Simulations of Systems with Chemical and Sorption Stores

An introduction to detailed reports on 3 systems

A Report of IEA Solar Heating and Cooling Programme - Task 32

Advanced storage concepts for solar and low energy buildings

Report B6 of Subtask B

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A technical report of Subtask B

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Executive Summary

Three systems with sorption or chemical storage have been simulated with the same boundary conditions as other stores using water or phase change materials. The buildings, including heat distribution system, hot water load, climate were all the same, as were the models used for the collector circuit. This report gives a brief background to these simulations and the target functions used, while the description of the simulation models and results for these three systems are described in three sub-reports, essentially three separate reports. The results from these systems and those using water and PCM storages are compared in report A4 [7]. No inter-comparison is made in this report.

All three systems use the store for seasonal storage of solar heat, but the systems and the degree of detail of the models are very different. It is important to consider this when studying the results presented in this report and its sub-reports.

The ECN TCM Model is a simplified model for a generic compact thermo-chemical seasonal solar heat store based on absorption of a salt hydrate. Suitable hydration/dehydration enthalpy and entropy changes were defined for salt hydrates such that the resulting temperature during discharge was suitable for the load. Many other assumptions and simplifications were been made. The results thus give only an indication of potential, rather than an estimate of achievable performance for a given prototype store. Parametric studies in enthalpy change, store size, collector type and area were performed.

The Closed-Cycle Sorption Model (Modestore) has a more detailed model of the store including heat exchanger and condensor/evaporator that has been validated against measured data for a laboratory prototype using silical gel/water. The system simulations were, however, made using the pair FAM-Z01/water, that have a higher temperature lift. Parametric studies were made for the UA-values of the condenser/evaporator and adsorber heat exchangers, heat loss coefficient of the sorption store, and collector and storage size.

The open cycle Monosorp system was simulated using a detailed one dimensional model for the extruded zeolite store. This model is simulated in another program that interacts with TRNSYS. Parametric studies of the store size and collector area showed a marked increase in savings compared to the system with the water store. As with the Modestore system, there is a significant increase in parasitic electricity consumption resulting in a relatively large difference between thermal and extended fractional energy savings.

For all these systems it was shown that evacuated tube collectors were required to make the systems perform well, and that high fractional energy savings can be made with the studied storage concepts. However, the increased system complexity and material use is large for relatively small gains. For example, the template system with 50 m^2 evacuated tube collector and water store of 1000 litres gives thermal fractional energy savings of 62% for the SFH30 house in Zurich. The Modestore system with a 10.000 kg zeolite store increases this to 79%. 85% savings could be achieved with a further 5.000 kg zeolite and 10 m^2 collector area. Each percentage point is equivalent to 100 kWh saved energy per year for these conditions. The Monosorp system had better savings, but this is partly due to the heat recovery that is part of the system.

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

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.

The density of storage for these techniques compared to that of water is theoretically 2 to 10 depending on the temperature range of comparison.

This reports describes the method that was used to simulate sorption storage concepts and is an introduction to the detailed reports of each of the 3 systems that has been simulated by 3 expert teams within Task 32.

The Operating Agent would like to thank the authors of this document 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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SUB-REPORTS
(System simulation results as separate reports, reports B6.1 – B6.3)

B6.1 **ECN TCM Model (Herbert Zontag, ECN, Holland)**

B6.2 **Closed-Cycle Sorption Storage “MODESTORE” (Dagmar Jaehnig, AEE-INTEC, Austria)**

B6.3 **Monosorp (Henner Kerskes, Karola Summer, ITW, Univ. Stuttgart, Germany)**

Nomenclature

Q_{SH}	space heating demand
Q_{DHW}	domestic hot water demand
$Q_{loss,ref}$	reference system losses
$E_{ref,month} = \frac{Q_{SH} + Q_{DHW} + Q_{loss,ref}}{\eta_{boiler,ref}}$	monthly final energy demand of reference system boiler
$E_{ref} = \frac{Q_{SH} + Q_{DHW} + Q_{loss,ref}}{\eta_{boiler,ref}}$	annual final energy demand of reference system boiler
Q_{boiler}	thermal energy load of auxiliary boiler
η_{boiler}	mean annual efficiency of auxiliary boiler
$E_{boiler} = \frac{Q_{boiler}}{\eta_{boiler}}$	final energy consumption of auxiliary boiler
$W_{el.heater}$	thermal energy load of el. heating element
$\eta_{el.heater}$	mean annual efficiency of el. heating element
$E_{el.heater} = \frac{Q_{el.heater}}{\eta_{el.heater}}$	primary energy consumption of el. heating element
W_{par}	parasitic energy consumption of solar combisystem
η_{el}	electricity generation efficiency
$E_{par} = \frac{W_{par}}{\eta_{el}}$	primary parasitic energy consumption of solar combisystem
$W_{par,ref}$	parasitic energy consumption of reference system
$E_{par,ref} = \frac{W_{par,ref}}{\eta_{el}}$	primary parasitic energy consumption of reference system
$E_{aux} = E_{boiler} + E_{el.heater}$	combined auxiliary energy consumption of solar combisystem
$E_{total} = E_{aux} + E_{par}$	combined total[1] energy consumption of solar combisystem
$E_{total,ref} = E_{ref} + E_{par,ref}$	combined total energy consumption of reference system

[1] The losses from refining and transportation of the fuels were neglected.

1 Introduction

One of the targets of IEA-SHC Task 32 was to compare different advanced store concepts for solar combisystems by means of annual system simulations. The following report summarizes the simulation methodology and the results for the systems using sorption and chemical storage.

To describe the performance of solar combisystems and to carry out an adequate comparison with detailed simulation models, it needs to be recognized that the result of a comparison depends on:

1.) the chosen **reference conditions** concerning energy demands, energy sources, parameter settings, and standard components,
2.) the **output or target function** of the annual system simulation that serves as a measure of the combisystem performance (e.g. the saved gas consumptions of a combisystem compared to the gas consumption of a non-solar reference heating system), and
3.) the **mathematical accuracy** of the system simulation and the choice of the same simulation models for identical parts of the systems

In order to carry out a comparison between combisystems that do not correspond to the reference conditions defined in [6], these non-complying combisystems were additionally characterized in a way that allows comparisons of different system designs for various climates and system sizes. A description of a **characterization method** developed in the framework of Task 26 is given in [1] and [2] and the extended method, including factors for seasonal storage, is given in [5].

2 Methodology of Modelling

2.1 Reference Conditions

The reference conditions are given in detail in [6]. They are summarized in the follwing:

- **Climate:** In order to cover the geographical range for the main markets of solar combi-systems it was decided to choose a moderate Northern European climate (Stockholm), a moderate, Central European climate (Zurich), a Mediterranean coastal climate (Barcelona) and a Mediterranean continental climate (Madrid) for all simulations. The hourly weather data was that included with the TRNSYS package, based on synthetic hourly data produced by Meteonorm 4 [3] based on long term average monthly values. Additionally the yearly temperature fluctuation of the ground water was taken into account.

- **Heat demand of buildings:** The heat demand of the buildings was defined by reference buildings with reference conditions for user behaviour, occupation, etc. These building models were also part of the TRNSYS model of each solar combisystem. Four single-family houses (SFH) of the same architectural design with 140 m^2 of floor area, but different insulation thicknesses and/or different ventilation systems, were defined in a way that the specific annual space heating demand for the Zurich climate amounts to 15, 30, 60 and 100 kWh/m^2a. The room temperature was allowed to vary between 19.5 and

24°C during the heating season. In the reference case the heat was delivered via radiators (NON-standard TRNSYS type 362 radiator). The flow temperature was controlled via the ambient temperature and internal loads were accounted for by thermostatic valves (NON-standard TRNSYS type 320 PID-controller).

- **Domestic hot water (DHW):** The DHW demand was fixed with 200 litres/day per house or apartment. The daily distribution was calculated with a software tool developed by [4]. It is based on a statistical distribution of the occurrence of having a bath-tub, taking showers, washing hands, etc. coupled with weekday/weekend differences and vacation periods. Figure 1 show an example of the domestic hot water demand over a period of three days.

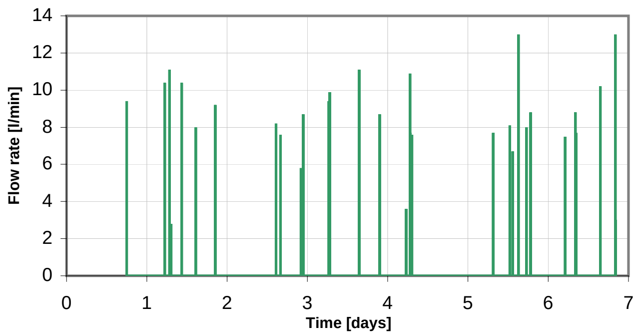

Figure 1 Domestic hot water demand for 72 hours and 200 litres/day [4]

- **Auxiliary heating device**: A burner model for a gas boiler were defined by specific characteristics such as range of modulation, convective and radiation losses, standby temperature etc. as standard burner models. Non-standard TRNSYS Type 370 was used for the burner calculations, the controller for the burner was non-standard TRNSYS type 323.

- **Solar collector:** Three types of collectors were defined for the comparisons; a typical flat plate collector with optically selective coated absorbers, a similar collector with non-selective surface and a typical evacuated tube collector. The collector parameters are shown in [6]. The NON-standard TRNSYS type 832 was used as collector model. Additionally the connecting tubes of the collector loop were defined.

- **Electricty consumption:** The parasitic electricity demand of a combisystem, W_{par}, and of a reference heating system (see chapter 2.2), $W_{par,ref}$, was defined as the sum of the annual electricity consumption, other than for heating, of all electrical system components (pumps, burner devices, valves and controllers).

2.2 Target Functions

The target function for the optimisation is based on fractional energy savings f_{sav} of the solar Combisystem compared to a reference system. According to CEN/TC 312, ISO/TC 180, f_{sav} is related to the purchased auxiliary energy. The reference systems were defined with the reference buildings for each climate coupled with a gas-boiler driven radiator heating system. No space heating water storage was used, the volume of the DHW store was 150 liters. Three different indicators were used, the same as those used in IEA-SHC Task 26 [1].

Fractional thermal energy savings ($f_{sav,therm}$)

This definition gives fractional energy savings based on the saved fuel input of the solar combisystem compared to the reference heating system.

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

with:

$\eta_{el.heater}$ = 40% for all systems in Task 32

Extended fractional energy savings ($f_{sav,ext}$)

In this definition, the above value takes into account the parasitic electricity W_{par} used by the system.

equ.2: $$f_{\text{sav, ext}} = 1 - \frac{\dfrac{Q_{\text{boiler}}}{\eta_{\text{boiler}}} + \dfrac{Q_{\text{el.hetaer}}}{\eta_{\text{el.heater}}} + \dfrac{W_{\text{par}}}{\eta_{\text{el}}}}{\dfrac{Q_{\text{boiler, ref}}}{\eta_{\text{boiler, ref}}} + \dfrac{W_{\text{par, ref}}}{\eta_{\text{el}}}} = 1 - \frac{E_{\text{total}}}{E_{\text{total, ref}}}$$

with:

$\eta_{el.heater}$ = 40% for all systems in Task 32

η_{el} = 40% for all systems in Task 32

Fractional savings indicator (f_{si})

This last definition includes also a penalty $Q_{penalty}$ for not fulfilling the comfort criteria's of domestic hot water (DHW) and room temperatures as described in [6] is added to the solar combisystem in the fractional energy savings, while the equivalent penalty for the reference system ($Q_{penalty,ref}$) is subtracted from it.

equ.3: $$f_{si} = 1 - \frac{\dfrac{Q_{boiler}}{\eta_{boiler}} + \dfrac{Q_{el,heater} + W_{par}}{\eta_{el}} + Q_{penalty} - Q_{penalty,ref}}{\dfrac{Q_{boiler,ref}}{\eta_{boiler,ref}} + \dfrac{W_{par,ref}}{\eta_{el}}}$$

2.3 Model calibration, optimization, sensitivity analysis

All TRNSYS system models of IEA-SHC Task 32 were checked for accuracy before the sensitivity analysis was performed. All systems were simulated with the same TRNLIB.DLL, which was supplied by TU Graz to the Task. Any additional components necessary to simulate the system were located in standalone DLL's, to be used for those specific systems.

The **simulation procedure** for the different systems was defined by a two step approach:
In the first step a sensitivity analysis was performed on each system model, where one parameter at a time was varied from a 'base case' with typical collector areas and store volumes.

In the second step values for the FSC method [1], that was extended in Task 32 to include the effects of seasonal storage (see report A3 [5]). The comparison of the systems based on these values are presented in report A4 [7].

The following steps were to be performed during the simulation procedure:

- Model the system in TRNSYS for the relevant climate (preferably Zurich) and the 60 kWh/m²a building with collector area and store volumes set by the participant.

- The target functions for the analysis are based on fractional energy savings. Three functions (ref. to chapter 2.2) are defined.
- Do a sensitivity analysis with this model.

- Optimize the system using the specified target function in chapter 2.2 (by hand and automatically). If available, cost functions can be included in the optimization. However, no systems from Subtask B have been optimized.

- Besides: country or company specific calculations could be performed

It should be mentioned that each participant of Subtask B of Task 32 did as much as possible within the system simulations, but of course, was restricted by funding available for the Task.

2.4 Common Report Structure

A common report structure for the system simulation reports was defined in Subtask C in Task 26. It consists of the following parts:

1 General description of the system
2 Modelling of the system
  2.1 TRNSYS model
  2.2 Definition of the components included in the system and standard inputs data
  2.3 Validation of the system model
3 Simulations for testing the library and the accuracy
4 Sensitivity Analysis and Optimization (the latter optional)
  4.1 Presentation of results
  4.2 Definition of the optimized system (optional)
5 Analysis using FSC
6 Lessons learned
7 References

3 Systems Modelled

The following 3 Systems were modelled within Subtask B of Task 32 and are described in detail in the following annexes to the report. A comparison of these results and those for simulations for systems with water and PCM stores is reported in report A4 [7] of Task 32.

Each are reported in separate reports, the numbers of which are given below.

Reports and Systems:

IEA-SHC Task 32 B6.1, ECN TCM Model (Herbert Zontag, ECN, Holland)

IEA-SHC Task 32 B6.2, Closed-Cycle Sorption Storage “MODESTORE” (Dagmar Jaehnig, AEE-INTEC, Austria)

IEA-SHC Task 32 B6.3, Monosorp (Henner Kerskes, Karola Summer , ITW, Univ. Stuttgart, Germany)

All are available on www.iea-shc.org under: Task 32, Publications.

4 Quality of the simulations

Modelling complex storage processes is not an easy task speically if the store is to be included in a system such as a combisystem.

We believe that Task 32 experts have achieved to derive new store models and fairly confident results as a first step in analyzing promising chemical storage.

5 References

[1] Weiss, W. (ed.), Solar Heated Houses - A Design Handbook for Solar Combisystems, James&James Science Publisher, 2003

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[5] Letz Thomas et al., Performances of solar combisystems with advanced storage concepts, December 2007, 46 pages, Technical Report A3 of Subtask A, IEA SHC-Task 32, www.iea-shc.org.

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