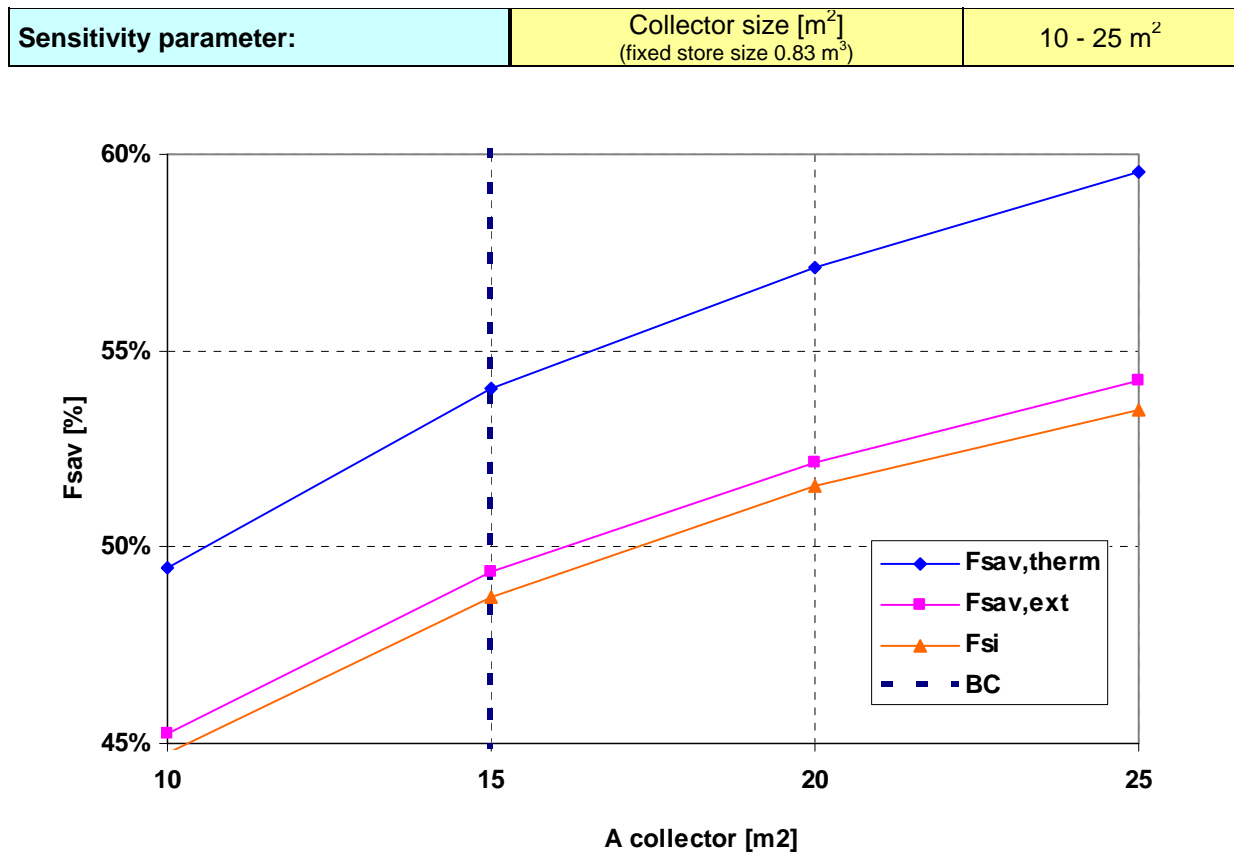


Figure 2. Variation of fractional energy savings vs collector size for a fixed storage volume of 0.83 m³.

Differences from Base Case (BC)

None

Description of Results

As expected, the increase of collector area increases the f_{save} . There are very few penalties occurred for the settings, so that $f_{si} \approx f_{sav,ext}$

Comments

With a small store volume, it is not consistent to run simulation with too high collector area.

Sensitivity parameter:	Storage medium	Water/Water+RT27 /Water+RT35 /Water+RT42
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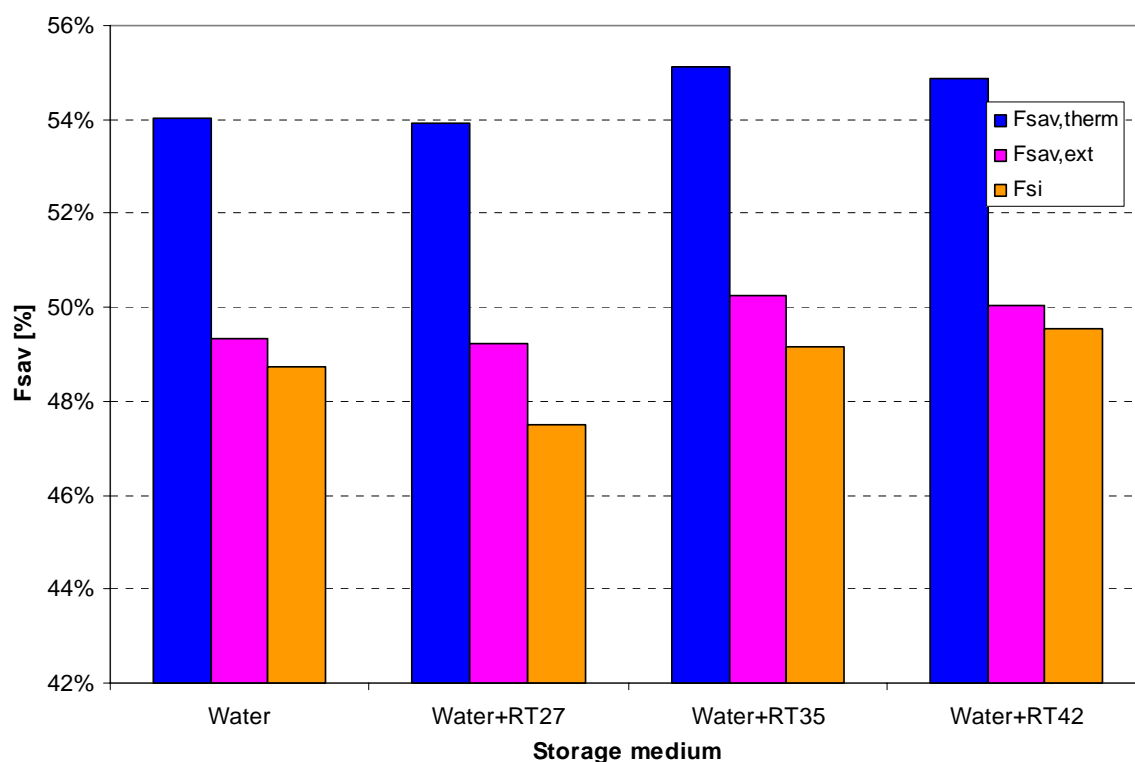


Figure 3. Variation of fractional energy savings for different heat storage compositions.

Differences from Base Case (BC)

Bulk elements of phase change materials are plunge in the water tank. The container diameter is 50mm. There is no PCM in the upper part of the tank to avoid DHW penalty. In fact the heat exchange between water and PCM module is not high enough to provide power for DHW draw-off

Description of Results

With PCM, the performance improvement is very low, compare to the storage tank with only water. There is an optimum due to the correlation between the phase change temperature and the space heating temperature.

Comments

It seems difficult to use this kind of PCM with a solar combisystem to get a big improvement. As well, the extra cost is a limitation with this material for this low gain.

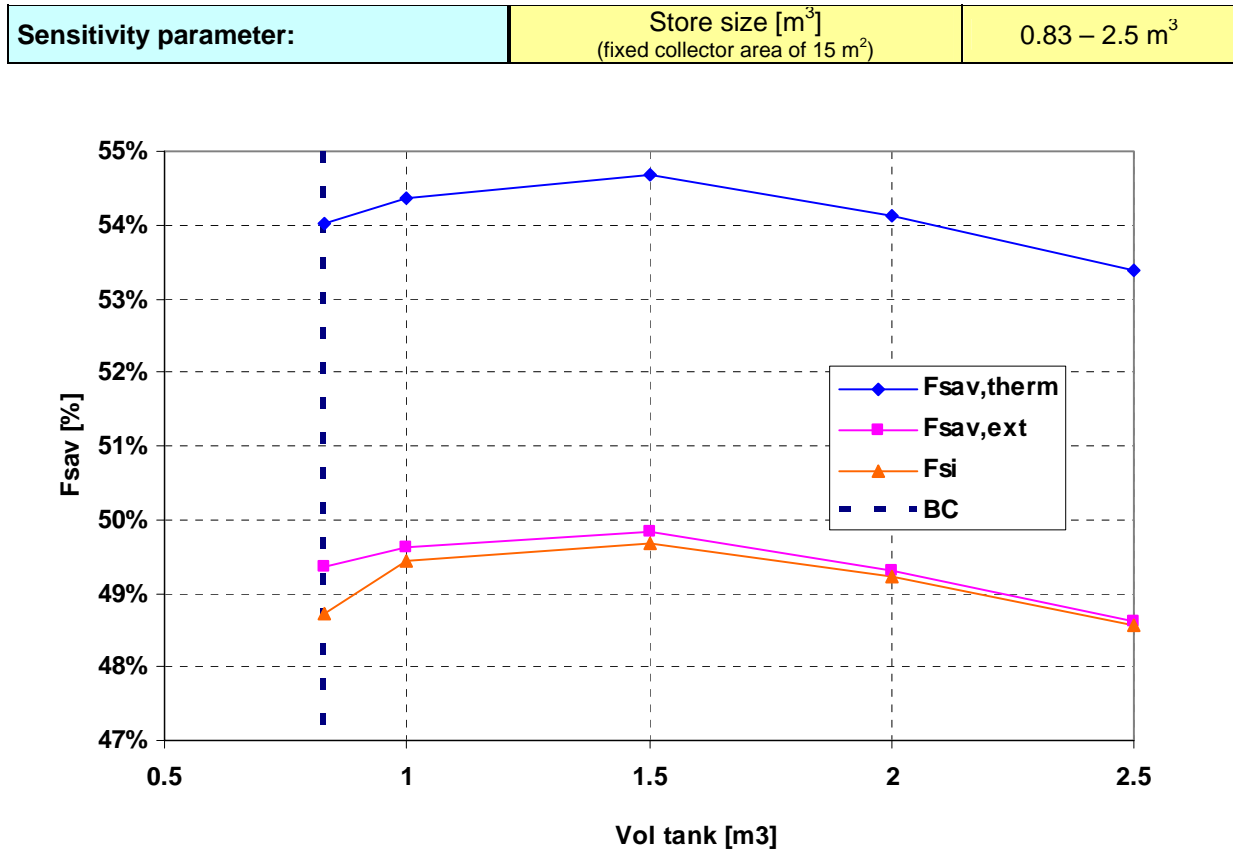


Figure 4. Variation of fractional energy savings vs storage tank volume for a fixed collector area of 15 m².

Differences from Base Case (BC)

- The DHW volume heated by the auxiliary change proportionally with the volume of the tank.
- The sensors for the thermostats controlling the store charging were always on the same height, at the outlet of heater.
- The height of the store is always the same (1.8 m).
- The insulation is the same for the different volume.

Description of Results

The optimum is around 1.5 [m³] in Zürich, with 15 [m²] of collectors and the 30 [kWh.m².a] building. The base case seems the limit before increase the DHW penalty.

Comments

Even the base case is not the optimum; this storage volume allows going through standard door in single family house.

Sensitivity parameter:	Collector azimuth [°] (fixed tilt of 45°)	-90 – 90°
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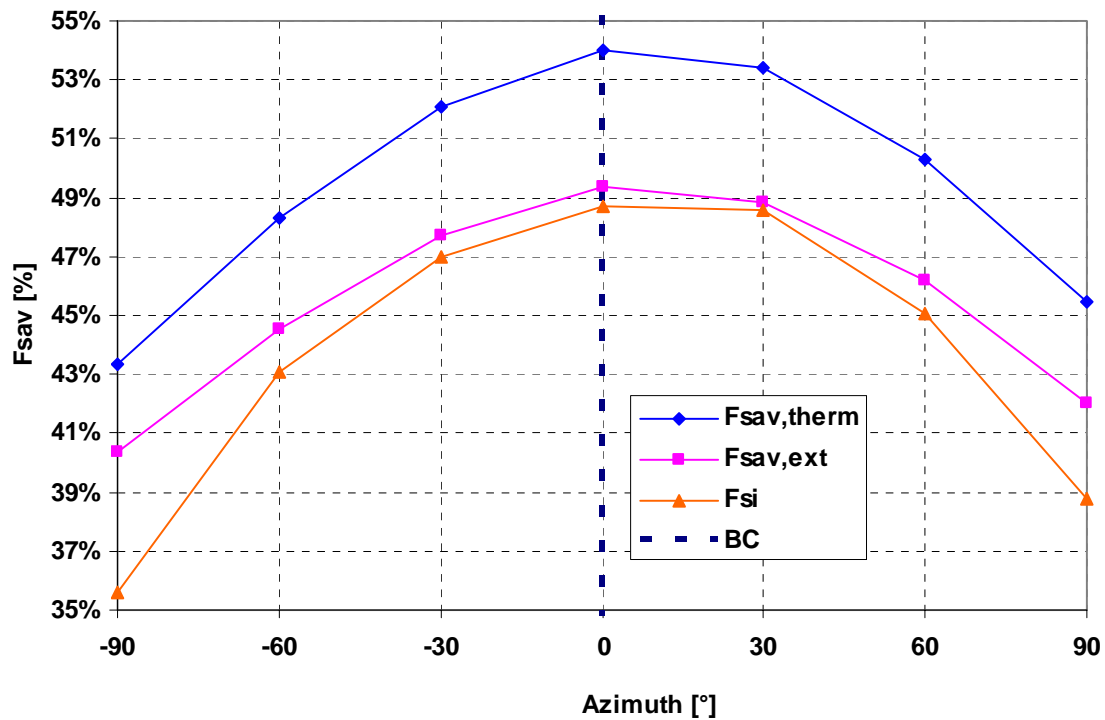


Figure 5. Variation of fractional energy savings vs collector azimuth for a fixed tilt angle of 45°.

Differences from Base Case (BC)

None

Description of Results

Here F_{sav} shows an optimum with a small shift in the west.

Comments

The value for -90° and $+90^\circ$ are extreme.

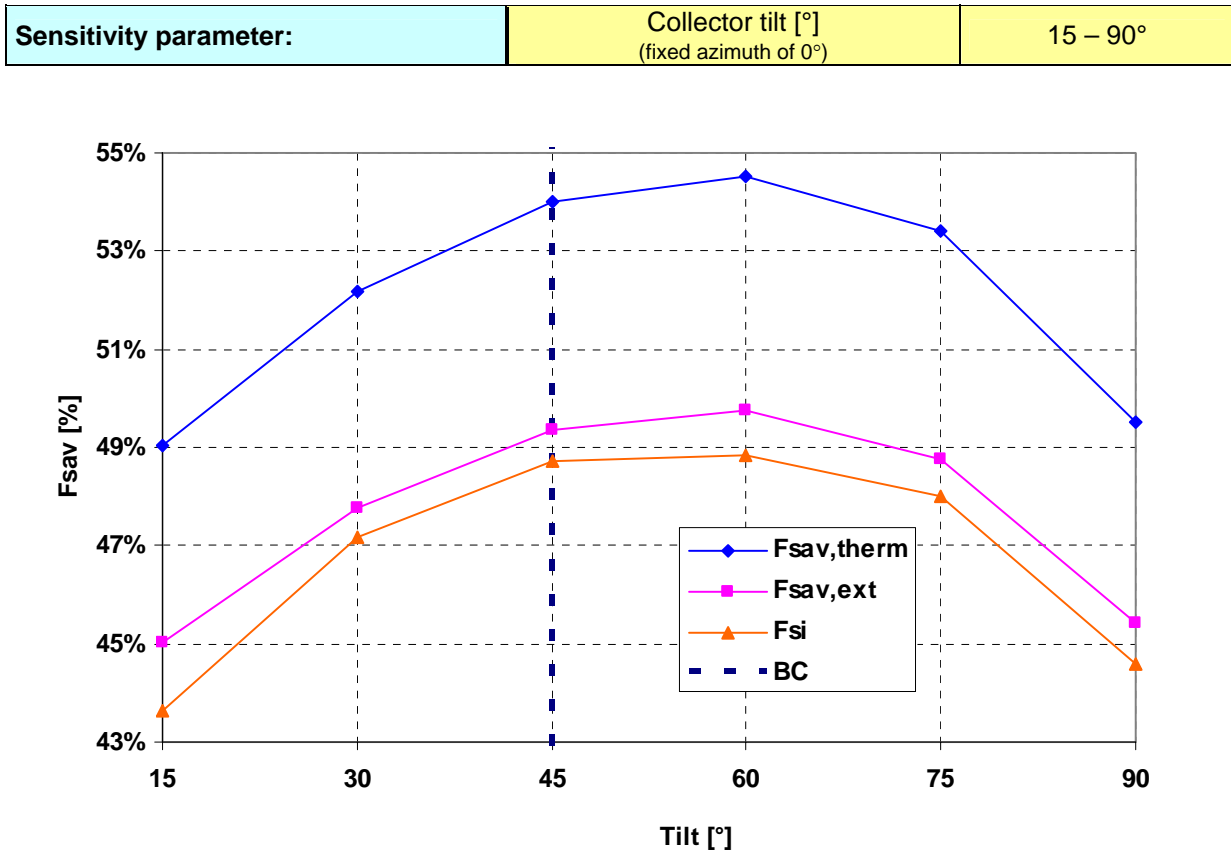


Figure 6. Variation of fractional energy savings vs collector tilt, for a fixed azimuth angle of 0°.

Differences from Base Case (BC)

None

Description of Results

In this case, the F_{sav} shows an optimum around 60° tilt. During winter time the sun height is low and we need to tilt the collector plan more than 45°.

Comments

The common tilt angle of roof is between 30 to 45°. It is possible to put solar collector on a wall or a bank to get an optimum angle.

Sensitivity parameter:	Specific Collector flow rate [$\text{kg}/\text{m}^2\text{-h}$]	15 – 45
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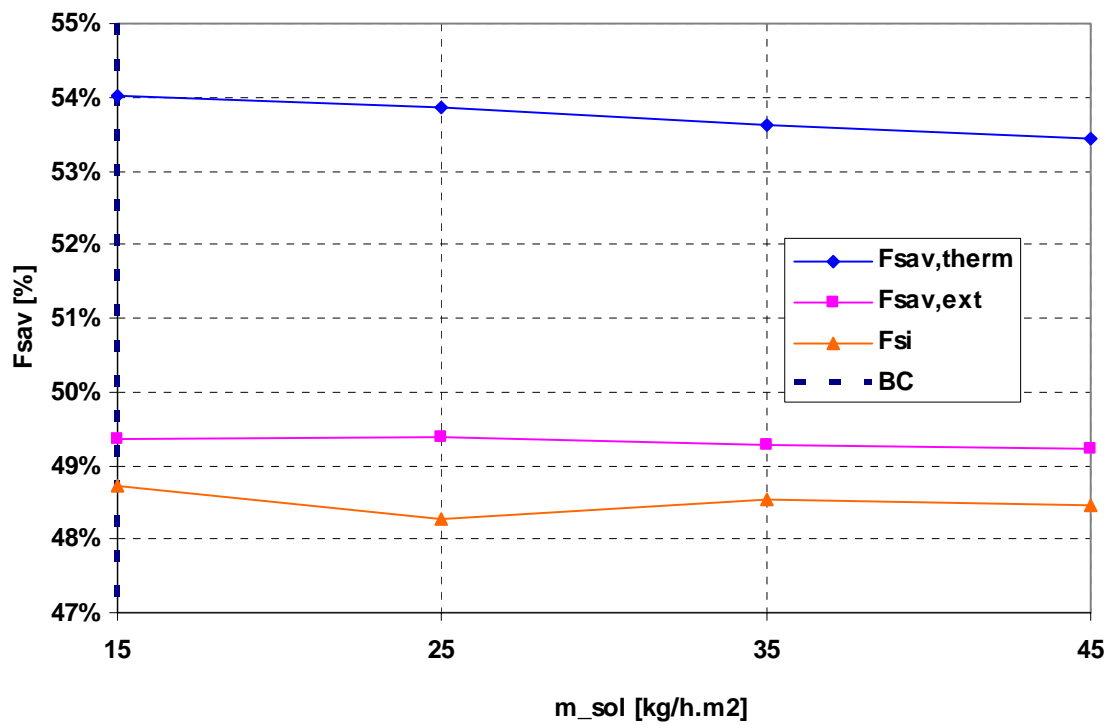


Figure 7. Variation of fractional energy savings vs specific collector flow rate.

Differences from Base Case (BC)

None

Description of Results

The store charge flow affects slightly the annual savings.

Comments

None

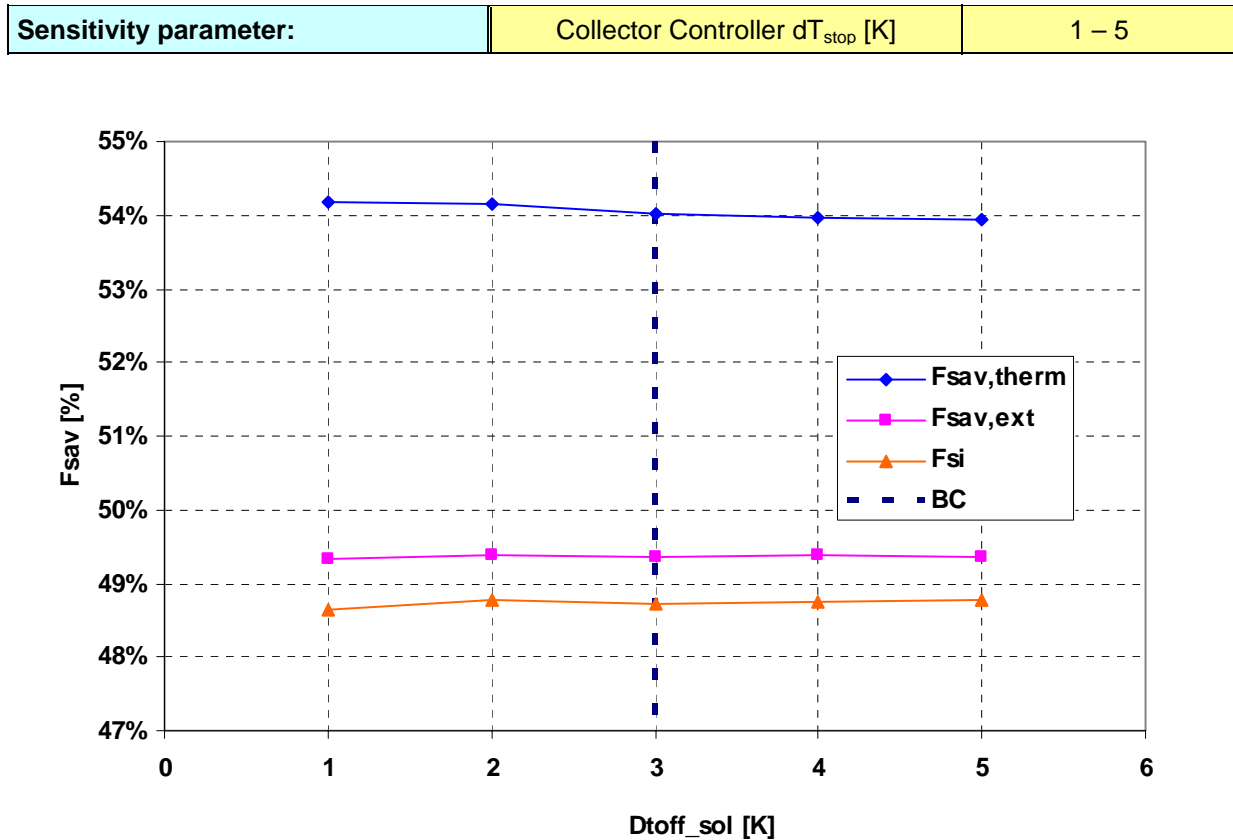


Figure 8. Variation of fractional energy savings vs collector controller dT_{stop} .

Differences from Base Case (BC)

Dt_{start} unchanged.

Description of Results

The dT_{stop} affects slightly the annual savings.

Comments

None

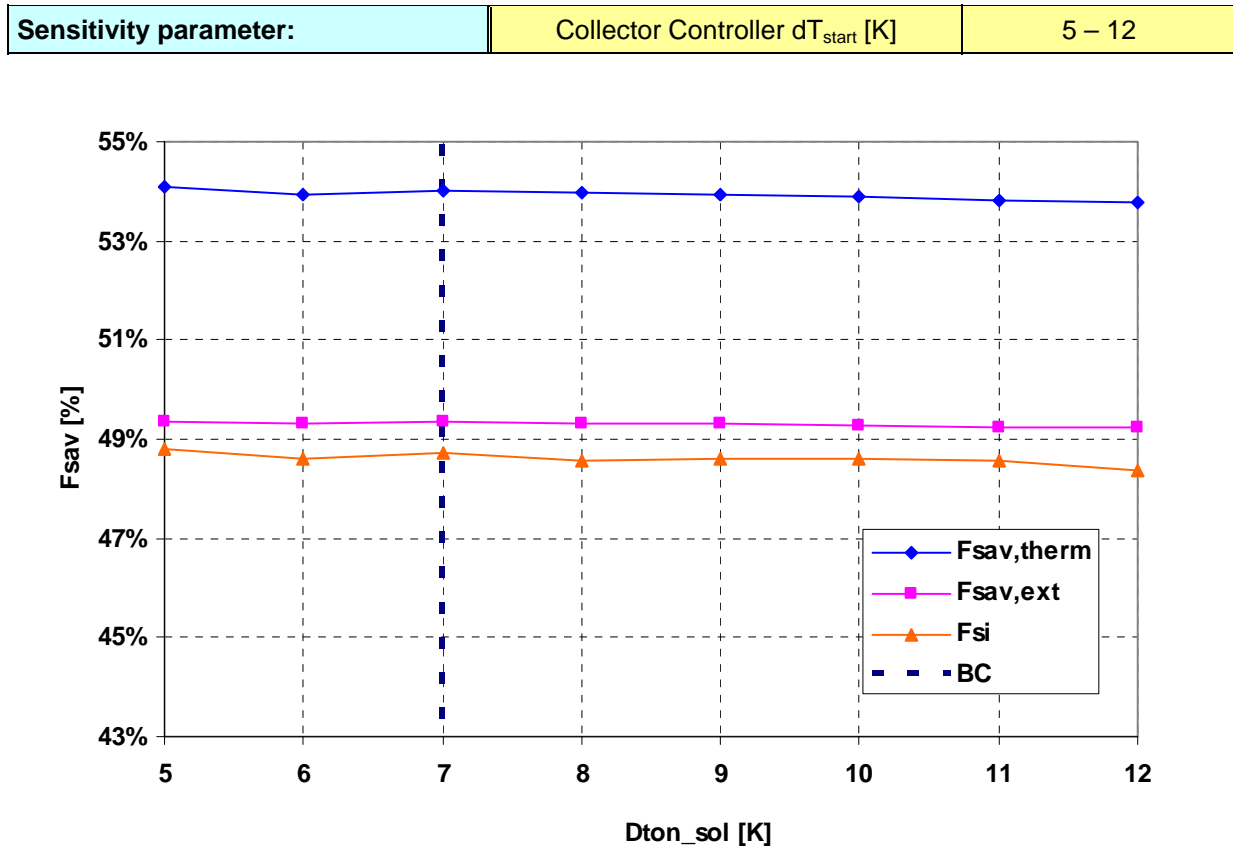


Figure 9. Variation of fractional energy savings vs collector controller dT_{start} .

Differences from Base Case (BC)

Dt_{stop} unchanged.

Description of Results

As for dT_{stop} , the dT_{start} affects the annual savings slightly.

Comments

None

Sensitivity parameter:	Climate (30 kWh MFH – Base Case (BC))	Bar./Mad. / Zur. / Stock.
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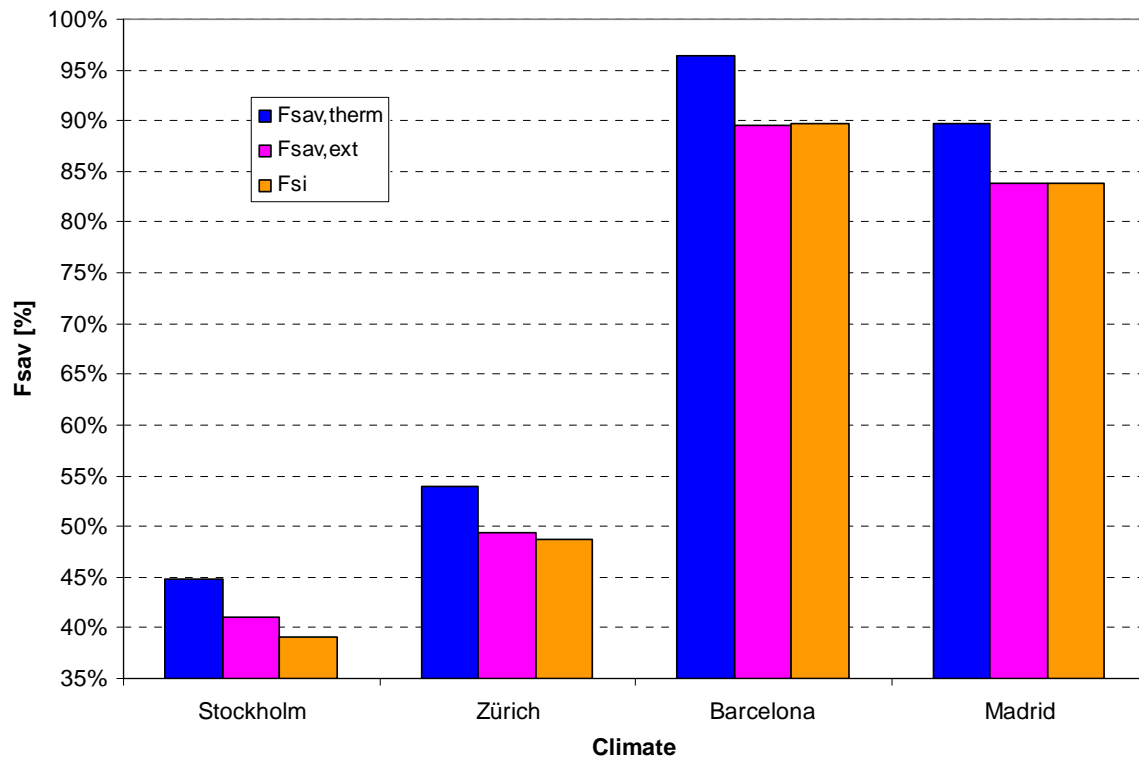


Figure 10. Variation of fractional energy savings for different climates.

Differences from Base Case (BC)

None

Description of Results

None

Comments

It seems that there are two kind of climate. There is not lot of difference between Stockholm and Zürich or Barcelona and Madrid.

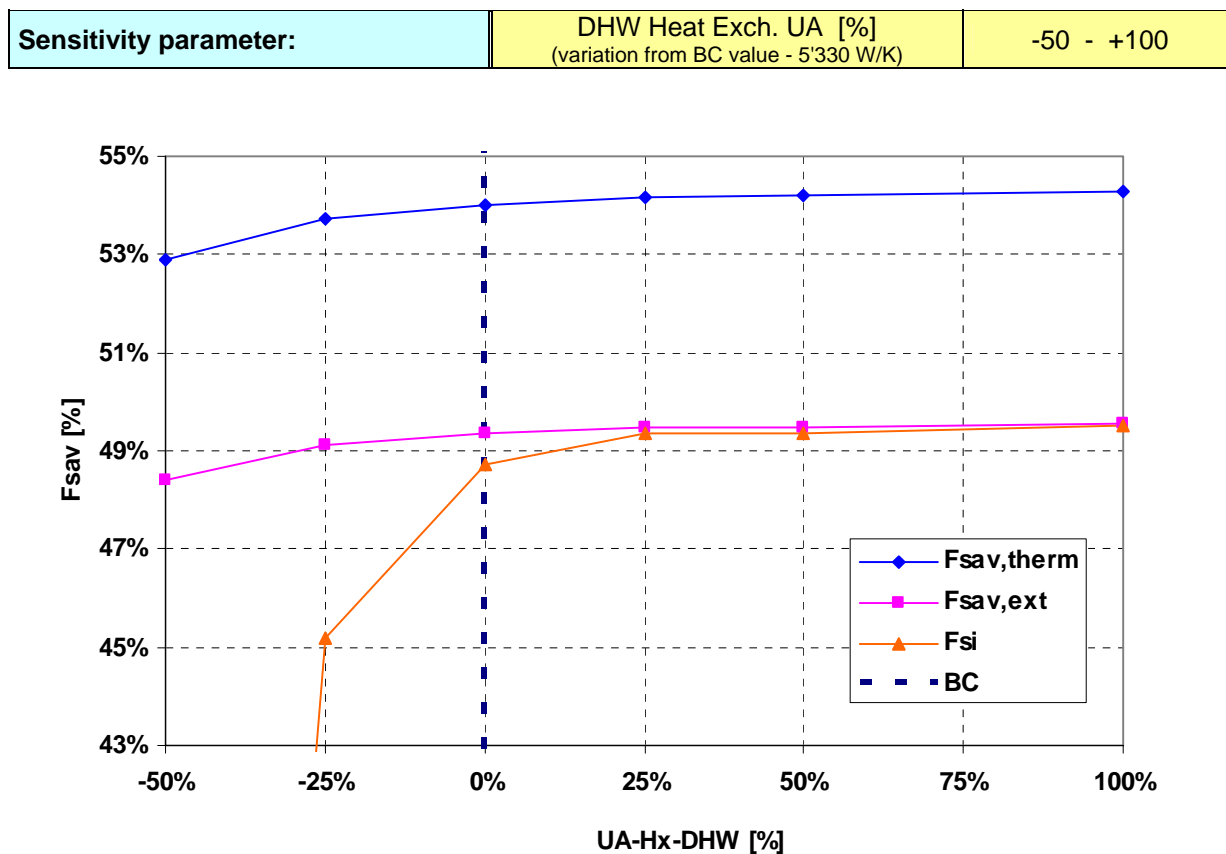


Figure 11. Variation of fractional energy savings vs UA value of the DHW heat exchanger.

Differences from Base Case (BC)

None

Description of Results

Just under the base case, the DHW penalty is very high.

Comments

The UA value is nearly optimised in the base case.

Sensitivity parameter:	DHW thermostat temperature [°C]	50 - 60
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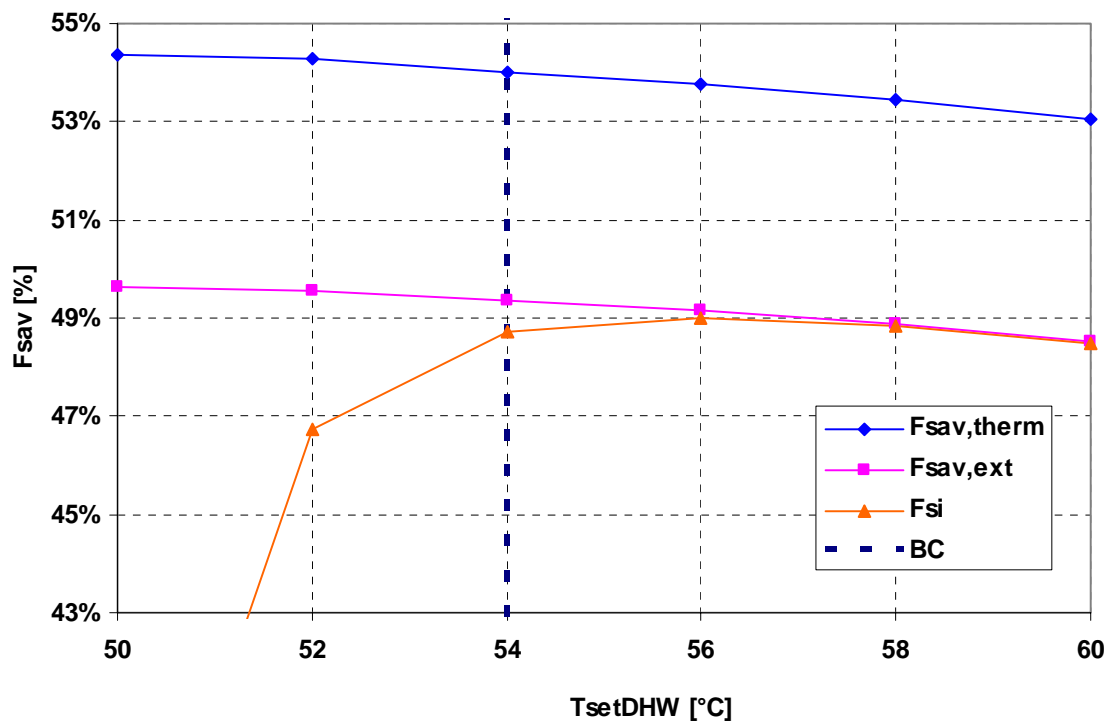


Figure 12. Variation of fractional energy savings vs DHW thermostat temperature.

Differences from Base Case (BC)

None

Description of Results

Just under the base case value, the DHW penalty is very high.

Comments

The thermostat temperature value is optimised in the base case. If we increase the thermostat temperature, the F_{si} goes up but the F_{sav} decreases.

Sensitivity parameter:	DHW dead band [K]	±2 - ±5
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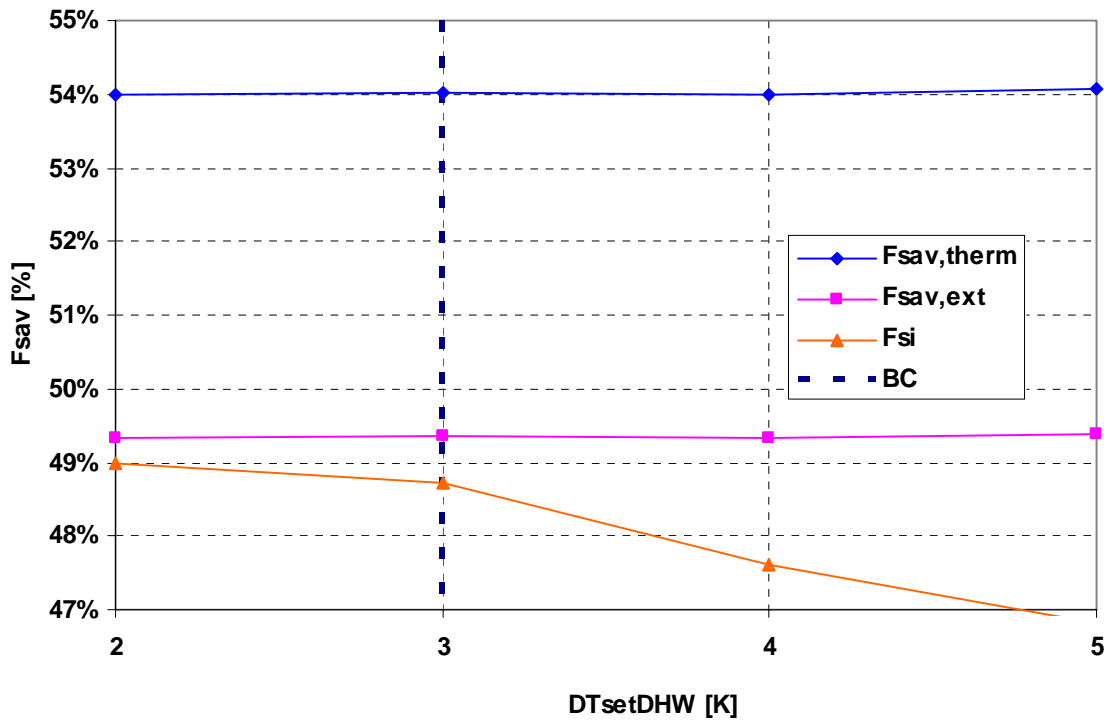


Figure 13. Variation of fractional energy savings vs DHW dead band of the thermostat temperature.

Differences from Base Case (BC)

None

Description of Results

Above the base case value, the DHW penalty increase.

Comments

To increase the F_{sav} , it is possible to decrease the dead band value. But its increase the number of start-up burner.

4.2 Definition of the optimized system

In an earlier phase of the project, experimental tests have been undertaken with a solar combisystem in which aluminium containers filled with PCM were placed in the storage tank (see C3 report). The results showed a slight improvement of the performance for the storage tank with PCM. These experimental tests confirmed simulation results. This system had two internal heat exchangers and a combustion chamber which took a lot of space. Therefore, the PCM storage tank could be filled with only 12% in volume of PCM. Furthermore, with the integrated burner, the PCM in the upper part of the storage tank is directly heated.

In order to increase the PCM volume, a water tank with no internal components is used. In addition, the external gas boiler doesn't heat the heating part of the tank to keep more heat capacity to the solar gain.

It is also possible to increase the storage volume (Figure 4). But in this case, it should be kept in mind that the tank's dimensions do not fit a common door.

The remaining of this chapter presents the results for this new solar combisystem with and without PCM.

5 Analysis using FSC'

For the optimised system the analysis based on FSC should be carried out for each building. Table 1 to 4 gives the results for the 30 kWh/m².a building. The same simulations have also been undertaken for the four other building types.

Table 1 Results of solar system HEIG-VD-W and HEIG-VD-PCM simulations for the climate Zurich

Building Climate	SFH 30 Zurich							
V_{Store} [m ³]	0.83							
Heat storage medium	Water				Water + paraffin RT35			
A_{col} [m ²]	10	15	20	25	10	15	20	25
$Q_{\text{solar,usable,heat}}$ [kWh/a]	5476	6496	7456	8127	5476	6496	7456	8127
E_{aux} [kWh/a]	4661	4243	3956	3734	4582	4140	3840	3615
E_{ref} [kWh/a]	9227	9227	9227	9227	9227	9227	9227	9227
E_{total} [kWh/a]	5829	5390	5094	4869	5755	5294	4983	4752
$E_{\text{total,ref}}$ [kWh/a]	10643	10643	10643	10643	10643	10643	10643	10643
$Q_{\text{in,store}}$ [kWh/a]	4581	4850	5039	5181	4644	4979	5207	5367
$Q_{\text{out,store}}$ [kWh/a]	3537	3718	3852	3959	3593	3826	3994	4112
$Q_{\text{st,aux}}$ [kWh/a]	4717	4301	4016	3796	4625	4184	3875	3655
$Q_{\text{st,coll}}$ [kWh/a]	3340	3822	4140	4379	3428	3951	4310	4563
$Q_{\text{st,dhw}}$ [kWh/a]	3047	3047	3047	3047	3047	3047	3047	3047
$Q_{\text{st,sh}}$ [kWh/a]	4071	4069	4066	4064	4070	4065	4065	4061
Q_{Coll} [kWh/a]	3646	4148	4486	4744	3725	4272	4649	4920
$W_{\text{pump,sol}}$ [kWh/a]	68	61	57	55	69	62	59	57
W_{burn} [kWh/a]	126	123	120	118	125	121	118	116
W_{contr} [kWh/a]	18	18	18	18	18	18	18	18
$W_{\text{pump,SH}}$ [kWh/a]	247	250	253	255	249	253	255	256
$W_{\text{pump,DHW}}$ [kWh/a]	8	8	8	8	8	8	8	8
W_{total} [kWh/a]	467	459	455	454	469	461	457	455
FSC	0.5935	0.7040	0.8081	0.8808	0.5935	0.7040	0.8081	0.8808
FSC'	0.6205	0.7516	0.8765	0.9711	0.6205	0.7516	0.8765	0.9711
$f_{\text{sav,therm}}$	0.4948	0.5402	0.5713	0.5953	0.5034	0.5513	0.5838	0.6083
$f_{\text{sav,ext}}$	0.4523	0.4935	0.5214	0.5425	0.4592	0.5026	0.5318	0.5535
f_{si}	0.4476	0.4872	0.5154	0.5347	0.4521	0.4916	0.5218	0.5446

Table 2 Results of solar system HEIG-VD-W and HEIG-VD-PCM simulations for the climate Stockholm

Building Climate	SFH 30 Stockholm							
V_{Store} [m ³]	0.83							
Heat storage medium	Water				Water + paraffin RT35			
A_{col} [m ²]	10	15	20	25	10	15	20	25
$Q_{\text{solar,usable,heat}}$ [kWh/a]	5563	6737	7454	8170	5563	6737	7454	8170
E_{aux} [kWh/a]	7092	6678	6386	6184	6999	6568	6270	6056
E_{ref} [kWh/a]	12086	12086	12086	12086	12086	12086	12086	12086
E_{total} [kWh/a]	8453	8023	7729	7519	8368	7918	7608	7397
$E_{\text{total,ref}}$ [kWh/a]	13614	13614	13614	13614	13614	13614	13614	13614
$Q_{\text{in,store}}$ [kWh/a]	4681	4966	5175	5309	4755	5086	5302	5464
$Q_{\text{out,store}}$ [kWh/a]	3673	3880	4043	4145	3751	3996	4156	4285
$Q_{\text{st,aux}}$ [kWh/a]	7251	6832	6539	6338	7140	6703	6405	6191
$Q_{\text{st,coll}}$ [kWh/a]	3249	3717	4033	4251	3348	3849	4189	4424
$Q_{\text{st,dhw}}$ [kWh/a]	3127	3128	3129	3129	3127	3128	3127	3128
$Q_{\text{st,sh}}$ [kWh/a]	6467	6464	6465	6462	6467	6463	6459	6461
Q_{Coll} [kWh/a]	3535	4022	4350	4584	3625	4146	4501	4756
$W_{\text{pump,sol}}$ [kWh/a]	64	58	54	52	66	59	56	54
W_{burn} [kWh/a]	143	139	137	135	142	138	136	134
W_{contr} [kWh/a]	18	18	18	18	18	18	18	18
$W_{\text{pump,SH}}$ [kWh/a]	312	316	321	321	314	317	318	323
$W_{\text{pump,DHW}}$ [kWh/a]	8	8	8	8	8	8	8	8
W_{total} [kWh/a]	545	538	537	534	547	540	535	536
FSC	0.4603	0.5575	0.6167	0.6760	0.4603	0.5575	0.6167	0.6760
FSC'	0.4779	0.5880	0.6614	0.7348	0.4779	0.5880	0.6614	0.7348
$f_{\text{sav,therm}}$	0.4132	0.4475	0.4716	0.4884	0.4209	0.4566	0.4812	0.4989
$f_{\text{sav,ext}}$	0.3791	0.4107	0.4323	0.4477	0.3854	0.4184	0.4411	0.4567
f_{si}	0.2999	0.3905	0.4204	0.4332	0.3123	0.3674	0.3824	0.4235

Table 3 Results of solar system HEIG-VD-W and HEIG-VD-PCM simulations for the climate Barcelona

Building	SFH 30					
Climate	Barcelona					
V_{Store} [m ³]	0.83					
Heat storage medium	Water			Water + paraffin RT35		
A_{col} [m ²]	10	15	20	10	15	20
$Q_{\text{solar,usable,heat}}$ [kWh/a]	4353	4353	4353	4353	4353	4353
E_{aux} [kWh/a]	319	159	123	337	178	122
E_{ref} [kWh/a]	4353	4353	4353	4353	4353	4353
E_{total} [kWh/a]	825	634	579	845	655	583
$E_{\text{total,ref}}$ [kWh/a]	6054	6054	6054	6054	6054	6054
$Q_{\text{in,store}}$ [kWh/a]	4313	4462	4527	4439	4588	4646
$Q_{\text{out,store}}$ [kWh/a]	2908	2930	2938	2931	2949	2957
$Q_{\text{st,aux}}$ [kWh/a]	303	155	120	316	169	118
$Q_{\text{st,coll}}$ [kWh/a]	4120	4392	4484	4209	4488	4588
$Q_{\text{st,dhw}}$ [kWh/a]	2828	2828	2828	2828	2828	2828
$Q_{\text{st,sh}}$ [kWh/a]	204	202	202	202	201	201
Q_{Coll} [kWh/a]	4574	4859	4952	4648	4940	5043
$W_{\text{pump,sol}}$ [kWh/a]	76	63	56	77	65	58
W_{burn} [kWh/a]	81	80	80	81	80	80
W_{contr} [kWh/a]	18	18	18	18	18	18
$W_{\text{pump,SH}}$ [kWh/a]	19	20	20	20	20	21
$W_{\text{pump,DHW}}$ [kWh/a]	8	8	8	8	8	8
W_{total} [kWh/a]	202	190	182	203	191	184
FSC	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FSC'	1.1696	1.2855	1.4014	1.1696	1.2855	1.4014
$f_{\text{sav,therm}}$	0.9267	0.9634	0.9718	0.9226	0.9591	0.9719
$f_{\text{sav,ext}}$	0.8638	0.8953	0.9044	0.8605	0.8918	0.9037
f_{si}	0.8663	0.8978	0.9078	0.8630	0.8944	0.9071

Table 4 Results of solar system HEIG-VD-W and HEIG-VD-PCM simulations for the climate Madrid

Building	SFH 30					
Climate	Madrid					
V_{Store} [m ³]	0.83					
Heat storage medium	Water			Water + paraffin RT35		
A_{col} [m ²]	10	15	20	10	15	20
$Q_{\text{solar,usable,heat}}$ [kWh/a]	5190	5341	5341	5190	5341	5341
E_{aux} [kWh/a]	788	554	440	775	537	419
E_{ref} [kWh/a]	5341	5341	5341	5341	5341	5341
E_{total} [kWh/a]	1426	1163	1034	1417	1150	1017
$E_{\text{total,ref}}$ [kWh/a]	7189	7189	7189	7189	7189	7189
$Q_{\text{in,store}}$ [kWh/a]	4718	4913	5010	4874	5082	5185
$Q_{\text{out,store}}$ [kWh/a]	3317	3402	3450	3380	3471	3524
$Q_{\text{st,aux}}$ [kWh/a]	783	555	442	760	530	412
$Q_{\text{st,coll}}$ [kWh/a]	4426	4748	4896	4538	4878	5041
$Q_{\text{st,dhw}}$ [kWh/a]	2978	2978	2978	2978	2978	2978
$Q_{\text{st,sh}}$ [kWh/a]	876	874	872	874	872	871
Q_{Coll} [kWh/a]	4863	5207	5356	4958	5315	5487
$W_{\text{pump,sol}}$ [kWh/a]	77	65	59	78	66	61
W_{burn} [kWh/a]	86	85	84	85	84	83
W_{contr} [kWh/a]	18	18	18	18	18	18
$W_{\text{pump,SH}}$ [kWh/a]	66	68	69	68	69	70
$W_{\text{pump,DHW}}$ [kWh/a]	8	8	8	8	8	8
W_{total} [kWh/a]	255	244	238	257	145	239
FSC	0.9717	1.0000	1.0000	0.9717	1.0000	1.0000
FSC'	1.1081	1.2294	1.3240	1.1081	1.2294	1.3240
$f_{\text{sav,therm}}$	0.8524	0.8964	0.9176	0.8548	0.8994	0.9215
$f_{\text{sav,ext}}$	0.8016	0.8383	0.8562	0.8029	0.8401	0.8586
f_{si}	0.8030	0.8388	0.8586	0.7953	0.8327	0.8593

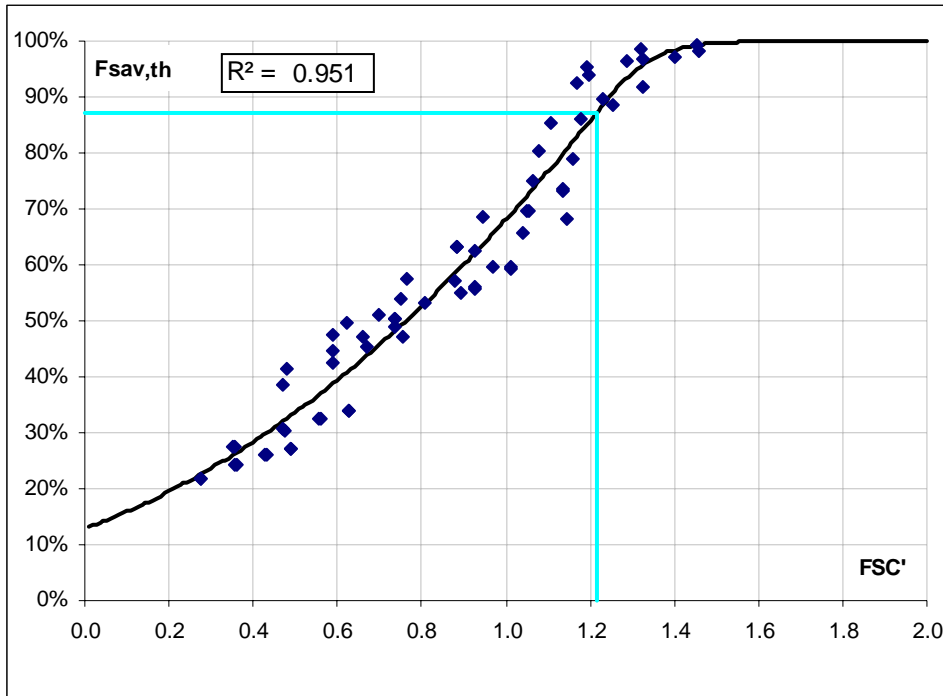


Figure 14. Water system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building).

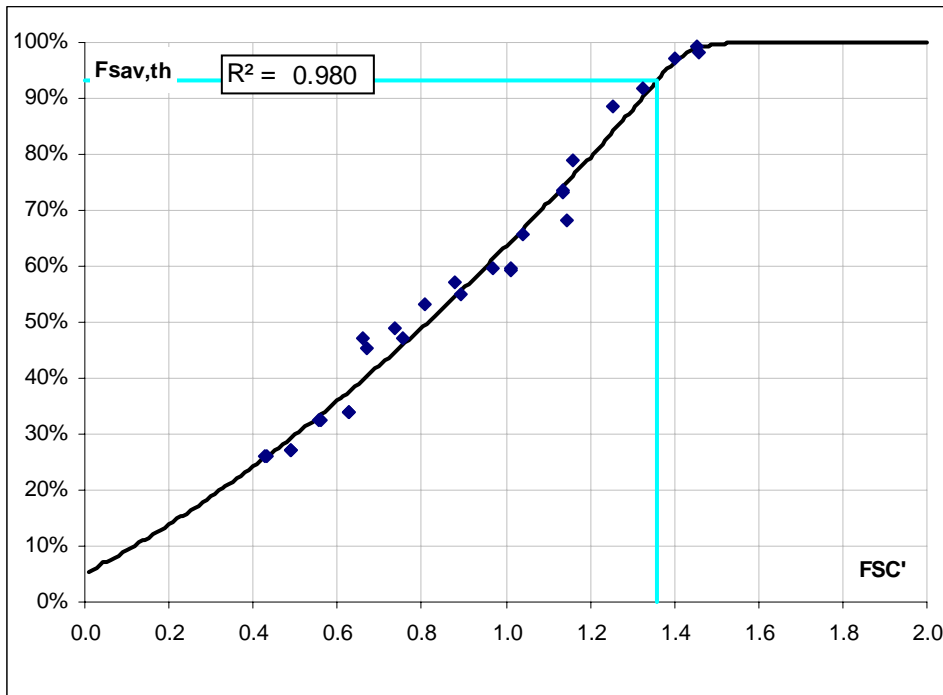


Figure 15. Water system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 33.2 and 45.1 l/m² collector.

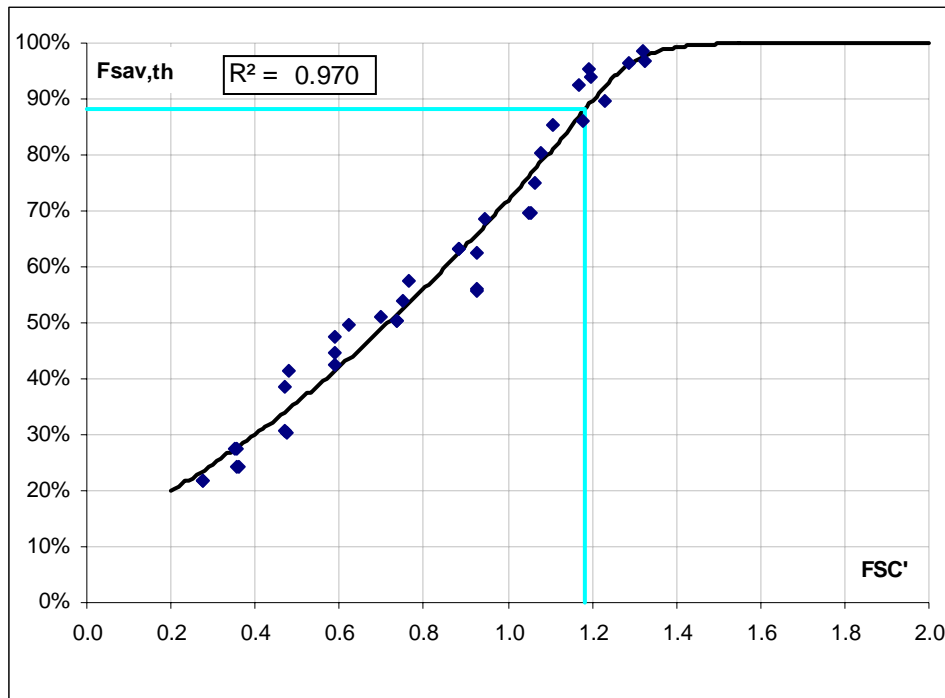


Figure 16. Water system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 55 and 83 l/m² collector.

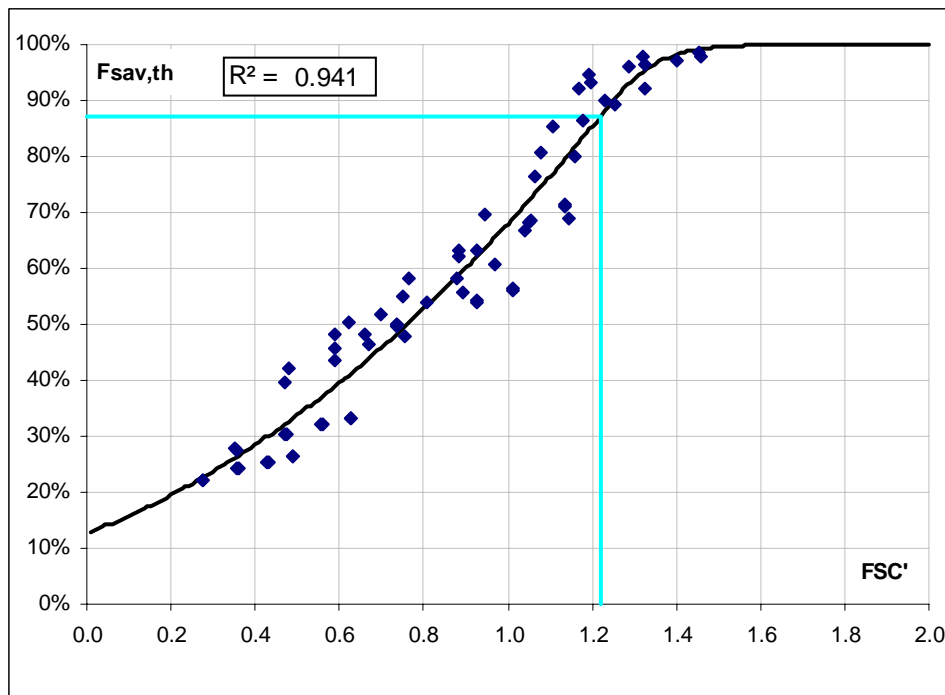


Figure 177. Water + PCM system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building).

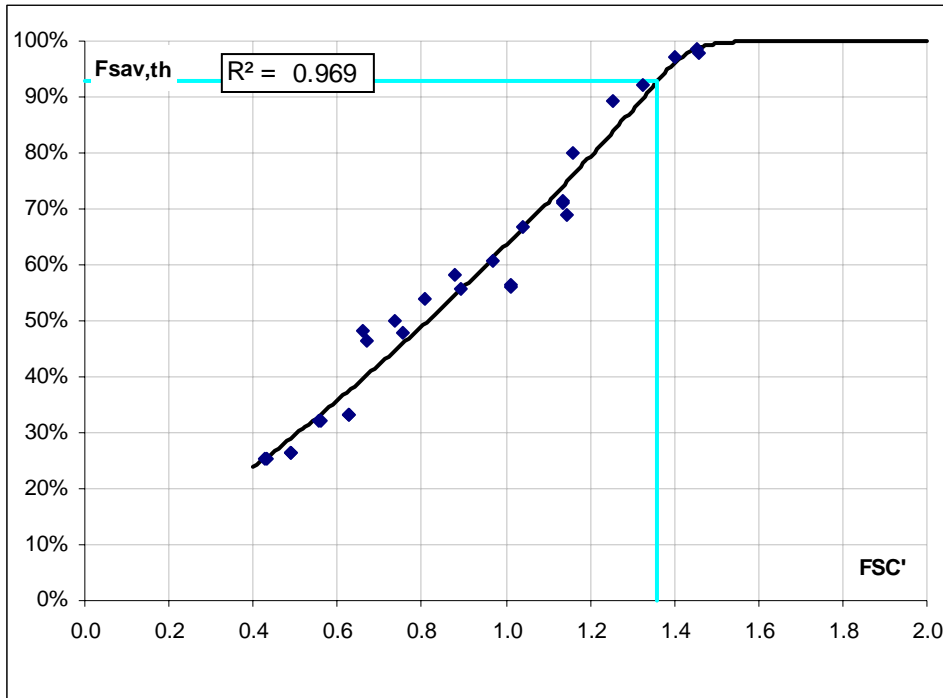


Figure 188. Water + PCM system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 2,7 and 3,4 kWh/m² collector.

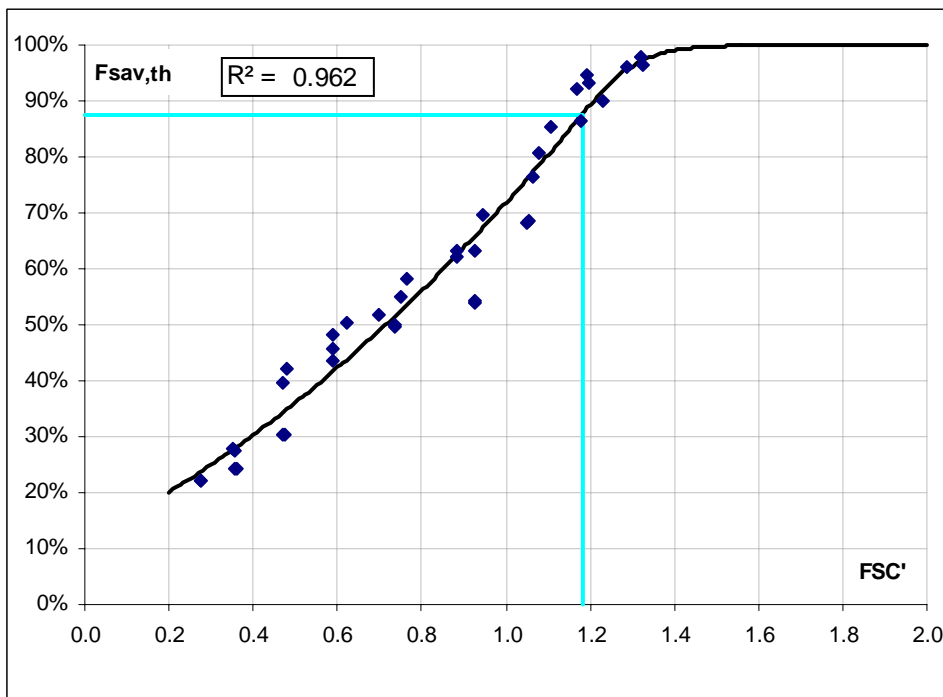


Figure 199. Water + PCM system, variation of thermal fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 4,5 and 6,7 kWh/m² collector.

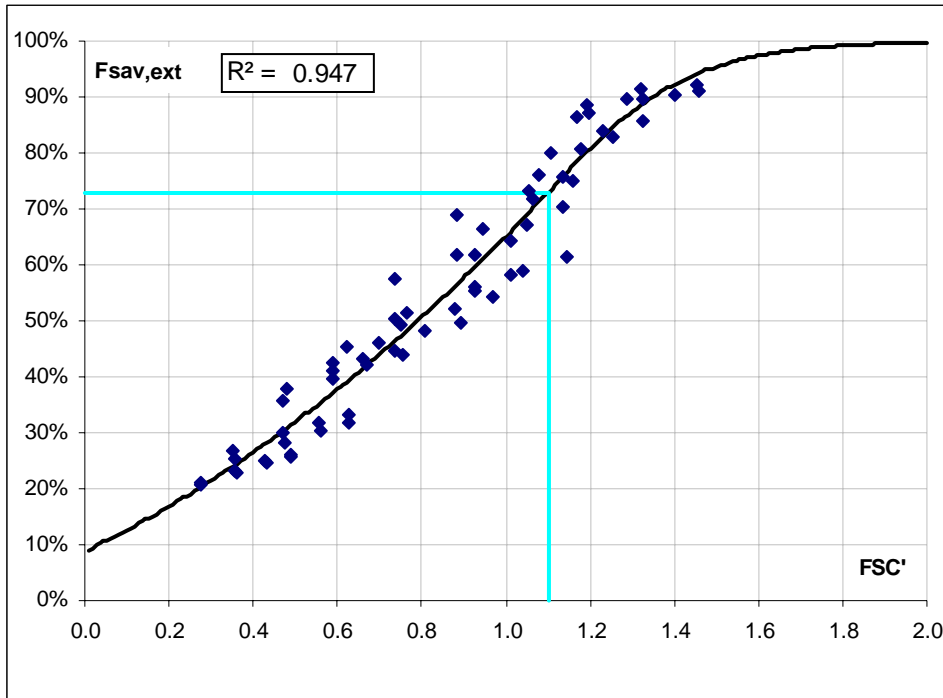


Figure 20. Water system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building).

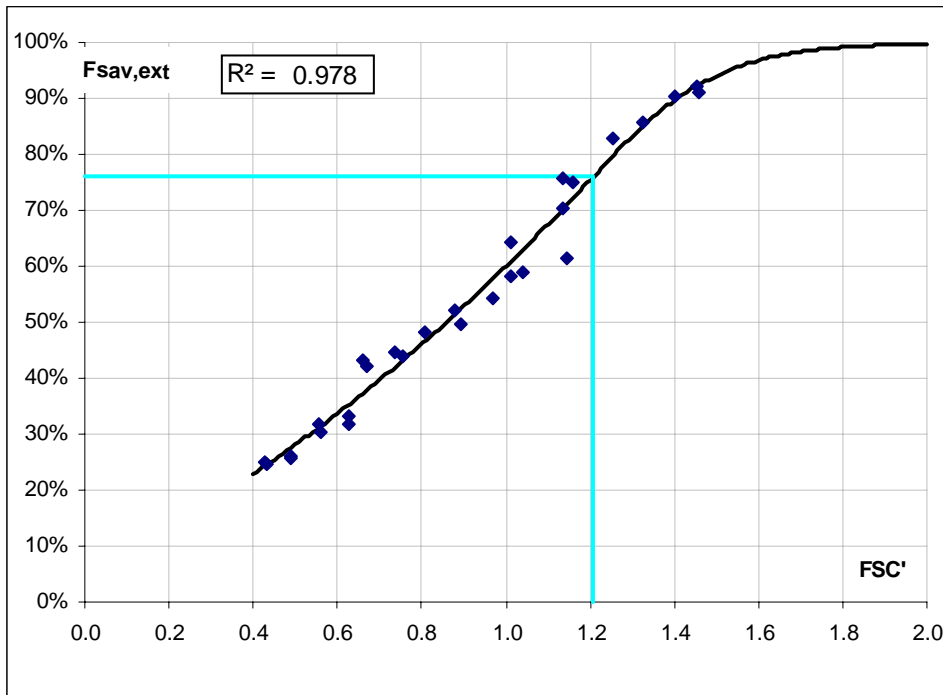


Figure 21. Water system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 33.2 and 45.1 l/m² collector.

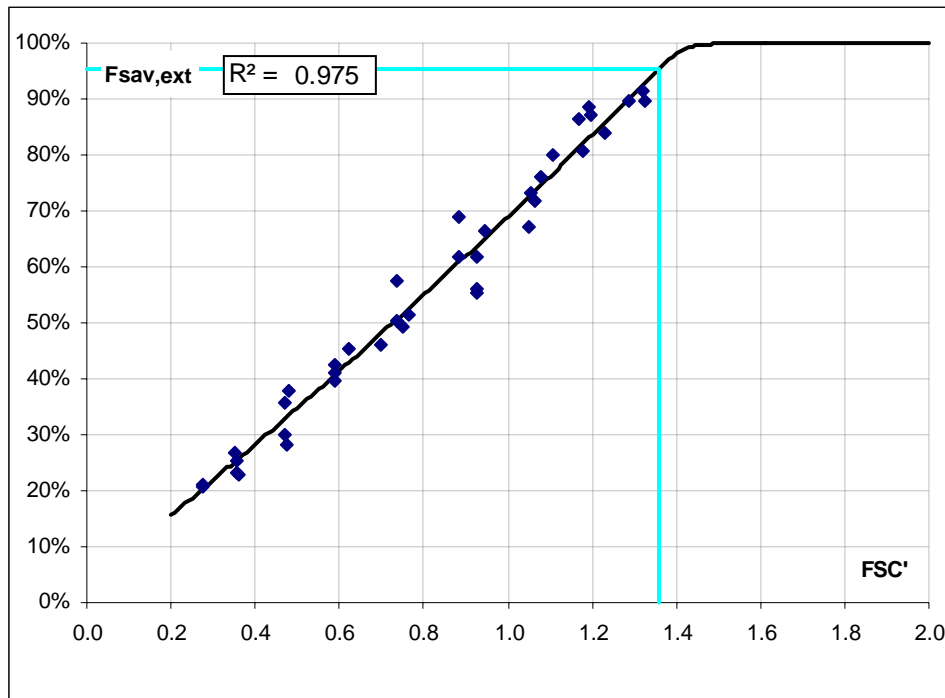


Figure 22. Water system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 55 and 83 l/m² collector.

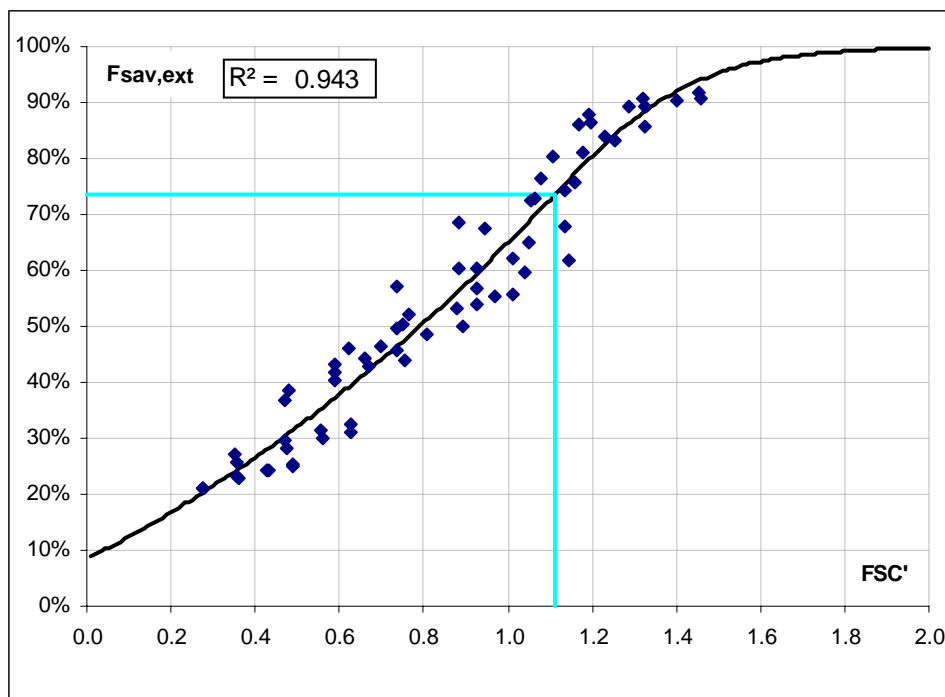


Figure 23. Water + PCM system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building).

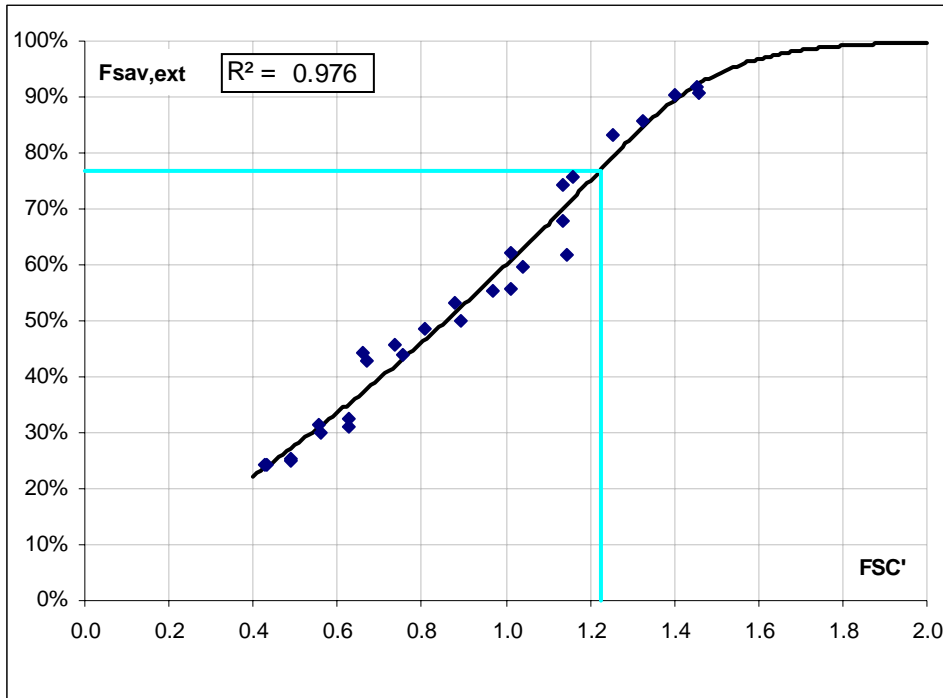


Figure 24. Water + PCM system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 2,7 and 3,4 kWh/m² collector.

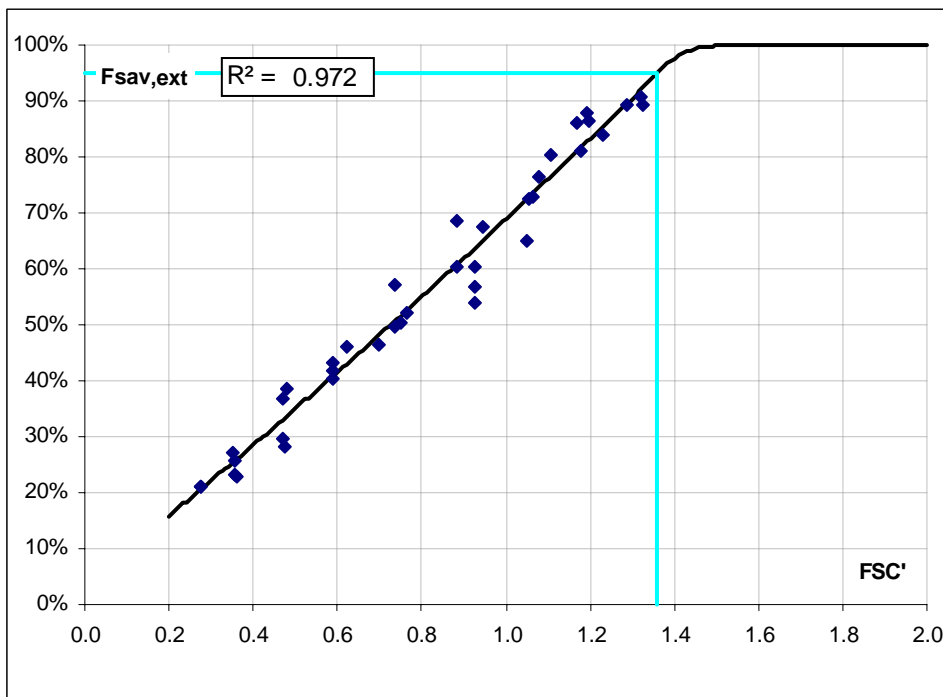


Figure 25. Water + PCM system, variation of extended fractional energy savings with the fractional solar consumption (FSC') for 4 climates (Zürich, Stockholm, Barcelona and Madrid) and five loads (15, 30, 60, 100 and 100n kWh/m²a single family building) with a storage ratio of 4,5 and 6,7 kWh/m² collector.

6 Lessons learned

6.1 Concerning simulation

It has been noticed, that the energy balance calculation is very important. In the first simulations, the global energy balance was good. In the latest simulations, where different configurations were analysed, it has been noticed that the energy was not balanced especially on the auxiliary loop. The difference is between 0 to 3 %.

In order to find the source of the mistakes, the storage tank, the auxiliary loop and the specific controller type has been tested separately.

- The type 60 "storage water tank" the energy balance was incorrect. It has been fixed in our Type 860 derived from type 60.
- The specific controller Type 889 has shown different behaviour between TRNSYS15 and TRNSYS16.

With these problem solved, the performances presented in Zurich, which showed an improvement between 6 to 8 %, are in fact less than 3%.

The energy balance of the type 860 (Type60+PCM) has shown a dependency to the inlet and outlet position. In the simulations presented in this document, the inlet and outlet position have been selected to avoid this problem, but we could not optimise these positions.

6.2 Concerning the system

It should be reminded that the proposed system has been analysed only from the simulation side, where we compare a water tank storage filled only with water or filled with water + PCM (paraffin RT35).

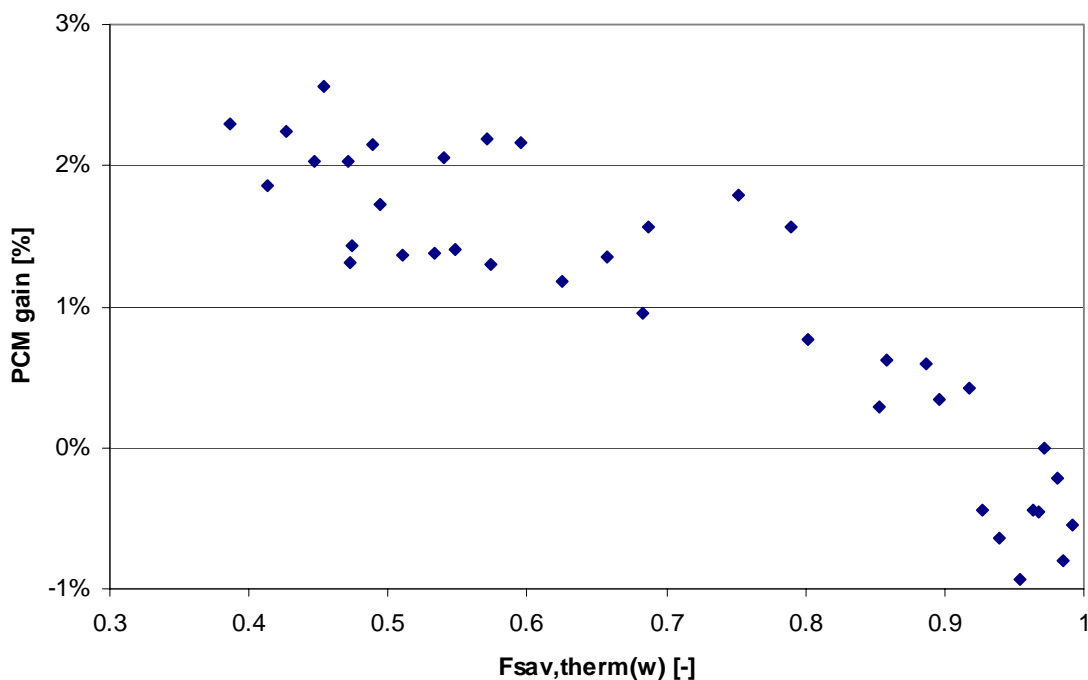


Figure 26. Difference between pure water and water + PCM system. The PCM gain = $F_{sav,therm(W+PCM)}/F_{sav,therm(W)} - 1$

To evaluate the impact of the PCM on the performances, it is possible to define the energy gain between the $F_{\text{sav,therm}}$ for the tank with PCM ($F_{\text{sav,therm}(W+PCM)}$) and only with water ($F_{\text{sav,therm}(W)}$). If this gain is higher than 0, then the PCM brings an advantage. As it can be seen in Figure , the gain due to using PCM is low. We can also notice the decrease of the RATIO according to the increase of the $F_{\text{sav,therm}}$. But it should be remembered, that when the $F_{\text{sav,therm}}$ is high, the solar installation is oversized. As it can be seen, adding a PCM becomes less interesting when the solar system is oversized. This is due to the fact, that when oversized, the storage of heating is less relevant.

According to the additional cost of adding the PCM and the environmental impacts results described in a previous report, this system with PCM does not show a substantial benefit compare to a storage tank filled only with water.

7 References

Heimrath R., Haller, M., 2007, Project Report A2 of Subtask A, the Reference Heating System, the Template Solar System, A Report of the IEA-SHC Task32

Streicher W., Heimrath R., et. al., 2002, IEA-SHC -TASK 26: SOLAR COMBISYSTEMS, Subtask C, Milestone Report C 0.2 - Reference Conditions (Climate, DHW- demand, SH- demand, reference buildings, auxiliary heater, solar plant, electricity consumption), 2002

Streicher W., Heimrath R., et. al., 2002, IEA-SHC -TASK 26: SOLAR COMBISYSTEMS, Subtask C, Milestone Report C 3.1, Optimization Procedure (reference system, penalty function, target function)

Letz T., 2007, The extended FSC procedure for larger storage sizes, internal paper Task 32

Klein S.A., 2005, TRNSYS16 reference manual

8 Appendix 1: Description of Components specific to this System

These are components that are

- a) not part of the TRNSYS standard library AND
- b) not part of the types used as "standard" by Task 32.

8.1 Type 889: Heating loop and auxiliary controller

Specific type base on existing controller for the space heating loop.

Parameters :

Mburner	MASS FLOW RATE INTO THE BOILER	(kg/h)
DT140	DIFFERENTIAL ON/OFF OF THE BURNER	(°C)
Text161	EXTERNAL REFERENCE MINIMUM TEMPERATURE	(°C)
Tch162	MAXIMUM REFERENCE TEMPERATURE START HEATING	(°C)
DT168	DIFFERENTIAL TEMPERATURE BOILER/HEATING T°	(°C)
I170	TYPE OF BUILDING (HEAVY=3/LIGHT=1)	(-)
R171	HEATING SPEED (1 OR 0)	(-)
Infl183	FRACTIONAL INFLUENCE OF INT. AMB. SENSOR	(-)
Tecs190	TEMPERATURE OF DHW	(°C)
DTecs191	DIFFERENTIAL TEMPERATURE FOR DHW	(°C)
mrاد	EXPONENT RADIATOR	(-)
mch_tot	MAX FLOW RATE OF THE HEATING LOOP	(kg/h)
DTchnom	DIFFERENTIAL TEMP. COME IN/RETURN HEATING	(°C)

Inputs :

Tm_cuve	TEMPERATURE IN THE MIDDLE OF THE TANK	(°C)
Thaut_cuve	TEMPERATURE IN THE TOP OF THE TANK (°C)	(°C)
Tcon_amb	ORDER TEMPERATURE FOR THE AMBIENT T° BUILDING	(°C)
Textn0	OUTSIDE TEMPERATURE	(°C)
Tret_ext	RETURN TEMP. OF HEATING LOOP	(°C)
Tamb	AMBIENT TEMPERATURE	(°C)
Tcuve_ch	OUTLET TEMPERATURE OF THE TANK FOR HEATING	(°C)

Outputs :

Tch_2	TEMPERATURE OF HEATING LOOP	(°C)
DTcheff	DIFFERENTIAL EFFECTIVE TEMPERATURE FOR SH	(°C)
mch_tot2	FLOW RATE FOR HEATING LOOP	(kg/h)
Aux	SWITCH ON OF THE BURNER	(-)
TretBur	RETURN TEMPERATURE TO THE BOILER	(°C)
TsetBurn	SET POINT TEMPERATURE FOR THE GAS BOILER	(°C)
mRetTank	RETURN FLOW RATE TO THE TANK	(kg/h)
mRetBurn	RETURN FLOW RATE TO THE GAS BOILER	(kg/h)
ECS1	DHW PRERATION MODE	(-)

Availability : DLL file available

8.2 Type 860: Water and Phase Change Material (PCM) storage tank (base on type60)

This specific type is based on the standard type60 from TRNSYS library. Please refer to TRNSYS description of this type60 for the conventional parameters, inputs and outputs. For more information see the IEA32 C5 report *Simulation model of PCM modules plunged in a water tank*.

Parameters :

modelat	NUMBER OF PCM ZONE (10 MAX)	(-)
nodesup	NUMBER OF UPPER PCM NODE	(-)
nodeinf	NUMBER OF LOWER PCM NODE	(-)
ENTHALPY CURVE CHARACTERISTIC		
Hyst	HYSTERESIS DT	(K)
Subcool	SUBCOOLING DT	(K)
Rho	MEAN PCM DENSITY	(kg/m ³)
Lamb1	RADIAL SOLID CONDUCTIVITY INTO PCM	(W/m.K)
Lamb1Liq	RADIAL LIQUID CONDUCTIVITY INTO PCM	(W/m.K)
Lamb2	AXIAL MEAN CONDUCTIVITY INTO PCM	(W/m.K)
NcPCM	NUMBER OF PCM NODE	(-)
Ep0	THICKNESS OF PCM CONTAINER	(mm)
Dia	Dimension of PCM module	(mm)
Contain1	KIND OF CONTAINER (1=sphere, 2=cyl. , 3=slab)	(-)
Ncont	NUMBER OF CONTAINER IN A HORIZONTAL CROSS SECTION	(-)
Rhoc	CONTAINER DENSITY	(kg/m ³)
NcPCM	NUMBER OF PCM NODE	(-)
Cpc	CONTAINER CP	(J/kg.K)
Lamb0	CONTAINER CONDUCTIVITY	(W/m.K)
KpcmAdd	ADDITIONAL DE-STRATIFICATION CONDUCTIVITY	(W/m.K)
PcmOutput	NUMBER OF NODE FOR PCM TEMPERATURE OUTPUT	(-)
Viscocin	PCM CINEMATIC VISCOSITY	(kg/m ³)
Hlimit	LIMIT ENTHALPY WHERE WE SUPPOSE TO BE LIQUID	(kJ/kg)
RhoLiq	PCM LIQUID DENSITY	(kg/m ³)
CpLiq	PCM LIQUID CP	(J/kg.K)
CoefDilat	DILATATION COEFFICIENT OF LIQUID PCM	(1/K)
LambLiq	PCM LIQUID LAMBDA	(W/m.K)

Inputs :

Idem type60

Outputs :

Twater_node	WATER TEMPERATURE AT PCM LEVEL	(°C)
Tpcm_node	TEMPERATURE INSIDE PCM NODE	(°C)
PCMpower	POWER FOR EACH PCM LEVEL	(W)
AlphaPCM	CONVECTIVE COEFFICIENT WATER/PCM FOR EACH LEVEL	(W/m ² .K)

Availability : DLL file available