Simulation Report

System: Closed-Cycle Sorption Storage "MODESTORE"

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

Report B6.2 of Subtask B

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Task 32
Storage

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

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IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first “oil shock,” the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia
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A total of 39 Tasks have been initiated, 30 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

Current Tasks:

Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*
Task 35	*PV/Thermal Solar Systems*
Task 36	*Solar Resource Knowledge Management*
Task 37	*Advanced Housing Renovation with Solar & Conservation*
Task 38	*Solar Assisted Cooling Systems*
Task 39	*Polymeric Materials for Solar Thermal Applications*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 22	*Building Energy Analysis Tools*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 28	*Solar Sustainable Housing*
Task 27	*Performance of Solar Facade Components*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*

Completed Working Groups:
CSHPSS, ISOLDE, Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

To find Solar Heating and Cooling Programme publications and learn more about the Programme visit **www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, e-mail: pmurphy@MorseAssociatesInc.com

September 2007

What is IEA SHC Task 32
"Advanced Storage Concepts for solar and low energy buildings" ?

The main goal of this Task is to investigate new or advanced solutions for storing heat in systems providing heating or cooling for low energy buildings.

- The first objective is to contribute to the development of advanced storage solutions in thermal solar systems for buildings that lead to high solar fraction up to 100% in a typical 45N latitude climate.

- The second objective is to propose advanced storage solutions for other heating or cooling technologies than solar, for example systems based on current compression and absorption heat pumps or new heat pumps based on the storage material itself.

Applications that are included in the scope of this task include:

- new buildings designed for low energy consumption
- buildings retrofitted for low energy consumption.

The ambition of the Task is not to develop new storage systems independent of a system application. The focus is on the integration of advanced storage concepts in a thermal system for low energy housing. This provides both a framework and a goal to develop new technologies.

The Subtasks are:
- Subtask A: Evaluation and Dissemination
- Subtask B: Chemical and Sorption
- Subtask C: Phase Change Materials
- Subtask D: Water tank solutions

Duration
July 2003 - December 2007.
www.iea-shc.org look for Task32

IEA SHC Task 32 Subtask B
"Chemical and Sorption Storage"

This report is part of Subtask B of the Task 32 of the Solar Heating and Cooling Programme of the International Energy Agency dealing with solutions of storage based on adsoprtion or absorption processes and on thermochemical reactions.

This report presents a simulation study on one of the advanced storage concepts that was proposed by a participating team in Task 32.
The concept and the simulation tool have been developped by the participating team. The framework for simulating the solar heating system including the new storage was developped within Task 32.

This joint effort has allowed Task 32 to address several new storage concepts thanks to a common work on different storage technologies but with the same reference system.

The Operating Agent would like to thank the author of this document and his institution for their implication in the search of future storage solutions for solar thermal energy, the key to a solar future for the heating and cooling of our buildings.

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for the Swiss Federal Office of Energy

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Content

1 General description of closed-cycle sorption storage ("MODESTORE")

The system simulated in this study is based on the pilot plant system tested within the project MODESTORE (EU-Project Contract No: NNE5/2001/979 and an Austrian national project within the program 'Haus der Zukunft'). However, the result of these projects was that the used material combination (silica gel and water) is not suitable for heat storage at the desired temperature levels for space heating. Therefore, this study was carried out using the material characteristics of a different sorption material (FAM-Z01 by Mitsubishi) which is available on the market but has not been used for storage applications because of its high costs. The purpose of this study is to show the possibilities of closed-cycle sorption heat storage with reasonable material properties knowing that for a market introduction of such a system more material research is necessary in order to identify a material with good properties but at reasonable costs.

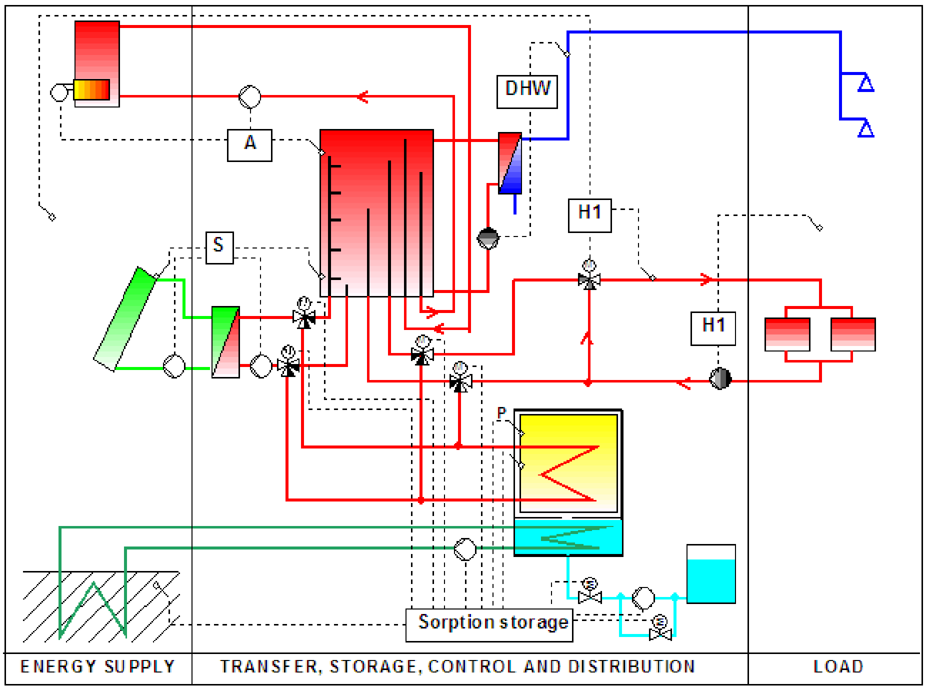
Main features

The system is meant to supply low energy single-family houses with heat for domestic hot water and space heating. The system consists of a standard solar combisystem with an added sorption storage tank. That is charged during the summer months and discharged to provide heat for space heating in winter. As a heat sink for condensation in summer and as a heat source for evaporation in winter, a ground heat exchanger is used.

Heat management philosophy

Solar loop:

The solar loop is used to charge primarily the water combistore. In summer when the combistore has reached a certain temperature, the excess heat from the collectors is used to charge the sorption store. In winter, the solar heat is used for domestic hot water preparation and space heating (as long as the temperature from the collectors is sufficient).



Auxiliary boiler:

The auxiliary boiler is used to heat the top part of the combistore to the set temperature for domestic hot water if the solar loop doesn't provide enough energy. Below that, there is a section in the store that is reserved for space heating purposes. It is only charged by the auxiliary boiler if solar has not heated it to the necessary temperature for space heating AND if there is not enough energy in the sorption store.

Space heating:
Space heating is supplied from the combistore as long as the temperature in the store is high enough. If the temperature in the space heating section of the combistore drops below the set temperature, heat for space heating is taken from the sorption store by evaporating water until the set temperature is reached in the adsorber. Only when the sorption store is completely discharged, the space heating section of the combistore is charged with auxiliary heat and the space heating loop is supplied from there.

Preparation of DHW:
Domestic hot water is prepared using an external plate heat exchanger connected to the combistore. The sorption store is not used for DHW preparation.

Influence of auxiliary energy source on system design and dimensioning
No information available. Simulations were carried out using a gas boiler.

Cost (range)
No information available.

Market distribution
The system is not available on the market.

2 Modeling of the system

The system was modeled by adding the sorption heat store with its evaporator / condenser unit to the template system (see Figure 1).
The following items have been changed or added compared with the template and will be described in more detail in the sections below:

- sorption store with adsorber, adsorber heat exchanger and evaporator/condenser
- solar loop can charge water tank and alternatively the sorption store
- partitioning of water tank
- auxiliary heating control strategy
- space heating can be supplied from water tank or from sorption tank
- ground heat exchanger as heat sink and heat source for sorption store

2.1 TRNSYS model

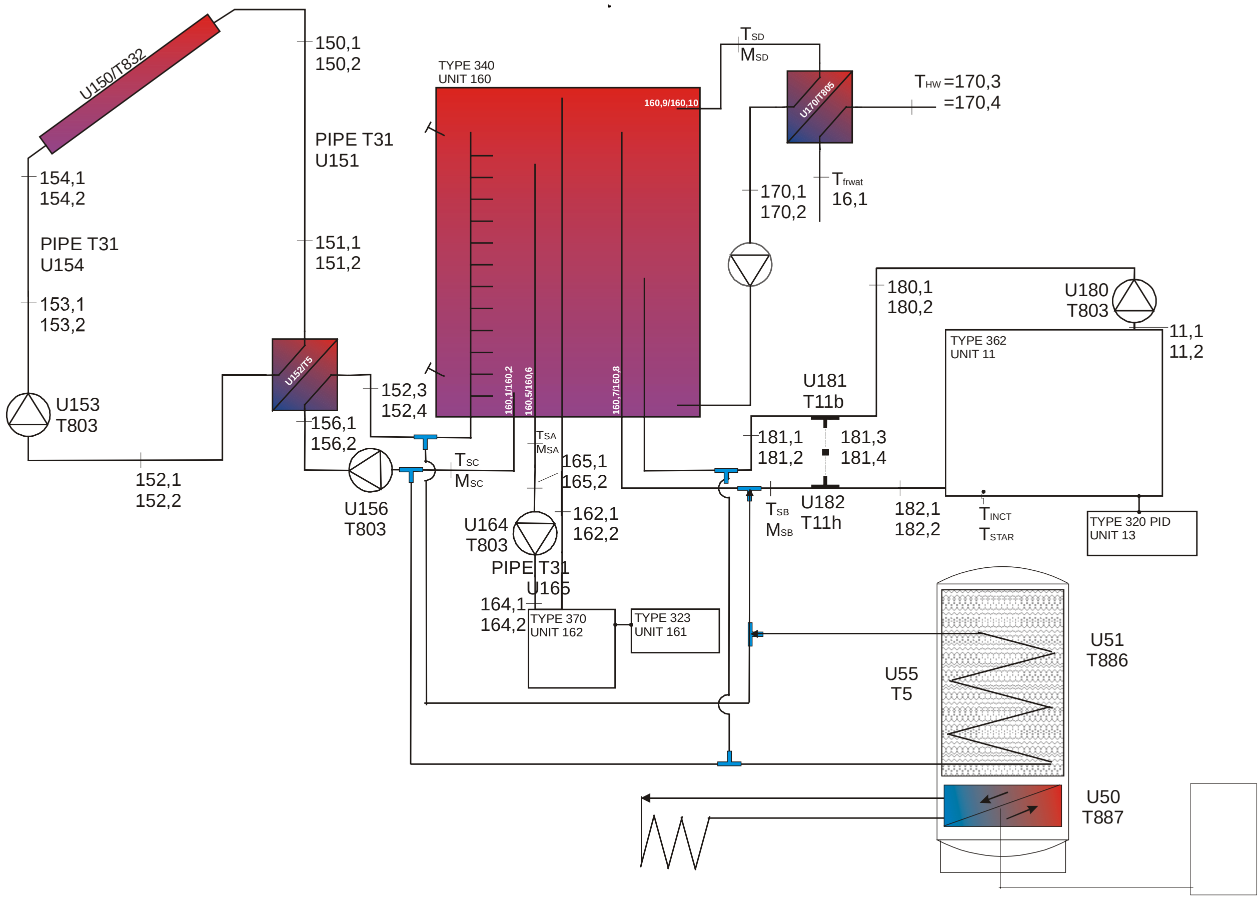


Figure 1. ***Modeling of "MODESORE" system in TRNSYS***

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

2.2.1 General Settings in the TRNEDIT template

General Settings (to be chosen by TRNEDIT):

Main	
simulation timestep	1/20 h
tolerance integration / convergence	0.01 / 0.01
length of simulation	24 months
climate	Zürich
building	SFH30
Auxiliary (only DHW)	
Nominal Power of Auxiliary	36000 kJ/h
Set temperature Auxiliary into store	63 °C
Auxiliary temperature rise	10 K
Collector	
type	Evacuated tube col (ref)
aperture area	50 m2
tilt angle	45°
azimuth (0° = south, 90° = west, 270° east)	0°
primary loop specific mass flow rate	40 kg/hm2
upper / lower dead band (switch on / off)	7 K / 4 K
relative height of low temperature sensor in store	0.1
cut-off temperature of collector	90 °C
boiling temperature of collector fluid (only valid for stagnation conditions if main store is charged)	110 °C
Store	
storage volume	1.00 m³
insulation thickness (λ=0.042 W/mK)	0.15 m
correction factor for heat loss	1.4

2.2.2 Collector

The standard evacuated tube collector was used.

Type: 832 Version Number: 2.06

Collector	η_0	0.773
	a_1	1.09 W/m²-K
	a_2	0.0094 W/m²-K²
	inc. angle modifier (50°)	0.95
	Area	50 m²
	Specific mass flow	40 l/m²h

2.2.3 Heat exchanger of collector loop

Heat exchanger heat transfer coefficient	(88.561*C_area+328.19)*3.6 W/K i.e. for 50 m² of collector area: 17,122 W/K
Specific mass flow secondary side	36.433 l/m²h (according to ratio of specific heat of water and water-glycol mixture)

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: 0.036 m	Total Length:	30 m
Insulation:	Thickness – 37 mm	Thermal Conductivity:	0.042 W/m-K

2.2.5 Control of the collector loop

In the winter months, only the water tank is charged. In summer, the excess solar energy is used to charge the sorption store. Primarily, the water store is charged. If the temperature in the water store at the height of the outlet to the auxiliary heater for space heating is above a certain limit (60°C, hysteresis: 10 K), charging is switched to the sorption store.
If the temperature of the collector is not sufficient anymore to charge the sorption store but the water tank can still be charged, charging is switched back to the water tank.

Type 2: Charging of water tank

Reason	***Sensor***	***Off-Criteria***	***Hyst.***
Upper dead beand (Udb)	Collector temperature (T-coll) and storage collector control (St-coll)	On: T-coll>st-coll + Udb	7 K
Lower dead band (Ldb)	Collector temperature (T-coll) and storage collector control (St-coll)	Off: T-coll>st-coll + Ldb	4 K
Collector stagnation	Collector Temperature	Boiling Temp. of fluid as defined by user (TRNEDIT)	15 K
Storage tank protection	Temperature in the uppermost Node of the store	Cut-off Temperature T_in as defined by user (TRNEDIT)	90°C

Type 2: Charging of sorption store

Reason	***Sensor***	***Off-Criteria***	***Hyst.***
Upper dead band (Udb)	Collector temperature (T-coll) and temperature of sorption store (T-store)	On: T-coll>T-store + Udb	20 K
Lower dead band (Ldb)	Collector temperature (T-coll) and temperature of sorption store (T-store)	Off: T-coll>T-store + Ldb	5 K
Storage tank protection	Temperature of the store	Cut-off Temperature	160°C

2.2.6 Water Storage Tank

Type: 340 Version Number: 1.99F

Storage tank	Total volume	1 m³
	Height	1.97 m
	Store volume for auxiliary (DHW)	0.2 m³
	Store volume for auxiliary (space heating)	0.1 m³
	Number of nodes	50
	Medium	Water
	Insulation thickness, thermal conductivity	15 cm, 0.042 W/m-K

Heat Exchanger N°1: Medium: Glycol (40%) / Water
Type of heat exchanger: external plate heat exchanger
Heat Transfer Coefficient: 17,122 W/K

Heat Exchanger N°2: Medium: Water / Water
Type of heat exchanger: external plate heat exchanger
Heat Transfer Coefficient: 5333 W/K

Relative heights of store doubleports and temperature sensors:

Double port description	***relative height***	***Dp Nr.***
inlet of collector loop (stratified)	$=1-\frac{1.5}{N_{\max}}$	1
outlet of collector loop	0.05	1
inlet of auxiliary heating (space heating)	$=1-\frac{V_{aux,dhw}}{V_s}$	3
outlet of auxiliary heating (space heating)	$=1-\frac{V_{aux,dhw}+V_{aux,sh}}{V_s}$	3
inlet of auxiliary heating (DHW)	1	6
outlet of auxiliary heating (DHW)	$=1-\frac{V_{aux,dhw}}{V_s}+\frac{2.5}{N_{\max}}$	6
inlet of DHW loop	$=\frac{0.5}{N_{\max}}$	5
outlet of DHW loop	$=1-\frac{0.5}{N_{\max}}$	5
inlet of space heating loop	0.15	4
outlet of space heating loop	$=1-\frac{V_{aux,dhw}}{V_s}-\frac{1.5}{N_{\max}}$	4

Sensor description	***relative height***
Collector control temperature	user defined (TRNEDIT)
Storage protection temperature	$=1-\frac{0.5}{N_{\max}}$
First auxiliary On/Off temperature (space heating)	$=1-\frac{V_{aux,dhw}+0.5\cdot V_{aux,sh}}{V_s}$
Second auxiliary On/Off temperature (space heating)	$=1-\frac{V_{aux,dhw}+0.75\cdot V_{aux,sh}}{V_s}$
First auxiliary On/Off temperature (DHW)	$=1-0.5\frac{V_{aux,dhw}}{V_s}$
Second auxiliary On/Off temperature (DHW)	$=1-\frac{V_{aux,dhw}}{V_s}+\frac{2.5}{N_{\max}}$

2.2.7 Sorption Storage Tank:

Type 886 (adsorber part), Type 887 (evaporator/condenser) and Type 5 (Heat exchanger in adsorber part)

Characteristic data for base case:

Adsorber material	Mitsubishi FAM-Z01 (characteristic curve: see Figure 2 below)
Mass of adsorber material	10,000 [kg]
UA-value of adsorber heat exchanger	18,000 [W/K]
UA-value of evaporator/condenser heat exchanger	2,000 [W/K]
UA-value of tank (heat losses to ambient)	5.75 [W/K]

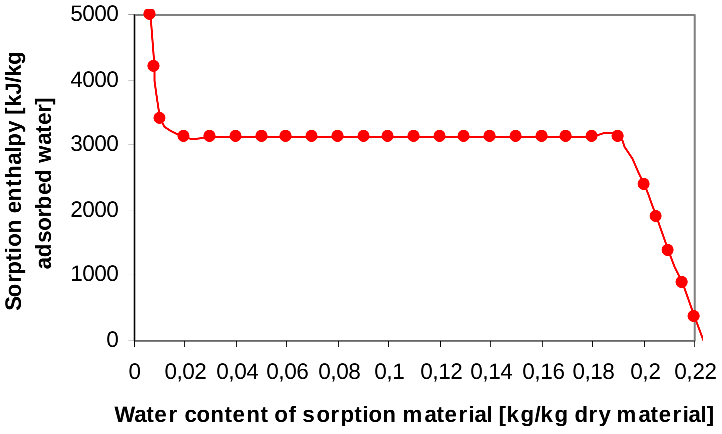


Figure 2. Characteristic curve of Mitsubishi FAM-Z01

The UA-value of the tank was assumed to vary with tank size (mass of sorption material) according to the following equation:

UA_tank=1.5994 ln(m_A) – 8.9798
where m_A mass of sorption material in kg
UA_tank UA value of tank insulation in W/K

The logarithmic relationship ensures the heat losses for larger tanks are relatively smaller than for small ones (see Figure 3).

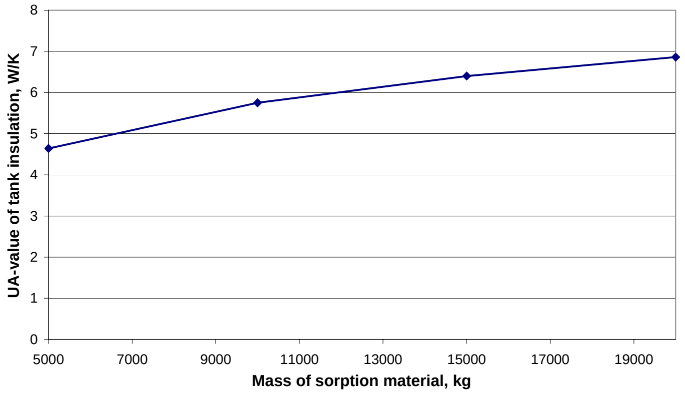


Figure 3: UA- value of sorption tank insulation as a function of tank size

The UA-value of the adsorber heat exchanger was assumed to vary with tank size (mass of sorption material) according to the following linear relationship:

UA_adsorber=2700 m_A / 1500
where m_A mass of sorption material in kg
UA_adsorber UA value of adsorber heat exchanger in W/K

This is assuming that the surface area of the adsorber hat exchanger is increasing linearly with the mass of the sorption material.

2.2.8 Auxiliary boiler:

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

Nr.	***Description***	***Value(s)***
1	temperature setpoint for auxiliary DHW to store	$T_{aux,set}$ [°C] set by the user (TRNEDIT)
2	Fueltype	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	0.25
10	mass of the boiler water	17.5 [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	1.5 [%]
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	$=P_{aux}/(dT_{aux}*Cp_{Wat})$ [kg/hr]

Type 323 is used as auxiliary controller.

Nr.	***Description***	***Value(s)***
3	ambient design temperature	taken from dataset for location chosen by the user
4	room set temperature	20 [°C]
6	set temperature for auxiliary heat supplied to store for DHW preparation	$T_{aux,set}$ [°C] set by the user (TRNEDIT)
7	nominal mass flow rate for DHW preparation	$=P_{aux}/(dT_{aux}*Cp_{Wat})$ [kg/hr]
9	radiator exponent n	0.2
10	radiator exponent m	0.3
12,13	minimum time off, minimum time on	MAX(dtSim*60;1) [min]

2.2.9 Building

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

2.2.10 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	$c_{p,wat} = 4.19$
7	max. flow rate of fluid	$\dot{m}_{B,max}$

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	55 [°C]

(Data defined in Heimrath, Haller 2007)

The mass flow in the radiators is determined by simulation of a thermostatic valve with the PID controller Type 320.

Nr.	*Description*	*Value(s)*
1	temperature width of PID band	3 [K]
2	proportional gain PID band	0.8 [1/K]
3	integral gain PID band	0.05 [1/Kh]
4	differential gain PID band	0 [h/K]
5	proportional gain P band	0.5 [1/K]
6,7	not used	0, 0

1	set temperature	room temperature setpoint
2	feedback temperature	room temperature of last timestep
3	control inversion option (direction of action)	2 (decreasing action)

2.2.11 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	
3	maximum allowed flow rate on primary (hot) side	1400 [kg/h]
4	temperature setpoint for secondary side outlet	45 [°C]
5	overall heat transfer coefficient UA of heat exchanger	19200 [kJ/hK]

2.2.12 Heat Source / Heat Sink for Sorption Store

For charging the sorption storage tank, heat has to be dissipated for condensing the desorbed water vapor. It is assumed that a temperature of 30°C is available for this purpose in summer. This could be an air to water heat exchanger to the ambient or a ground heat exchanger. Because of the high temperature lift that the chosen material combination needs, the solar thermal collectors have to be operated at at least 120°C. Therefore, evacuated tube collectors were used.

For discharging the store, the high temperature lift is an advantage. For the winter operation a constant heat source temperature of 5°C was assumed which could again come from a ground heat exchanger. This way, the necessary temperatures for the space heating loop can easily be reached.

2.3 Validation of the system model

The model was validated with data from laboratory tests of a much smaller prototype system and using a different sorption material (200 kg of silica gel Grace 127B).
The model consists of only three model parameters, UA-value of the adsorber heat exchanger, UA-value of the evaporator/condenser heat exchanger and the UA-value for the heat losses from the store to ambient, as well as the characteristic curve of the adsorber material. The characteristic curve was taken as given from measurement results of the material itself. The other three parameters were fitted using test sequences. Inputs were the inlet temperatures of the heat exchangers, the ambient temperature and the initial values of adsorber temperature and water content. The outputs that had to fit with the measured values were the outlet temperature of the heat exchangers, the average silica gel temperature, the water content of silica gel and the power transferred across the heat exchangers.

The following figures show the measured and calculated values for an adsorption process. The values fit reasonably well.

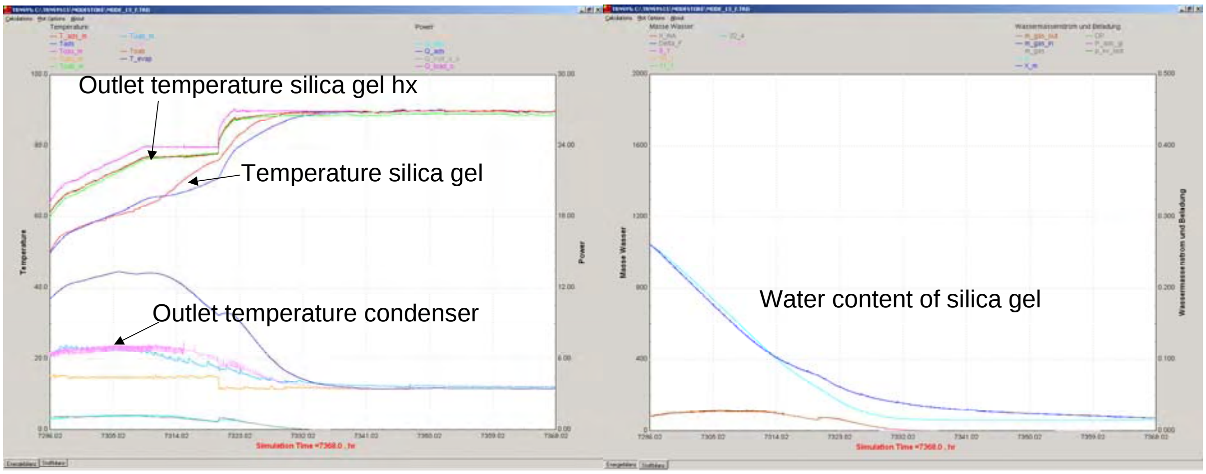


Figure 4: Validation sequence (adsorption)

3 Simulations for testing the library and the accuracy

The accuracy and timestep check was done for a system with 10,000 kg of sorption material, 100 l of water storage tank and 50 m² of evacuated tube collectors (base case), Zurich climate and the 30 kWh(m² a) building.

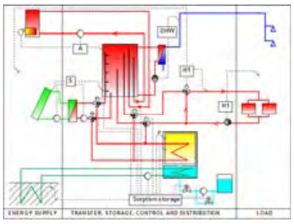
Table 1: Simulation runs for accuracy check

Convergence = Tolerance	Time step	Simulation runs?	Fsav,therm	ε
0,001	1 min	yes	0,7538	
0,001	2 min	yes	0,7534	-0,06%
0,001	3 min	yes	0,7524	-0,19%
0,003	1 min	yes	0,7550	0,15%
0,003	2 min	yes	0,7534	-0,06%
0,003	3 min	yes	0,7514	-0,32%
0,005	1 min	yes	0,7530	-0,11%
0,005	2 min	yes	0,7542	0,05%
0,005	3 min	yes	0,7527	-0,16%
0,01	1 min	yes	0,7519	-0,26%
0,01	2 min	yes	0,7517	-0,28%
0,01	3 min	yes	0,7521	-0,23%

The used simulation time step is 3 min = 1/20 h and the tolerances for convergence and integration are 0.01.

4 Sensitivity Analysis

4.1 Presentation of results



Closed-Cycle Sorption Storage (“MODESTORE”)

Main parameters (Base Case (BC)):			
Building:	*SFH 30*	Storage volume (water):	*1 m³*
Climate:	*Zurich*	Storage height (water)	*1.97 m*
Collector area:	*50 m²*	Mass of sorption material in sorption store	*10,000 kg*
Collector type:	*Standard Evacuated Tube*	Thermal insulation	*15 cm*
Specific flow rate (collector)	*15 kg/(m² hr)*	Nominal auxiliary heating rate	*24 kW*
Collector azimuth/tilt angle	*0 / 45°*	UA-value of adsorber heat exchanger	*18,000 W/K*
Collector upper dead band	*10 °K*	UA-value of evaporator/ condenser heat exchanger	*2000 W/K*
Heat Exchanger:	*9185 W/K*	UA-value of sorption storage tank (heat losses)	*5.75 W/K*
Simulation parameter:		Storage nodes (water)	*20 l/Node Max. 150*
Time step	*1/20 h*	Tolerances Integration Convergence	*0.01 / 0.01*

Summary of Sensitivity Parameters			
Parameter	Variation	[1]Variation in $f_{sav,ext}$	
Base Case (BC)	-	38.97%	
UA-value of evaporator/condenser heat exchanger [W/K]	200 – 4,000	60.6 – 65.7%	Figure 5
UA-value of adsorber heat exchanger [W/K]	3,000 – 33,000	62.5 – 63.3%	Figure 6
UA-value of sorption storage tank (heat losses) [W/K]	0 - 18	53.3 – 66.0%	Figure 7
Collector Size [m^2] (fixed store size (10,000 kg))	20 - 90	44.5 – 67.0 %	Figure 8
Mass of sorption material [kg] (fixed collector area of 50 m^2)	5,000 – 20,000	57.5 – 67.8 %	Figure 9

[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.

Sensitivity parameter:	UA-value of evaporator/condenser heat exchanger [W/K]	200 – 4000 W/K

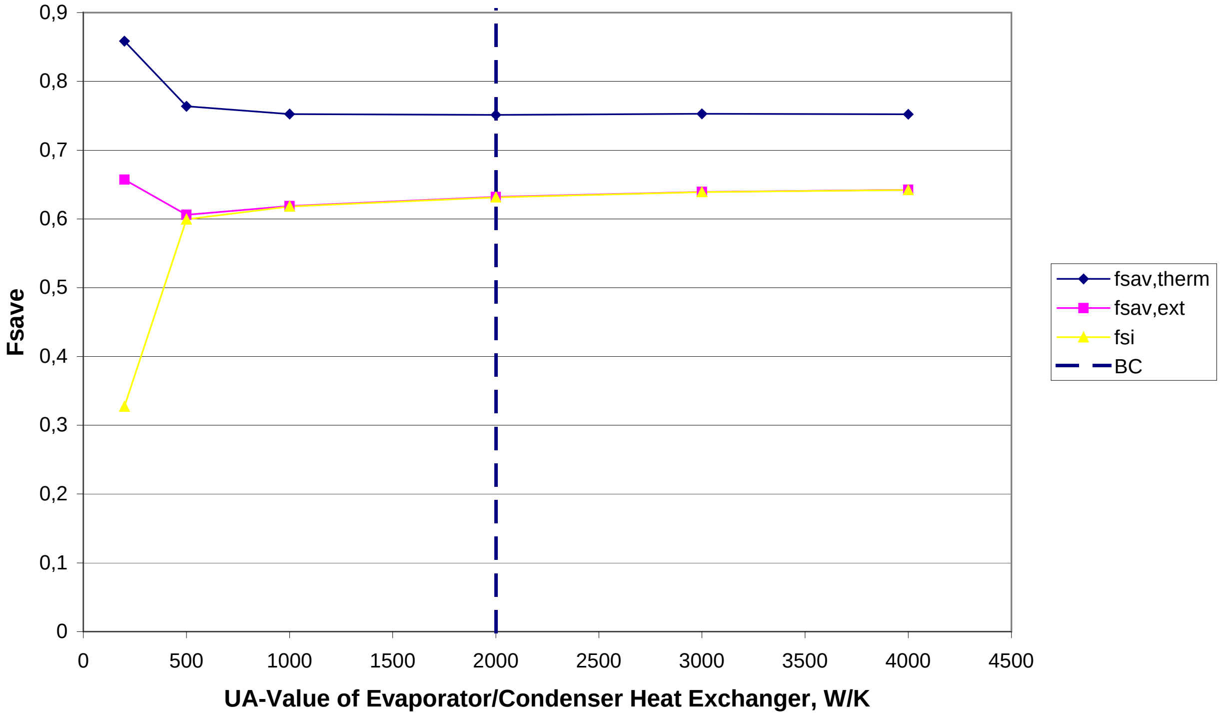


Figure 5. Variation of the UA-value of the evaporator/condenser heat exchanger.

Differences from Base Case (BC)
The UA-value of the evaporator/condenser heat exchanger was varied from very low values (200 W/K) to very high values (4,000 W/K).

Description of Results
The thermal energy savings do not change significantly as a function of the UA-value of the evaporator/condenser heat exchanger. This is due to the chosen material characteristic and the heat source and heat sink temperature. The temperature lift of the material is high enough over the entire operating range The extended fractional energy savings increase slightly with increasing UA-value because the temperature loss across the heat exchanger decreases and therefore the running time of the ground heat exchanger pump decreases.

Penalties occur only for the lowest UA-value where the space heating demand cannot be met anymore in some winter months. The reason for that is probably not due to the system design but that the chosen control parameters for auxiliary heating for space heating are not suitable for this case. Otherwise $f_{si} \approx f_{sav,ext}$.

Comments
None

Sensitivity parameter:	UA-value of adsorber heat exchanger [W/K]	3,000 – 33,000

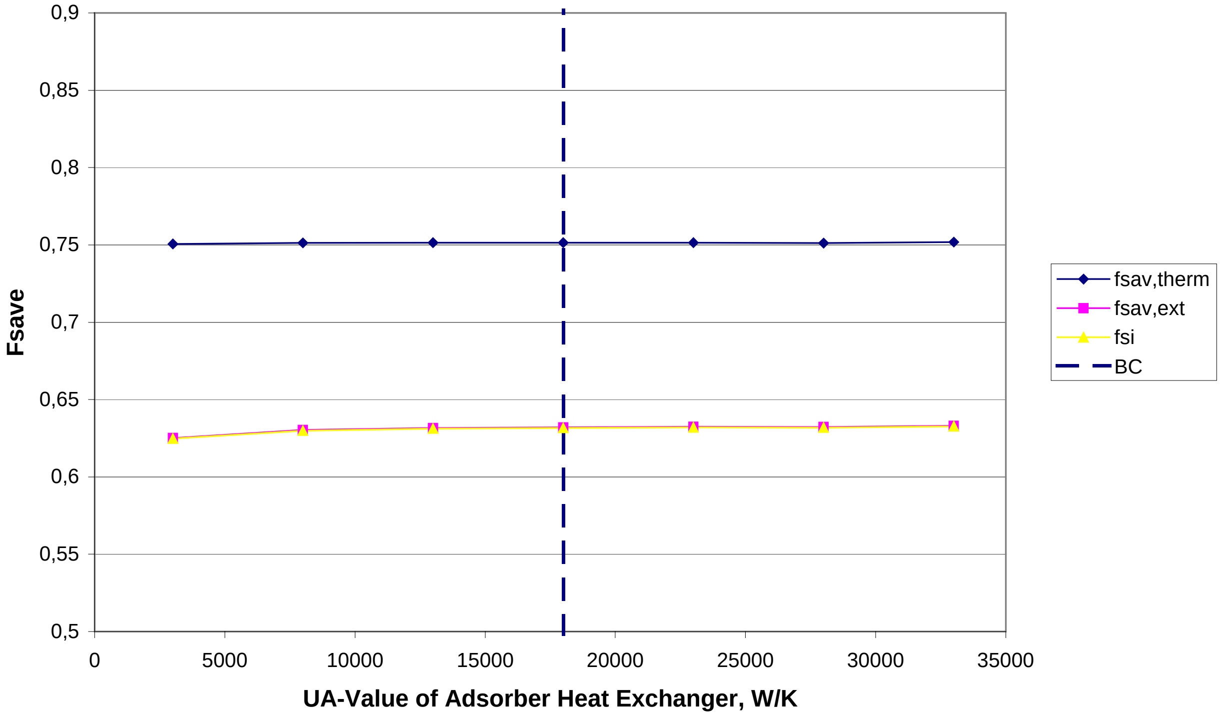


Figure 6. Variation of the UA-value of the adsorber heat exchanger.

Differences from Base Case (BC)
The UA-value of the adsorber heat exchanger was varied from very low values (3,000 W/K) to very high values (33,000 W/K).

Description of Results
There is no significant influence of the UA-value of the adsorber heat exchanger on the fractional energy savings. This is again due to the fact that the temperature lift of the chosen sorption material is high enough over the entire operating range so that temperature losses across the heat exchangers are not significant.

Comments
None

Sensitivity parameter:	UA-value of sorption storage tank (heat losses) [W/K]	0 - 18

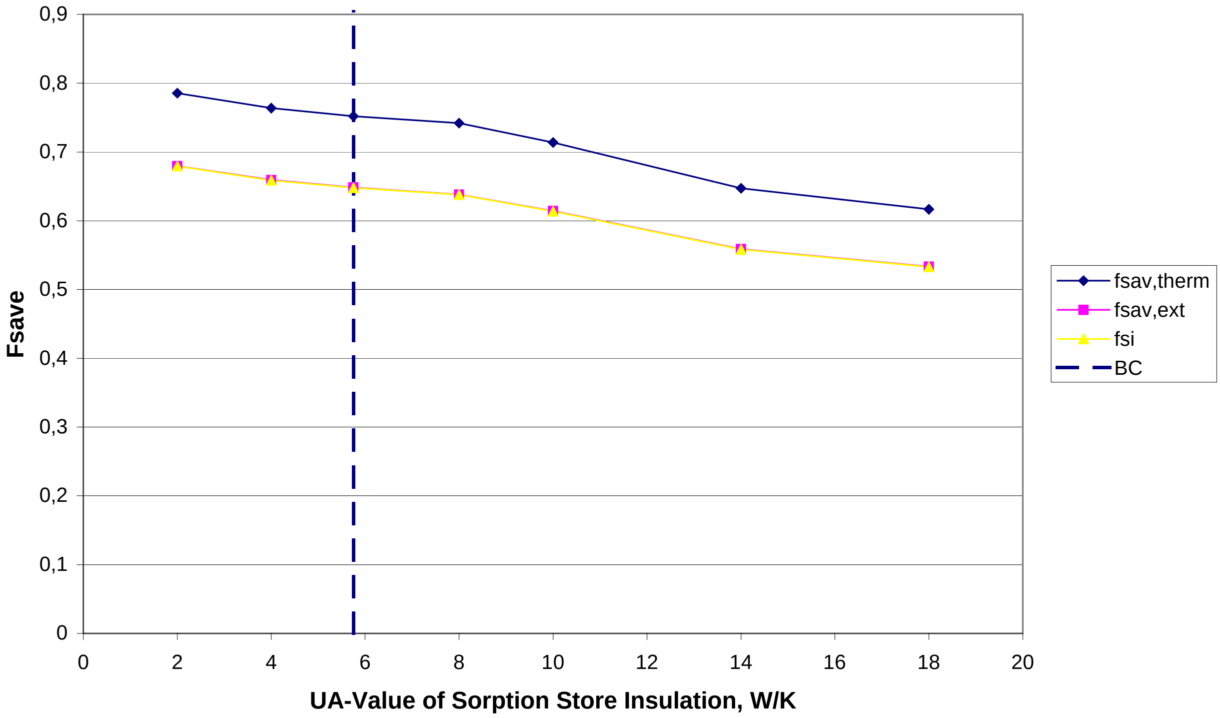


Figure 7. Variation of the UA-value of sorption store insulation.

Differences from Base Case (BC)
The UA-value of the sorption store insulation was varied from very low values (2 W/K) to very high values (18 W/K).

Description of Results
The influence of the level of insulation of the sorption store is significant. With increasing UA-value of the store insulation, both thermal and extended fractional energy savings decrease.

The insulation level chosen for the base case is quite an optimized one. The reason for the big influence of the insulation level are the high temperatures in the store during charging. During discharge the influence is smaller because the temperatures are much lower especially if the sorption store is only used for space heating with a low temperature heat distribution system.

Comments
None

Sensitivity parameter:	Collector Size [m²] (fixed store size (10,000 kg))	20 - 90

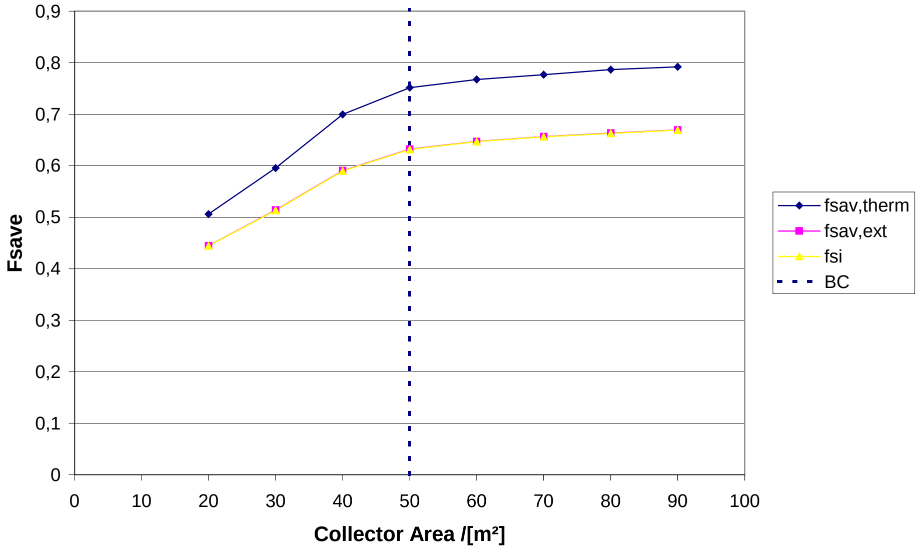


Figure 8. Fractional energy savings vs. collector area for a constant mass of sorption material of 10,000 kg.

Differences from Base Case (BC)
Collector area

Description of Results
Increasing the collector area for a given sorption storage size leads to rapidly increasing fractional energy savings up to a value of 50 m² collector area. Up to here, an increasing part of the sorption store is actually being used. For larger collector areas, there is a much smaller increase in fractional energy savings because the sorption store is already used entirely and cannot store more energy. Only the conventional water store, can be charged a little more due to higher flow temperatures because of the large collector area.

Comments
None

Sensitivity parameter:	Mass of sorption material [kg] (fixed collector area of 50 m²)	5,000 – 20,000

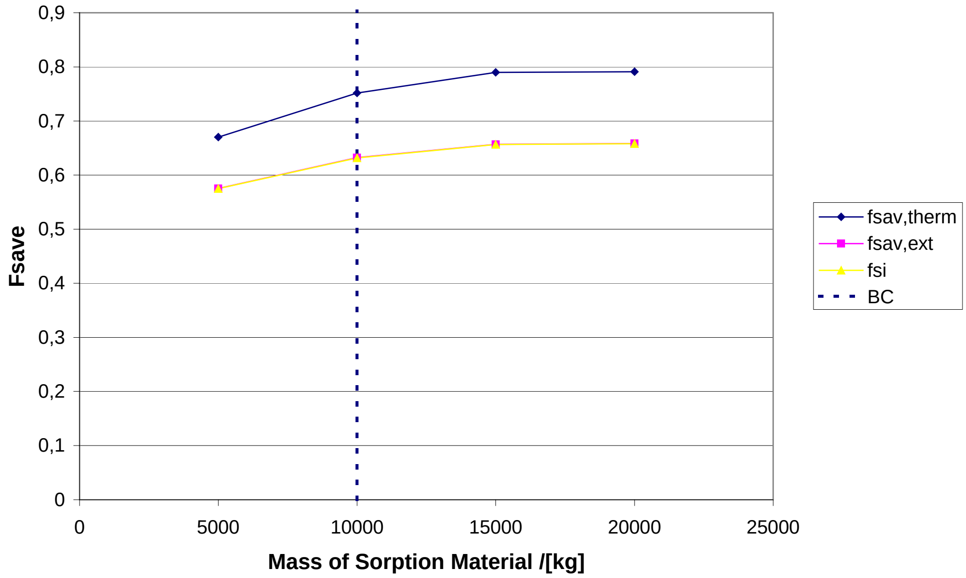


Figure 9. Fractional energy savings vs. mass of sorption material for a constant collector area of 50 m².

Differences from Base Case (BC)
Mass of sorption material

Description of Results
The mass of sorption material used in the system determines the amount of excess solar energy in summer that can be stored to be used during the winter months. For a given collector area, the fractional energy savings increase with increasing mass of sorption material until the entire sorption material is desorbed in summer. With 5000 kg of sorption material and 50 m² of collector area, there is more solar energy in summer than can be stored in the available sorption material. With 15,000 kg of sorption material, the curve already gets flatter which means that some of the sorption material cannot be desorbed in summer because there is not enough collector area. With 20,000 kg of sorption material, the extra 5000 kg cannot be used due to the small collector area. Therefore, the fractional energy savings are the same as for 15,000 kg.

Comments
None

Figure 10 is a combination of Figure 8 and Figure 9. It shows the fractional thermal energy savings for all simulated sorption storage sizes and collector areas in a single graph. For comparison it also shows the results of the solar combisystem template with a 1000 l water storage tank.

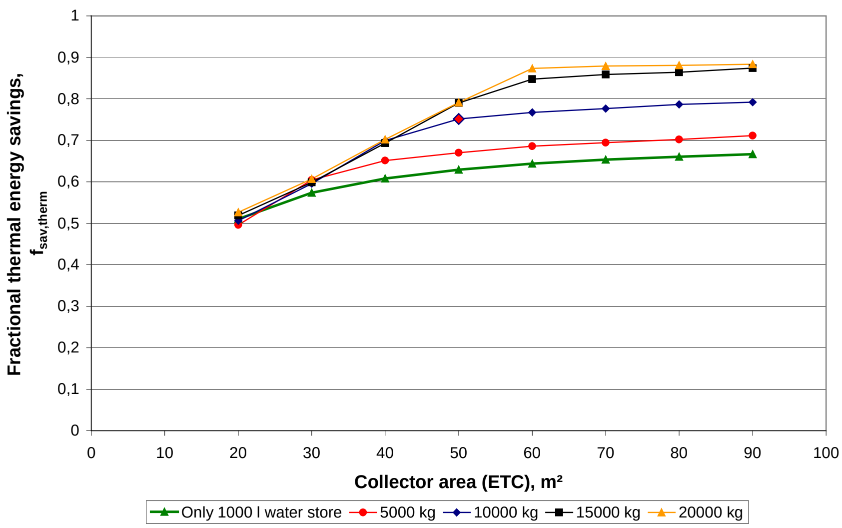


Figure 10. Fractional thermal energy savings vs. collector area for different sorption storage sizes.

For the smallest simulated collector area (20 m²), the fractional energy savings with and without sorption storage are practically identical for all sizes of sorption store. The reason for that is that the 20 m² of collector area are used for domestic hot water heating in summer and the excess solar energy is not sufficient to significantly charge the sorption store. With 30 m² of collector area, the results with sorption store are slightly better than without but again it does not depend on the size of the sorption store. That shows that only a small part of the sorption store is being charged and it does not make sense to use a bigger sorption store because the excess solar energy in summer is not enough to charge the store further.

Increasing the storage size to more than 15000 kg does not increase the fractional energy savings much even for large collector areas. The reason for that is that with this store size, 100 % of the space heating demand can be met by solar energy. This leads to fractional thermal energy savings around 88%. The energy savings cannot increase further because of the system setup that does not use the sorption store for domestic hot water preparation. It would be possible to use the sorption store also for domestic hot water (the sorption material chosen for this study provides a temperature lift that is sufficient) but heat losses from the sorption store would also increase because the temperatures in the sorption store would be significantly higher during discharge.

The red diamond in the figure shows the chosen base case.

5 Analysis using FSC'

5.1 Simulations for one climate and building

Simulations made for Zürich climate and SFH 30 for different sizes of sorption store and different collector sizes.

- All simulations contain a 1000 l water store.
- Sorption store contains between 5 000 and 20 000 kg of sorption materiel (FAM-Z01), with an energy content of 0.15 kWh per kg sorption material

Table 2. Results 'MODESTORE' simulations for the climate Zurich (5,000 kg).

Building	SFH 30							
Climate	Zurich							
A_{col} [m²]	20	30	40	50	60	70	80	90
$m_{Sorption\ store}$ [kg]	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
$V_{Water\ store}$ [m³]	1	1	1	1	1	1	1	1
$Q_{solar,usable,heat}$ [kWh/a]	7,457	8,586	9,227	9,227	9,227	9,227	9,227	9,227
E_{aux} [kWh/a]	4,648	3,626	3,198	3,015	2,880	2,792	2,719	2,673
E_{ref} [kWh/a]	9,227	9,227	9,227	9,227	9,227	9,227	9,227	9,227
E_{total} [kWh/a]	5,994	5,096	4,669	4,478	4,346	4,264	4,217	4158
$E_{total,ref}$ [kWh/a]	10,643	10,643	10,643	10,643	10,643	10,643	10,643	10,643
$Q_{st,coll,water}$ [kWh/a]	5,008	5,603	5,960	6,167	6,320	6,416	6,501	6,548
$Q_{st,coll,sorption}$ [kWh/a]	1,883	2,680	3,034	3,215	3,350	3,459	3,550	3,636
$Q_{st,dhw}$ [kWh/a]	3,048	3,048	3,048	3,048	3,048	3,048	3,048	3,048
$Q_{st,sh,water}$ [kWh/a]	4,059	3,607	3,512	3,511	3,510	3,508	3,513	3,507
$Q_{st,sh,sorption}$ [kWh/a]	111	561	655	657	657	659	654	660
$W_{pump,sol}$ [kWh/a]	184	197	207	217	231	245	275	267
W_{burn} [kWh/a]	243	234	230	228	227	227	226	226
W_{contr} [kWh/a]	22	22	22	22	22	22	22	22
$W_{pump,SH}$ [kWh/a]	878	997	993	975	965	958	955	950
$W_{pump,DHW}$ [kWh/a]	20	20	20	20	20	20	20	20
W_{total} [kWh/a]	1,346	1,469	1,472	1,463	1,466	1,472	1,498	1,484
FSC	0.8081	0.9305	1	1	1	1	1	1
FSC'	1.1731	1.5329	1.8539	2.1177	2.3814	2.6451	2.9088	3.1725
$f_{sav,therm}$	0.4963	0.6047	0.6516	0.6702	0.6860	0.6945	0.7020	0.7115
$f_{sav,ext}$	0.4368	0.5176	0.5582	0.5752	0.5887	0.5955	0.5997	0.6092
f_{si}	0.4363	0.5171	0.5578	0.5748	0.5883	0.5951	0.5992	0.6087

Table 3. Results ‘MODESTORE’ simulations for the climate Zurich (10,000 kg).

Building Climate	SFH 30 Zurich							
A_{col} [m²]	20	30	40	50	60	70	80	90
$m_{Sorption\ store}$ [kg]	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
$V_{Water\ store}$ [m³]	1	1	1	1	1	1	1	1
$Q_{solar,usable,heat}$ [kWh/a]	7,457	8,586	9,227	9,227	9,227	9,227	9,227	9,227
E_{aux} [kWh/a]	4,556	3,731	2,772	2,292	2,146	2,060	1,968	1,918
E_{ref} [kWh/a]	9,227	9,227	9,227	9,227	9,227	9,227	9,227	9,227
E_{total} [kWh/a]	5,912	5,173	4,360	3,915	3,756	3,655	3,583	3,517
$E_{total,ref}$ [kWh/a]	10,643	10,643	10,643	10,643	10,643	10,643	10,643	10,643
$Q_{st,coll,water}$ [kWh/a]	4,991	5,598	5,968	6,194	6,345	6,457	6,545	6,589
$Q_{st,coll,sorption}$ [kWh/a]	2,306	3,072	3,933	4,526	4,722	4,881	5,015	5,127
$Q_{st,dhw}$ [kWh/a]	3,048	3,048	3,047	3,047	3,047	3,048	3,047	3,048
$Q_{st,sh,water}$ [kWh/a]	3,969	3,706	3,120	2,853	2,843	2,854	2,843	2,833
$Q_{st,sh,sorption}$ [kWh/a]	200	463	1,047	1,312	1,322	1,310	1,321	1,331
$W_{pump,sol}$ [kWh/a]	192	197	215	233	244	258	288	278
W_{burn} [kWh/a]	242	235	226	221	220	219	218	218
W_{contr} [kWh/a]	22	22	22	22	22	22	22	22
$W_{pump,SH}$ [kWh/a]	880	969	1,105	1,127	1,104	1,076	1,066	1,060
$W_{pump,DHW}$ [kWh/a]	20	20	20	20	20	20	20	20
W_{total} [kWh/a]	1,356	1,443	1,588	1,623	1,610	1,595	1,615	1,598
FSC	0.8081	0.9305	1	1	1	1	1	1
FSC’	1.3685	1.8566	2.3111	2.7159	3.1208	3.5256	3.9305	4.3354
$f_{sav,therm}$	0.5046	0.5957	0.6996	0.7516	0.7674	0.7768	0.7867	0.7921
$f_{sav,ext}$	0.4410	0.5139	0.5903	0.6321	0.6471	0.6565	0.6633	0.6696
f_{si}	0.4406	0.5135	0.5899	0.6317	0.6467	0.6561	0.6629	0.6691

Table 4. Results 'MODESTORE' simulations for the climate Zurich (15,000 kg).

Building Climate	SFH 30 Zurich							
A_{col} [m²]	20	30	40	50	60	70	80	90
$m_{Sorption\ store}$ [kg]	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
$V_{Water\ store}$ [m³]	1	1	1	1	1	1	1	1
$Q_{solar,usable,heat}$ [kWh/a]	7,457	8,586	9,227	9,227	9,227	9,227	9,227	9,227
E_{aux} [kWh/a]	4,439	3,700	2,829	1,939	1,407	1,302	1,253	1,162
E_{ref} [kWh/a]	9,227	9,227	9,227	9,227	9,227	9,227	9,227	9,227
E_{total} [kWh/a]	5,817	5,124	4,399	3,652	3,156	3,035	2,995	2,860
$E_{total,ref}$ [kWh/a]	10,643	10,643	10,643	10,643	10,643	10,643	10,643	10,643
$Q_{st,coll,water}$ [kWh/a]	4,967	5,581	5,956	6,192	6,359	6,472	6,546	6,611
$Q_{st,coll,sorption}$ [kWh/a]	2,622	3,385	4,234	5,152	5,839	6,039	6206	6,339
$Q_{st,dhw}$ [kWh/a]	3,048	3,048	3,048	3,047	3,047	3,047	3,047	3,047
$Q_{st,sh,water}$ [kWh/a]	3848	3,672	3,164	2,517	2,155	2,150	2,168	2,135
$Q_{st,sh,sorption}$ [kWh/a]	321	496	1,002	1,646	2,007	2,012	1,993	2,027
$W_{pump,sol}$ [kWh/a]	200	201	216	239	262	276	305	293
W_{burn} [kWh/a]	241	234	226	218	212	212	211	210
W_{contr} [kWh/a]	22	22	22	22	22	22	22	22
$W_{pump,SH}$ [kWh/a]	896	947	1,085	1,214	1,233	1,203	1,184	1,153
$W_{pump,DHW}$ [kWh/a]	20	20	20	20	20	20	20	20
W_{total} [kWh/a]	1,378	1,424	1,570	1,713	1,749	1,733	1,742	1,698
FSC	0.8081	0.9305	1	1	1	1	1	1
FSC'	1.5341	2.1308	2.6983	3.2228	3.7472	4.2717	4.7961	5.3206
$f_{sav,therm}$	0.5189	0.5990	0.6934	0.7899	0.8475	0.8589	0.8642	0.8741
$f_{sav,ext}$	0.4534	0.5186	0.5867	0.6569	0.7034	0.7149	0.7186	0.7313
f_{si}	0.4530	0.5181	0.5863	0.6565	0.7030	0.7144	0.7182	0.7309

Table 5. Results 'MODESTORE' simulations for the climate Zurich (20,000 kg).

Building		SFH 30							
Climate		Zurich							
A_{col}	[m²]	20	30	40	50	60	70	80	90
$m_{Sorption\ store}$	[kg]	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
$V_{Water\ store}$	[m³]	1	1	1	1	1	1	1	1
$Q_{solar,usable,heat}$	[kWh/a]	7,457	8,586	9,227	9,227	9,227	9,227	9,227	9,227
E_{aux}	[kWh/a]	4,367	3,627	2,747	1,926	1,169	1,115	1,097	1,074
E_{ref}	[kWh/a]	9,227	9,227	9,227	9,227	9,227	9,227	9,227	9,227
E_{total}	[kWh/a]	5,765	5,045	4,305	3,636	2,989	2,897	2,872	2,800
$E_{total,ref}$	[kWh/a]	10,643	10,643	10,643	10,643	10,643	10,643	10,643	10,643
$Q_{st,coll,water}$	[kWh/a]	4,930	5,565	5,946	6,183	6,368	6,483	6,548	6,609
$Q_{st,coll,sorption}$	[kWh/a]	2,878	3,666	4,537	5,430	6,293	6,535	6,673	6,777
$Q_{st,dhw}$	[kWh/a]	3,048	3,048	3,047	3,047	3,047	3,047	3,047	3,047
$Q_{st,sh,water}$	[kWh/a]	3,763	3,594	3,084	2,501	1,939	1,983	2,024	2,053
$Q_{st,sh,sorption}$	[kWh/a]	406	574	1,082	1,662	2,222	2,178	2,137	2,108
$W_{pump,sol}$	[kWh/a]	205	207	220	240	265	282	309	295
W_{burn}	[kWh/a]	240	234	225	217	210	210	210	209
W_{contr}	[kWh/a]	22	22	22	22	22	22	22	22
$W_{pump,SH}$	[kWh/a]	910	937	1,070	1211	1,303	1,248	1,214	1,180
$W_{pump,DHW}$	[kWh/a]	20	20	20	20	20	20	20	20
W_{total}	[kWh/a]	1,398	1,419	1,557	1,710	1,821	1,782	1,775	1,727
FSC		0.8081	0.9305	1	1	1	1	1	1
FSC'		1.6825	2.3765	3.0454	3.6770	4.3086	4.9403	5.5719	6.2035
$f_{sav,therm}$		0.5267	0.6070	0.7023	0.7913	0.8733	0.8791	0.8811	0.8836
$f_{sav,ext}$		0.4583	0.5259	0.5955	0.6583	0.7191	0.7278	0.7302	0.7369
f_{si}		0.4579	0.5255	0.5951	0.6579	0.7187	0.7274	0.7297	0.7365

Using the definition of FSC' given in [LETZ 2007], the results of the 32 simulations give the following curves for Fsav,th and Fsav,ext (Figures 11 and 12).

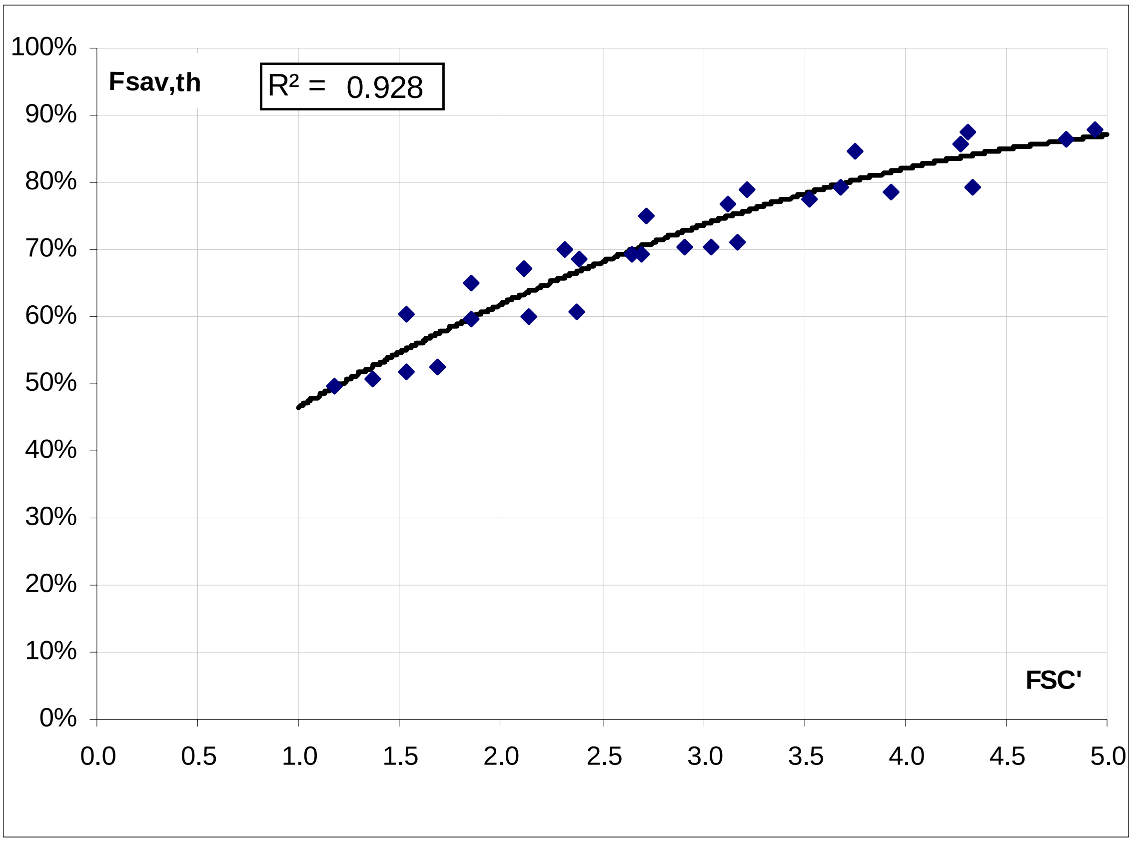


Figure 11. Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 2/3) for Zürich climate and SFH 30.

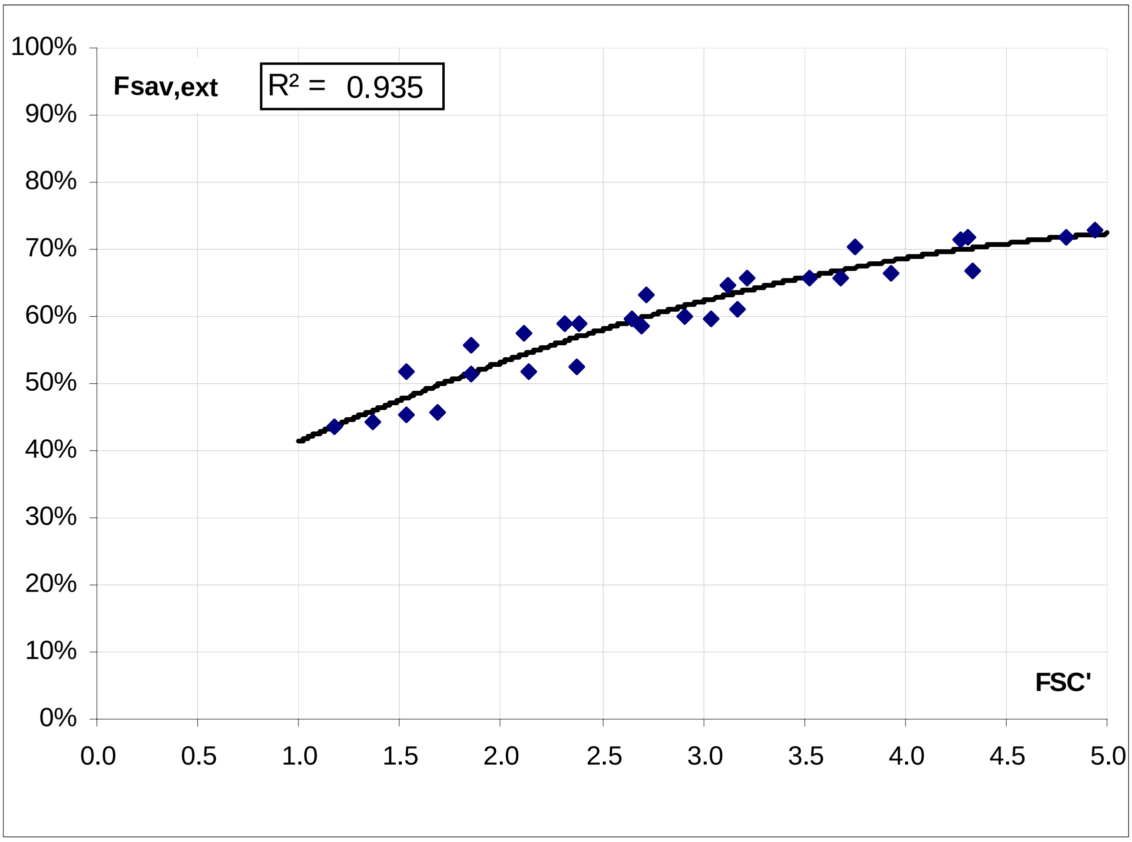


Figure 12. Extended fractional energy savings $F_{sav,ext}$ as a function of FSC' (α = 2/3) *for Zürich climate and SFH 30.*

Comments:

- It is difficult to derive significant curves since simulations have been done with only one climate and one building. Especially the part of the curve for small FSC' values (between 0 and 1) cannot be drawn.

- The simulations have been done with different collector areas and different storages sizes in a large range. Therefore the ratio storage size / collector size is not constant, varying between 9 and 154 kWh/m². Sorting the results according to ratio storage size / collector size, the correlation can be improved. For example, the two following diagrams have been obtained with a ratio storage size / collector size between 10 and 50 kWh/m²

5.2 Simuations for a range of climates and buildings

Simulations made for Zürich climate and SFH 30 for different sizes of sorption store and different collector sizes.

- All simulations contain a 1000 l water store.
- Madrid, Zurich and Stockholm climates with the SFH30 and SFH60 buildings.
- Collector areas of 30, 50 and 70 m^2 with 200 kg/m^2 of sorption materiel (FAM-Z01), with an energy content of 0.15 kWh per kg sorption material

Figures 13 and 14 show the curves for these simulations. One simulation is inconsistent with the others, that for Madrid climate and SFH30 building. No reason could be found for this.

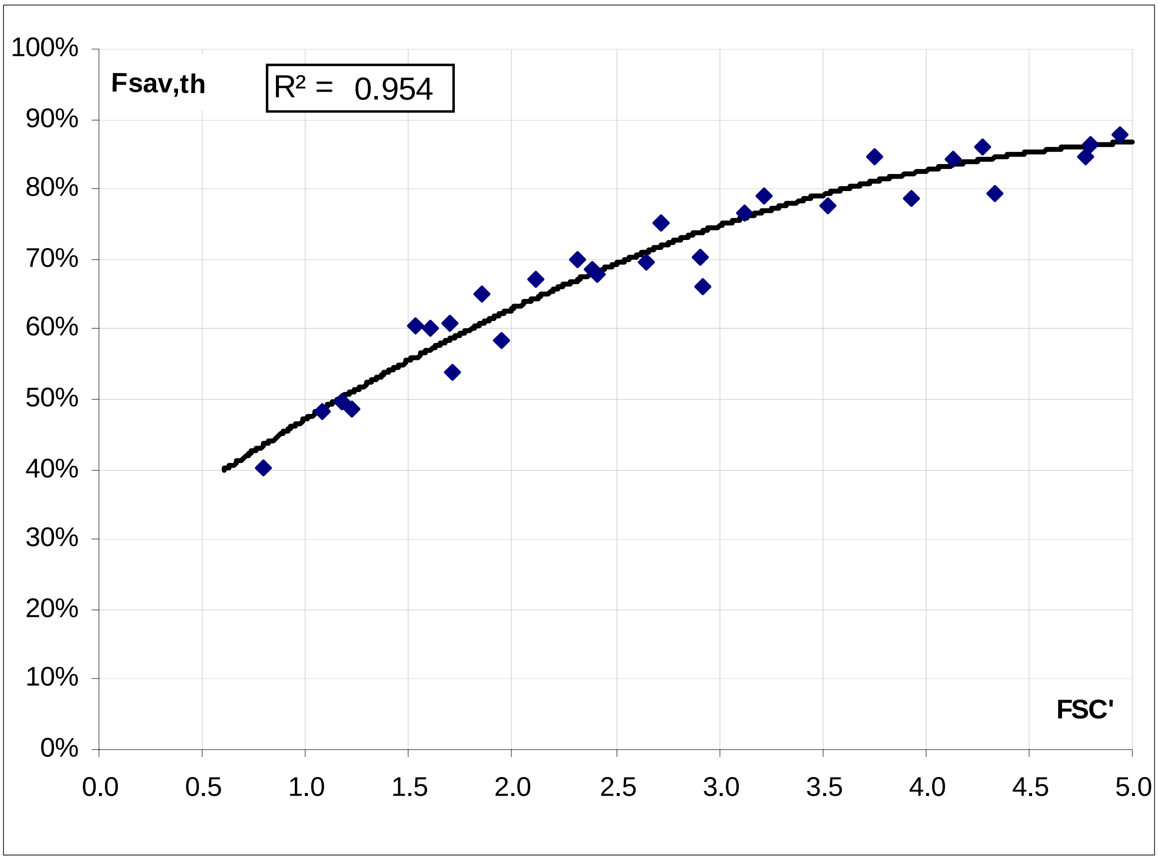


Figure 13. Thermal fractional energy savings $F_{sav,th}$ as a function of FSC' (α = 2/3) for a range of climates and buildings.

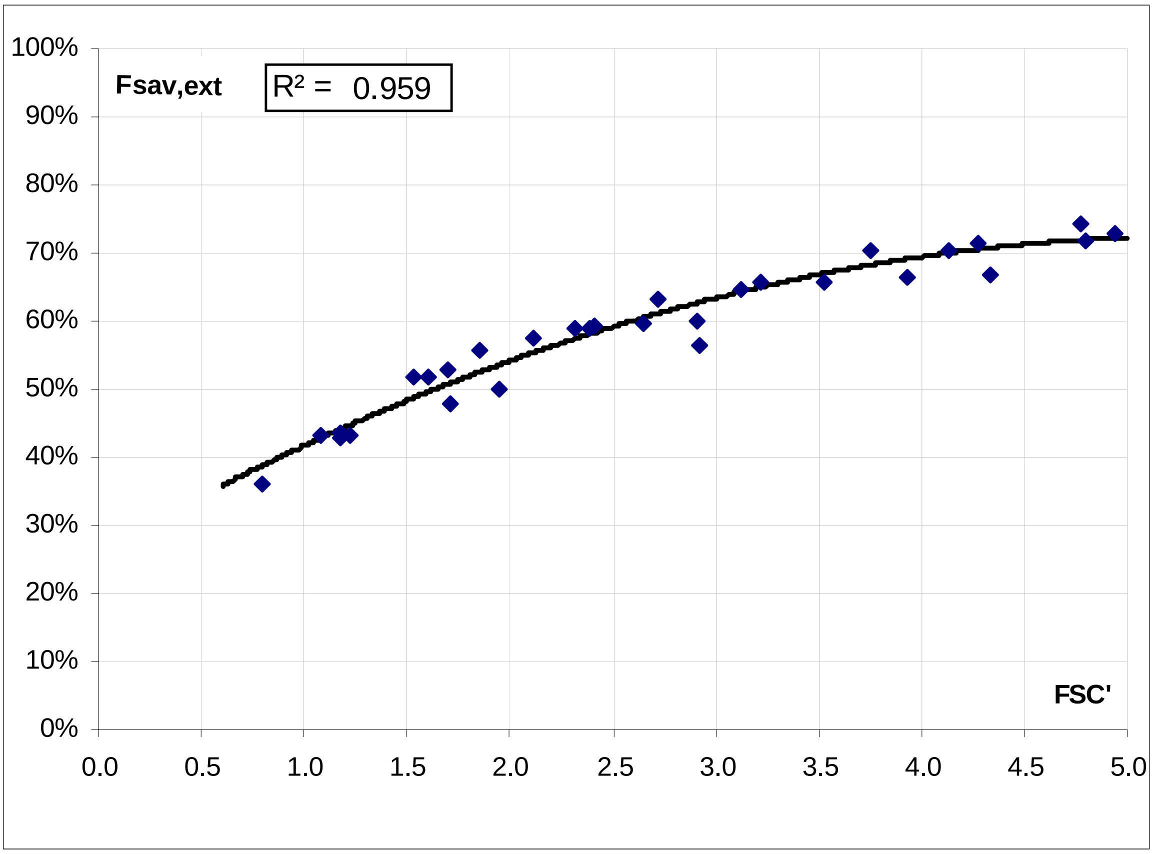


Figure 14. Extended fractional energy savings $F_{sav,ext}$ as a function of FSC' (α = 2/3) for a range of climates and buildings

<u>Conclusion:</u>

1. For large FSC' values corresponding to large collector areas, this SCS seems to need quite a lot of electricity, because the curve for the $F_{sav,ext}$ indicator is located far under the one for the $F_{sav,th}$ indicator.

2. More simulations done with other climates and loads would be needed for a deeper analysis of the behaviour of the system.

6 Lessons learned

- The characteristics of the analyzed sorption material show high temperature lifts so that the size of the heat exchangers in the sorption store are not as significant anymore. This is in contrast to the results of the previous project where silica gel and water have been used. However, the size of the evaporator/condenser heat exchanger has an influence on the pump running time and therefore the parasitic electricity consumption of the system.

- Maximum thermal energy savings are limited to about 88% because the system design uses the sorption store only for space heating and not for domestic hot water preparation. If a sorption material with a high temperature lift is used, the sorption store could also be used for domestic hot water preparation. However, heat losses from the store would increase during discharge.

- It is important to use a collector area – storage size combination that matches. If the collector area is too small, not the entire sorption store can be charged in summer. The additional investment for the store would be wasted. If the sorption store is too small, 100% solar fraction cannot be reached.

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

Letz T., 2007, The extended FSC procedure for larger storage sizes, A Report of IEA Solar Heating and Cooling programme - Task 32 - Advanced storage concepts for solar and low energy buildings - Report A1 of Subtask A - December 2007, 19 p.

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 886: Sorption heat store

Version of April 4, 2007

Parameters: 3
Inputs: 9
Outputs: 4
Derivatives: 2

For more details please refer to the report 'Store Models for Thermo-Chemical and Sorption Storage Units', a Report of IEA Solar Heating and Cooling Programme - Task 32, advanced storage concepts for solar and low energy buildings, report B5 of Subtask B, edited by Chris Bales, SERC, Sweden

Availability: AEE INTEC, Gleisdorf, Austria
Type has not yet been well documented.

8.2 Type 887 : Evaporator/Condenser Heat Exchanger for Sorption Heat Store

Version of April 6, 2007

Parameters: 1
Inputs: 4
Outputs: 2

For more details please refer to the report 'Store Models for Thermo-Chemical and Sorption Storage Units', a Report of IEA Solar Heating and Cooling Programme - Task 32, advanced storage concepts for solar and low energy buildings, report B5 of Subtask B, edited by Chris Bales, SERC, Sweden

Availability: AEE INTEC, Gleisdorf, Austria
Type has not yet been well documented.