Simulation Report
System : Monosorp

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

Report B6.3 of Subtask B

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Author:
Henner Kerskes
Sebastian Asenbeck
ITW, Univ. Stuttgart
Stuttgart, Germany

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

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	Finland	Portugal
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	United States
European Commission	New Zealand	
Germany	Norway	

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

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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.

Jean-Christophe Hadorn

Operating Agent of IEA SHC Task 32
for the Swiss Federal Office of Energy

BASE Consultants SA - Geneva
jchadorn@baseconsultants.com

Content

1 General description of the Monosorp-System

Main features

The reference combi system has been extended by an open cycle adsorption store in conjunction with a ventilation heat recovery system, resulting in two main advantages:

- *Long term heat storage:* Solar excess heat in the summer can be used for desorption of the sorption material so that adsorption heat is available during the heating period.
- *Additional short term heat storage capacity:* During the desorption process the sorption material has to be heated up to temperatures of at least 120°C and therefore provides a further heat reservoire for sensible heat. In spring and autumn the sensible heat stored in the sorption material capacity can be used for space heating in addition to the adsorption heat.

Because of the high desorption temperatures required (120 ... 180°C) the use of a highly efficient vacuum tube collector is essential for the overall efficiency of the solar heating system.

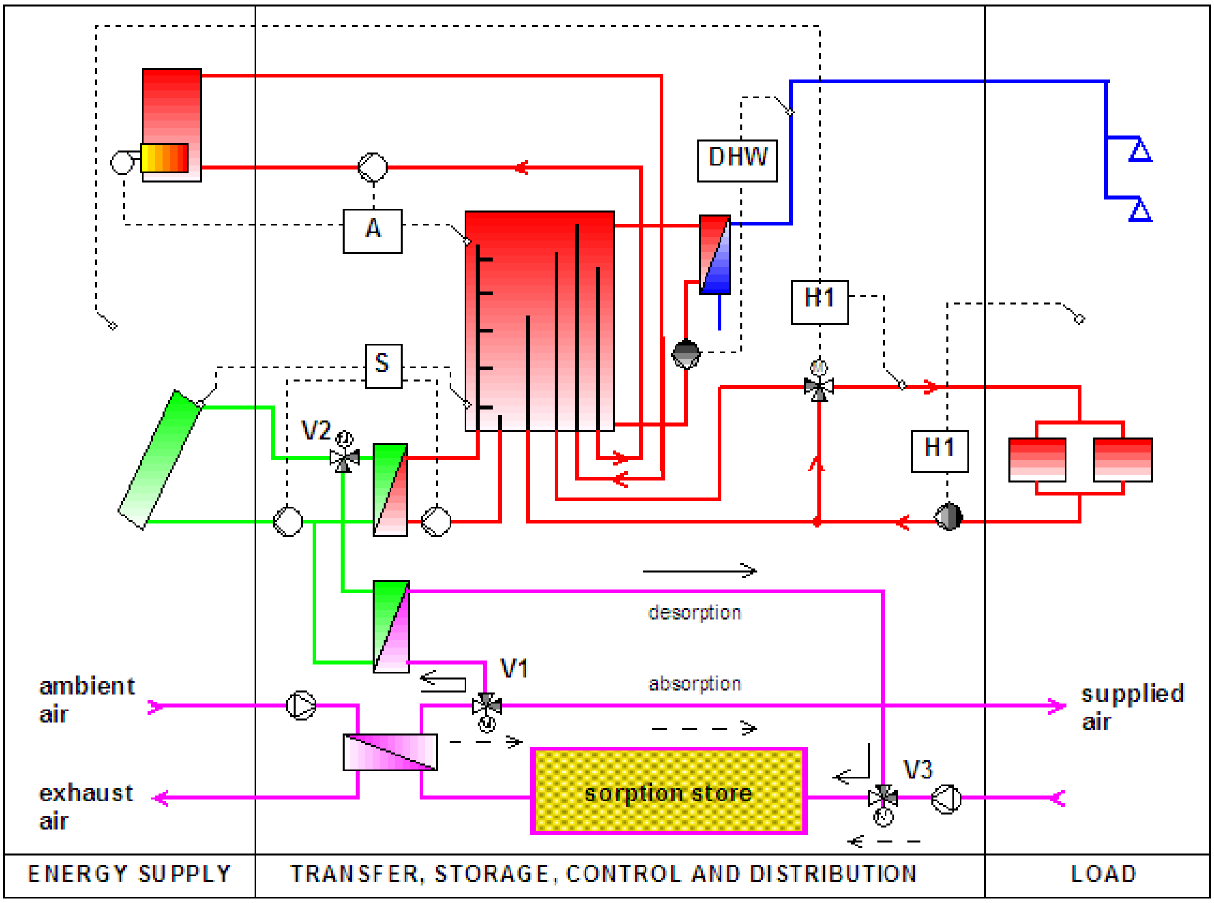

Figure 1. Principal configuration of the monosorp system.

Heat management philosophy

Solar loop:
The system provides two options of storing solar heat:

- A 1m³ combi water storage is charged as long as the cut off temperature of 80°C is not reached. The control strategy is taken from the reference simulation deck described elsewhere (Heimrath and Haller, 2007).
- Otherwise, a sorption store is charged as soon as the collector temperature reaches at least 120°C. Then, the collector loop is switched on via a water/air heat exchanger, transferring the heat to an air flow used for the desorption of the sorption store.

Space heating:
Two mechanisms of supplying heat to the rooms are realised:

- *Combined Heat Recovery System and discharging of the Sorption Store:* The heat recovery system supplies the rooms with fresh air drawn in from ambient, which is preheated by the exhaust air flow. Additionally, the exhaust air can be dried and further raised in temperature in advance by adsorbing its humidity in the sorption store (see figure above). Alternatively, the exhaust air flow can be directly lead to the heat recovery heat exchanger by switching on a sorption store bypass (not considered in principal figure above) in case that no further room heating is needed. In detail, the temperature of the supplied fresh air is controlled by splitting up the exhaust air in two part flows, an extra heated sorption store flow and a bypass flow respectively, both finally heading into the heat recovery heat exchanger with the desired mixed temperature.
  Space heating via discharging the sorption store by the exhaust air flow is restricted to a specified adsorption period, which has been fixed to December until April for the simulation studies.
- *Discharging the combi store*: In case that the options above do not fully cover the heating demand, the desired room temperature is guaranteed by the space heating system implemented in the reference simulation deck, i.e. by discharging the combi store which itself is recharged by an auxiliary heater if necessary.

Auxiliary boiler and preparation of DHW:
See reference simulation system

Cost (range)
Costs are split up in the following main parts:

- Costs as estimated for the reference combi system including a ventilation heat recovery system.
- Costs for further integration equipment of the sorption store (e.g. Water/air heat exchanger): about 2000 Euro.
- Costs for sorption storage material (zeolithe honey combs): not available yet

Market distribution
None so far.

2 Modelling of the system

2.1 TRNSYS model

The TRNSYS model consists of the reference solar combi system including a ventilation heat recovery system which has been adapted for the integration of the sorption storage. The thermal adsorption/desorption process is calculated in Pdex outside the TRNSYS environment. The final results are obtained after several TRNSYS/Pdex iteration steps.

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

2.2.1 General Setting in the TRNEDIT template

General Settings (to be chosen by TRNEDIT):

Main	
simulation timestep	1/20 h
tolerance integration / convergance	0.01 / 0.01
Length of simulation	24 months
Climate	Zürich
Building	SFH60
Auxiliary	
Nominal Power of Auxiliary	10 kW
Set temperature Auxiliary into store	63 °C
Auxiliary temperature rise	10 K
Collector	
Type	CPC (ITW: Microtherm)
Aperture area	15 ... 30 m2
tilt angle	45°
Azimuth (0° = south, 90° = west, 270° east)	20°
Primary loop specific mass flow rate	15 kg/hm2
Combi store: upper / lower dead band (switch on/off)	7 K / 4 K
Relative height of low temperature sensor in combi store	0.1
cut-off temperature of collector (combi store)	80 °C
boiling temperature of collector fluid	200 °C
Combi 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

Type: 832	Version Number: 2.06	
Collector	η_0	0.665 -
	a_1	0.59 W/m²-K
	a_2	0.00186 W/m²-K²
	inc. angle modifier *for diffuse radiation*	0.8311 -
	Area	15 ... 30 m²
	Specific mass flow	15 kg/m²h

2.2.3 Heat exchanger of collector loop

Brine/water heat exchanger (Type 5) for charging combi store

Mode	2 (counter flow)
Specific mass flow secondary side (water)	13.7 kg/m²h

Brine/air heat exchanger (Type 91) for desorption of sorption store

Effectiveness	0.95
Specific mass flow secondary side (air)	4 ... 20 kg/m²h

2.2.4 Air heat exchanger of Heat Recovery System and Desorption Process

Air/air heat exchanger (Type 91) of Heat Recovery System

Effectiveness	0.85
Specific mass flow secondary side (air)	according to reference deck (140.6 kg/h)

Air/air heat exchanger (Type 91) for preheating ambient air during desorption process

Effectiveness	0.85
Specific mass flow secondary side (air)	4 ... 20 kg/m²h

2.2.5 Pipes between Collector and Storage:

Model: One Type 31 for hot side and one Type 31 for cold side
Pipes: Total Length: 30m
For calculation of heat transfer coefficients see reference simulation deck.

2.2.6 Control of the collector loop

For charging the combi water store (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)	15 K
Storage tank protection	Temperature in the uppermost Node of the store	Cut-off Temperature T_in as defined by user (TRNEDIT)	5 K

Remark: Stagnation does no longer occur as all solar heat is used for heating up and desorbing the sorption store.

For heating up/desorbing the sorption store (Type 2):

Reason	***Sensor***	***Off-Criteria***	***Hyst.***
Upper dead band (Udb = 5K)	Collector temperature (T-coll)	On: T-coll>120°C + Udb	
Lower dead band (Ldb = -35K)	Collector temperature (T-coll)	Off: T-coll<120°C + Ldb	

2.2.7 Combi Storage:

Type: 340 Version Number: 1.99F

Storage tank	Total volume	1 m³
	Store volume for auxiliary	0.2 m³
	Media	Water

For further details see reference simulation deck.

2.2.8 Sorption Storage:

Simulated externally (Pdex)

storage volume	7.85 … 15 m3
void fraction of fixed bed	0.174
density of zeolithe	892 kg/m³
specific heat capacity of zeolithe	1.07 kJ/kg K
mean adsorption enthalpy of zeolithe (including vaporization enthalpy)	3600 kJ/kg

2.2.9 Auxiliary gas burner:

Type 370 – Specific Type, data defined by Heimrath, Haller 2007
Type 323 is used as auxiliary controller.
For further details see reference simulation deck.

2.2.10 Building

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

2.2.11 Heat distribution

See reference simulation deck

2.2.12 Draw-Off loop

See reference simulation deck.

2.3 Validation of the system model

A detailed system validation for the whole system is not available at the current state of investigation. For the following subsystems validation has been performed:

- The model of the combi system is taken from the TRNSYS reference system which is well tested.
- The numerical model of the sorption store in Pdex, here describing the ad-sorption/desorption process, is well tested and validated, compare *Kerskes H (2001)* and *Kirchner Th. (1997).*
- For the adsorption equilibrium of the zeolites, calculations have been performed which are in good accordance with the measured adsorption isotherms given by the manufacturer.

The model of the sorption store is based on two simplifications:

- The adsorption kinetics have been modelled by assuming a linear driving force,
- the heat losses have been modelled by a marginal constant standby leackage air flow through the store.

3 Sensitivity Analysis

3.1 Presentation of results

Main parameters (exemplary Case (BC)):			
Building:	*SFH 60*	Storage Volume (Combi/Sorption):	*1/ 10 m³*
Climate:	*Zurich*	Storage height	*Reference*
Collectors area:	*20 m²*	Position of heat exchangers	*Reference*
Collector type:	*CPC (Microtherm)*	Position of in/outlets	*Reference*
Specific flow rate (Collector)	*15 kg/m²-h*	Nominal auxiliary heating rate	*10 kW*
Collector azimuth/tilt angle	*45°*	Storage nodes	*Reference l*
Collector upper dead band	*10 °K*	Tolerances Integration Convergence	*0.01 / 0.01*
Simulation parameter:			
Time step	*1/20 h*		

Parameter	Variation	[1]Variation in $f_{sav,ext}$
Base Case (BC)	-	64.1%
Collector size [m^2] (fixed sorption store size 10 m^3)	20 – 30	64.1 – 69.8%
Sorption Store Volume [m^3] (fixed collector size 25m²)	7.85 – 15	65.2 – 70.9%

Sensitivity parameter 1:	Collector size [m²]	10 – 30 m²
Sensitivity parameter 2:	Sorption store size [m³]	0 – 15 m³

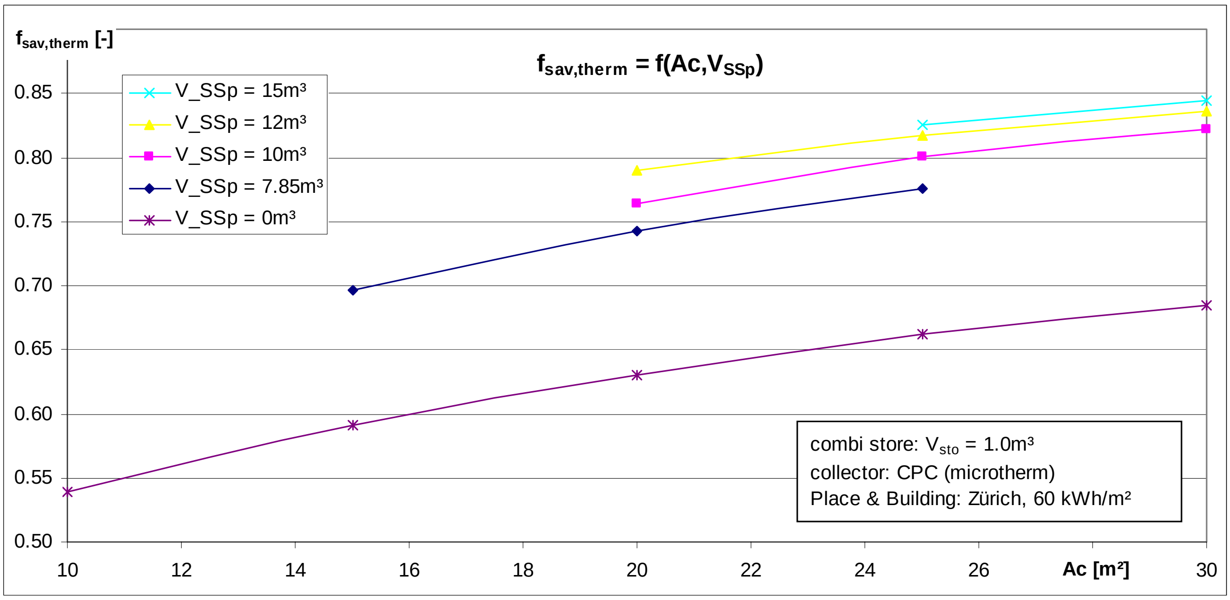

Figure 2. Variation of fractional thermal energy savings with collector size and sorption store size.

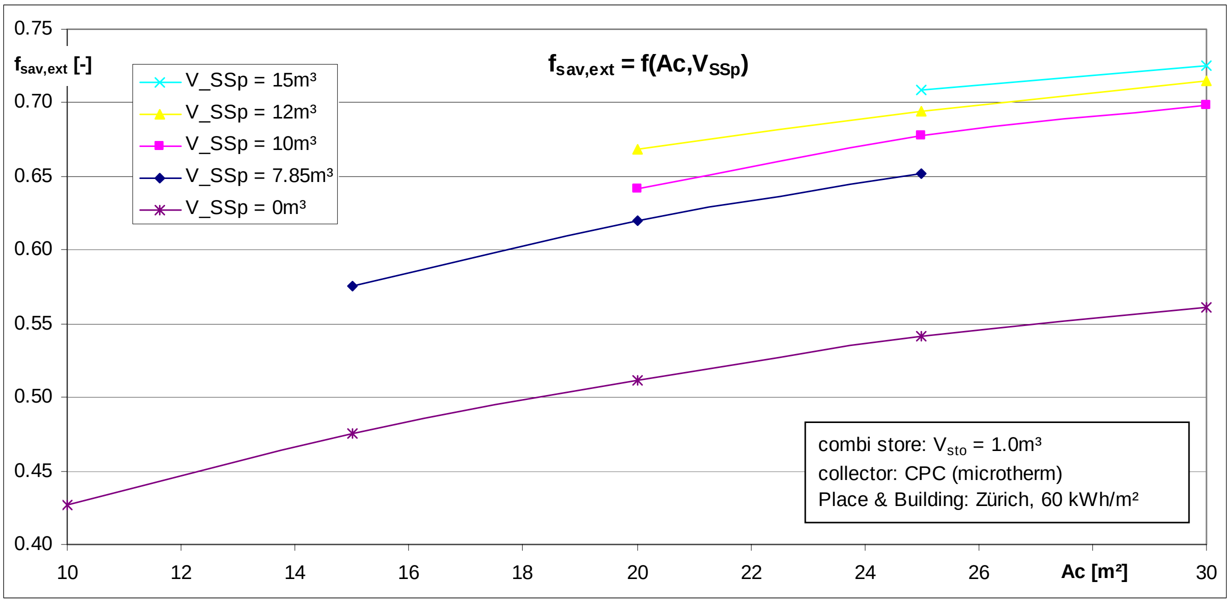

Figure 3. Variation of fractional energy savings with collector size and sorption store size.

Differences from Base Case (BC): None

Description of Results:
As expected the installation of the long term sorption storage leads to an obvious increase of the energy savings compared to a system without sorption store (V_{SSp} = 0m³). The highest saving is reached for the lowest but sufficient collector area for each storage volume, such that the sorption store can just be desorbed completely during the summer months.

Comments: None

4 Analysis using FSC

Building		SFH 60						
Climate		Zurich						
A_{col}	[m²]	15	20	25	15	20	20	25
V_{Store}	[m³]	0	0	0	7.85	10	12	15
$Q_{solar,usable,heat}$	[kWh/a]	8156	9201	10221	8156	9201	9201	10221
E_{aux}	[kWh/a]	5859	5294	4832	4352	3372	3002	2499
E_{ref}	[kWh/a]	14312	14312	14312	14312	14312	14312	14312
E_{total}	[kWh/a]	8376	7795	7326	6783	5730	5291	4648
$E_{total,ref}$	[kWh/a]	15972	15972	15972	15972	15972	15972	15972
$Q_{in,store}$	[kWh/a]	9660	9741	9807	8191	7745	7300	6997
$Q_{out,store}$	[kWh/a]	8140	8140	8140	6643	6086	5621	5230
$Q_{st,aux}$	[kWh/a]	4961	4453	4041	3544	2663	2327	1901
$Q_{st,coll}$	[kWh/a]	4699	5288	5766	4646	5082	4973	5096
$Q_{st,dhw}$	[kWh/a]	3047	3047	3047	3047	3047	3048	3047
$Q_{st,sh}$	[kWh/a]	5093	5093	5093	3596	3039	2574	2183
$Q_{HRS+SSp,sh}$	[kWh/a]	4053	4053	4053	5290	5752	6144	6513
Q_{Coll}	[kWh/a]	5404	6094	6661	7748	9668	9550	11319
$W_{pump,sol}$	[kWh/a]	158	154	152	157	148	146	137
W_{burn}	[kWh/a]	94	93	92	91	89	88	87
W_{contr}	[kWh/a]	9	9	9	9	9	9	9
$W_{pump,SH}$	[kWh/a]	349	349	349	301	275	250	198
$W_{pump,DHW}$	[kWh/a]	8	8	8	8	8	8	8
W_{vent}	[kWh/a]	388	388	388	407	414	416	421
W_{total}	[kWh/a]	1007	1001	998	973	943	916	860
FSC		0.569	0.642	0.714	0.569	0.642	0.642	0.714
FSC’								
$f_{sav,therm}$		0.591	0.630	0.662	0.696	0.764	0.790	0.825
$f_{sav,ext}$		0.476	0.512	0.541	0.575	0.641	0.669	0.709
f_{si}		0.389	0.425	0.455	0.489	0.555	0.582	0.622

Table 1 Detailed results of solar system monosorp simulations for the climate Zurich

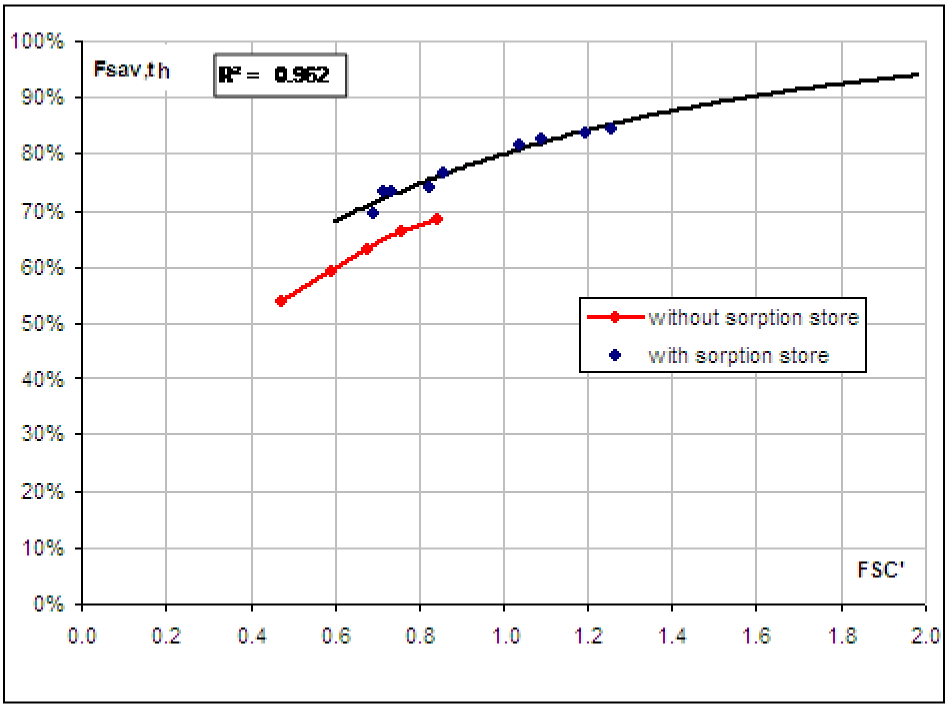

Figure 3. Variation of fractional energy savings with the fractional solar consumption (FSC') for Zurich and one load (60kWh/m²a multi family building).

5 References

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6 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 26.

6.1 One dimensional model of the sorption store in Pdex

The thermal behaviour of the sorption store is simulated outside of TRNSYS by using a parabolic differential equation solver included in the Pdex package. Yearly simulation data is iteratively transferred between TRNSYS and Pdex until a given tolerance is reached.
For more detailed description see IEA Task 32 Subtask B report 5