Final report of Subtask B
"Chemical and Sorption Storage"
The overview

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

Advanced storage concepts for solar and low energy buildings

Report B7 of Subtask B

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Task 32 Storage

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Final Report of Subtask B "Chemical and Sorption Storage"

by

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Final report of Subtask B

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Executive Summary

This report is the final report of a Subtask of the Task 32 "Advanced Storage Concepts for solar and low energy buildings" of the Solar Heating and Cooling Programme of the International Energy Agency.

As a final report of a Subtask it has two aims:

1. it summarizes all the works conducted in the Subtask during the period of the Task (June 2003 – December 2007) highlighting some important results that the participants in the Subtask reached and it refers to all the detailed documents that have been produced by the Subtask and Task 32,
2. it presents some hints on the management of an IEA Subtask in order to improve future collaborative works within this framework

In Subtask B, major achievements have been:

1. Identification of potentially suitable materials for long term storage of solar heat and publication of material properties.
2. Documentation of State of the Art in chemical and sorption storage in Task 32 Handbook.
3. Development of new concepts of short and long term storage of solar heat to prototype stage with lab and field tests.
4. Development of models for simulation of chemical and sorption storage.
5. Simulation of three systems with long term chemical or sorption storage with the Task 32 boundary conditions (reports for only two of these were completed).
6. Support in the commercialisation of a chemical heat pump with short term thermal storage for solar heating and cooling applications.
7. Input for the storage part of the strategic research agenda of the European Solar Thermal Technology Platform, further refining the compact heat storage R&D questions that should be tackled on an international level.

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

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"

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 global view on the activities and results of the Subtask B of Task 32 during 4,5 years, a subtask devoted to "Chemical and Sorption storage".

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.

My very special thanks go to the Subtask B leader Chris Bales who has committed himself to Task 32 work all along the Task years and has managed to bring more light and knowledge to the international community of solar experts on this difficult topic "chemical and sorption storage".

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Table of Contents

1 Description of scope of Subtask

Subtask B dealt with a type of storage technology that is new for solar thermal, namely chemical reactions and sorption storage. The scope, in terms of general system aspects, for Subtask B was the same as that for the whole of Task 32, namely solar heating and cooling systems for residential buildings, principally detached houses for one up to a few families. Buildings with a larger specific heat load (>100 kWh/m^2 for Zurich climate) are not considered. The main focus was to be storage solutions sized to achieve a significant solar fraction.

In terms of temperature, the storage solutions have been limited to temperatures < 250°C, with the emphasis on materials suitable up to around 150°C.

The scope in terms of storage concepts includes chemical reactions and thermo-chemical storage, which in this subtask is restricted to sorption processes, both adsorption and absorption. Figure 1 shows a classification of processes for chemical and thermo-chemical storage of heat. All types of the processes given in the diagram have been addressed in the task, but not all materials.

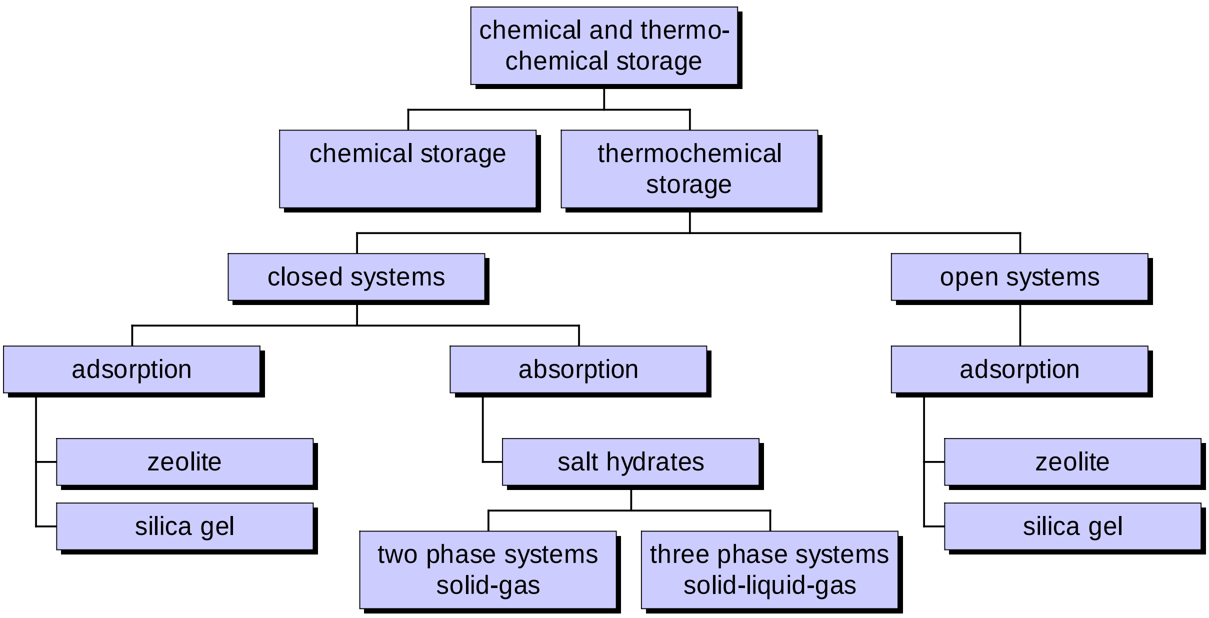

Figure 1. Classification of chemical and thermo-chemical processes for heat storage applications [1].

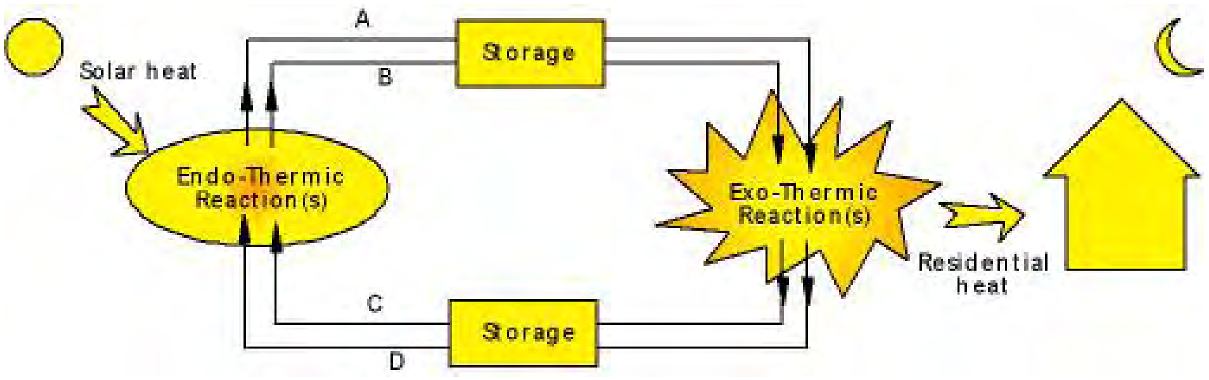

Figure 2. Schematic of Solar Energy Storage in Chemical reactions [1].

Figure 2 shows a schematic of the basic principles of chemical storage of heat, requiring reversible endothermic and exothermic reactions at suitable temperatures for this application. A, B, C & D refer to different chemical substances formed and used in these reactions.

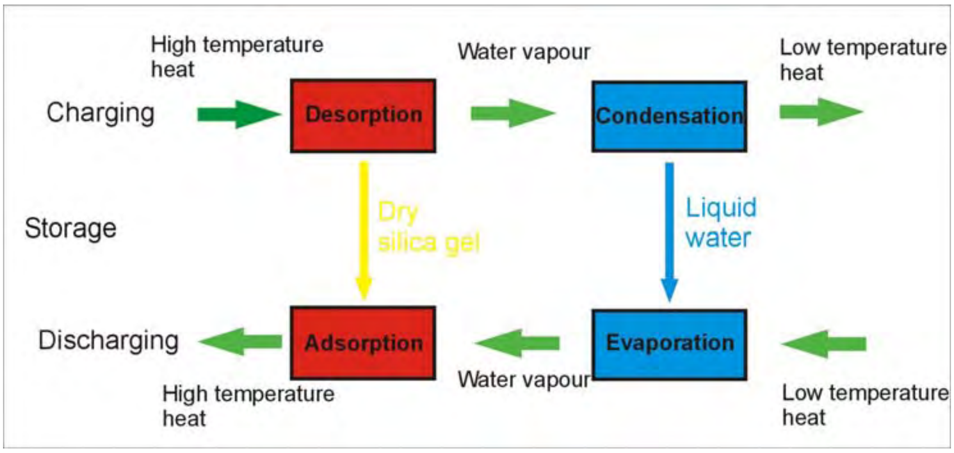

Figure 3. Working principle of an adsorption heat storage in a closed system [1].

Figure 3 shows the basic principle of a closed sorption (thermo-chemical process) where heat, but not matter, is exchanged with the ambient and the sorbate needs to be condensed in the charging phase and then evaporated in the discharge phase. The evaporation process requires low grade heat >~5°C to evaporate the water used in all sorption stores in Subtask B. This low grade heat can be extracted from the building, thus cooling the building, or from the ambient or other “free” source while the exothermic sorption into the sorbent is used for heating the building. The thermal storage can thus be used for providing cooling or heating.

2 Projects within Subtask B

There were six related projects included in Subtask B of Task 32. Table 1 show their basic data. Only one of the projects deals with chemical reactions, that based at ECN in Holland. The others are based on sorption, two with close absorption and three with adsorption. Of these only one system is an open system, Monosorp that has been developed by ITW in Germany. All projects apart from that for the Thermo-chemical accumulator (TCA) deal with seasonal storage of heat, while the TCA project is more related to cold storage.

Table 1. Projects within Subtask B of IEA-SHC Task 32 and brief description of the contents of relevance to Task 32.

Group / Project	Description
ECN and Univ. Eindhoven, Holland. *Compact chemical seasonal storage of solar heat.*	Theoretical analysis of suitable chemical reactions in the range 60 - 250°C. Choice of most suitable material and experimental studies of material properties ($MgSO_4.7H_2O$). Simple modelling of the chemical heat store and system simulations with the Task 32 boundary conditions.
SERC, Högskolan Dalarna, Sweden. *Evaluation of thermo-chemical accumulator (TCA)*.	Measurements on a prototype and commercial TCA chemical heat pump, based on a 3-phase closed absorption process, in the lab. Modelling of the process and of the prototype and commercial machines. System simulations for cooling in district heating and solar cooling systems for Swedish and Spanish conditions.
Institut für Solartechnik SPF, Switzerland. *Sorption storage.*	Solid closed system adsorption process with zeolite or silica gel. Studies of material properties and theoretical analysis. Measurements of heat and mass transfer dynamics.
AEE INTEC, Austria. *Modestore (Modular high energy density heat storage).*	Design of closed system adsorption heat store with silica gel with all components integrated into one unit. Testing in the lab and in the field. Modelling of the store, design of system and then simulation for full scale domestic seasonal storage for the Task 32 boundary conditions.
ITW, Univ. Stuttgart, Germany. *Monosorp.*	Initial study of open adsorption system using zeolite. Heat storage and removal from the store utilises the ventilation heat recovery system and moisture in the house. Measurements on prototype heat store in the lab. Modelling of the store and design of system. System simulations of seasonal storage for German conditions as well as the Task 32 boundary conditions.
EMPA, Switzerland. *Closed NaOH absorption storage.*	Development of closed two-phase absorption process with NaOH. Measurements on a prototype in the lab.

3 Main results of Subtask B

Only one storage solution dealt with in Subtask B has become commercial within the time frame of Task 32 (TCA). This has been commercialised by the company ClimateWell from Sweden, with over 35 stores/heat pumps having been sold, mostly for solar heating and cooling systems in Spain. ClimateWell were not represented directly within the Task, but had strong collaboration with SERC who did participate. A demonstration system of a closed adsorption store was made in the Modestore project, but the materials available for the field test were shown to be not suited for seasonal storage. Three other projects have got as far as design and testing of lab prototypes of sorption stores, and the sixth project is still in the stage of material characterisation.

3.1 Compact Chemical Seasonal Storage of Solar Heat (ECN and TU Eindhoven, Holland)

The main findings of the studies on storage through chemical reactions, as reported by ECN and TU Eindhoven, are the following:

- An extensive theoretical study at ECN [2, Subtask B report B2] indicated magnesium sulphate heptahydrate as potential interesting storage material using the following reversible reaction: $MgSO_4.7H_2O(s) + heat \Leftrightarrow MgSO_4(s) + 7H_2O(g)$
  The theoretical storage density of the material is 11 times that of water [Subtask B report B4].
- Initial characterization experiments reveal that the dehydration of $MgSO_4.7H_2O$ actually proceeds through three steps: first, $MgSO_4.6H_2O$ is formed after releasing one water molecule, in the second step 5.8 water molecules are released and finally $MgSO_4$ is formed in the third step. The second dehydration step is most interesting since it is able to store ~420 kWh/m3 energy (6 times that of water) [3, Subtask B report B4]
- After dehydration, $MgSO_4$ was able to take up water in a single step until $MgSO_4.6H_2O$ was formed. The vapour transport between the particles is the limiting factor for hydration of magnesium sulphate [3, Subtask B report B4]
- The cyclability of the material at hydration temperature of 20°C was very good, however, no water uptake was observed at 40°C, which may be caused by a lower water vapour pressure. Currently, experiments are performed to investigate this observation [Subtask B report B4].
- System studies were carried out, indicating that a large increase in solar fraction can be obtained by adding a TCM storage to a solar system with sufficient collector area. Care should be taken to find materials with a good DH (not too low for heating, but also not too high for the solar array). The system performance turned out to be very sensitive to the value of DH. Correspondingly, the system yield was found to decrease significantly if flat-plate collectors were used instead of vacuum tube collectors. [report B6].
- It was found that the coupling of the TCM system to a water storage tank significantly reduces the power requirements on the TCM reactor [report B6]. The water tank can then supply the high-power loads, while the TCM tank can afterwards recharge the water tank at a lower power level. Simulations were carried out for the case in which the solar collector system gives priority to the charging of the water tank and uses any excess heat to charge the TCM tank. However, it is now very important that the solar array is large

enough to be able to provide significant charging of the TCM tank. For the case of the 15 kWh/m2/a building in Zürich (total load 7.3 GJ for space heating and 10.9 GJ for domestic hot water), it was found that the collector array required to charge a 6.6 GJ TCM storage completely was about 20 m^2 vacuum tube if a TCM material with a DH of 66 kJ/mol of water was used; for higher DH the required collector area increases strongly.

More details can be found in the IEA-SHC Task 32 reports: B1, B2, B4, B5 and B6.1.

3.2 Closed Three-Phase Absorption (SERC, Sweden)

The main findings of the studies on the TCA technology [8], as reported by SERC, are the following:

- In comparison to storage in water, cold storage is more interesting that heat storage, as the available temperature range for water is much lower for cold than for heat. For the commercial machine the storage density for the store (that is also a heat pump) is roughly 5 times greater than that for water for cold whereas it is only 1.5 times greater for heat [4].
- The thermal storage of the TCA is sufficient for small scale solar cooling applications that do not have large night cooling loads. Otherwise additional storage is required. [4,5].
- The temperature lift for the prototype and commercial heat pump/stores is relatively low and limits the application range to systems with low temperature differences between cold/heat distribution system and the desired temperature of the conditioned space [5].
- LiCl, the salt used in all stores so far, is not suitable for seasonal storage due to its high cost (~3600 €/m^3) [4]. However, the storage density would be approximately 2.7 times that of water for seasonal storage of 1000 kWh.
- A TRNSYS model of process [6] and the controller for commercial machine [7] has been developed and is available from the authors.
- The problems with unwanted crystallisation and non-condensable gases in the storage have been solved and the store has been redesigned for rational production resulting in a reliable process [4, Subtask B report B7]. The technology has been commercialised under the product name ClimateWell 10. The heat pump/store is sold mainly for solar heating and cooling applications in the Mediterranean countries [9].

More details can be found in the IEA-SHC Task 32 reports: B1, B3, B4, and B5.

3.3 Solid Closed Adsorption Storage (SPF, Switzerland)

The main findings of the studies on closed adsorption storage, as reported by SPF in Switzerland, are the following:

- The geometrical parameters and the dynamical behaviour of the closed sorption system are strongly related. The available temperature depends on the pressure of the sorbate and the driving force is limited by the external temperature ranges - the low temperature energy source - the mid temperature source/sink and – the high temperature energy source, which is aimed to be a solar collector.
- The measured temperature behaviour as a function of time in the sorbent module and in the sorbate (water) tank is indicating an optimum cycle time in the range 3 to 8 min. The determined power output shows a higher system performance for cooling than for heating because of a higher heat transfer in the evaporation of the sorbate. Regarding the short cycle time and the higher power output for cooling, the adsorption process is more suitable for cooling application of a thermally driven heat pump. At this development level a scaling up to long term storage is doubtful.
- A further understanding of the sorption system will be needed for a maximum power design because it will be determined by the geometric dimension of the system i.e. particle distribution of the sorbent fixed bed in a defined solid sorbent – liquid sorbate material combination.
- In a comparison of the solid adsorption and a the liquid absorption processes the liquid system could be favoured for storage application – exactly because the fluid can be pumped from one storage tank through a reaction zone to an other storage tank.
- Thermal energy storage in a sorption storage system is depending on the available thermal energy sources and sinks. So, the selection of the sorbent – sorbate material combination has to be done under these general conditions, beside of others. With the idea of the reduction of moving parts i.e. pumps in a solid sorption system the power limiting low heat transfer coefficients are leading to a layer structure in the sorption module. But a layer structure applied to a heat exchanger will limit the energy output of the system.

More details can be found in the IEA-SHC Task 32 reports: B1, B3 and B4.

3.4 Modestore (AEE INTEC, Austria)

The main findings of the studies on closed adsorption storage, as reported by AEE-INTEC in Austria, are the following:

- A sorption heat store with the material pair silica gel and water was developed, the system was scaled up for use in a single-family house and a first pilot plant was built.
- In this project, it could be shown for the first time that sorption technology for heat storage is technically feasible in a live test. The system concept, as well as the control strategy, have been proven to be functional under real operating conditions.
- The operation of the system was satisfactory and the system concept could be implemented in further systems. It has been shown that sorption storage with the used material combination is technically feasible. However, the temperature lift that can be achieved is only technically useful in a relatively small range of water contents. As long as the silica gel is very dry, the temperature lift is sufficient. But starting at a water

content of approximately 13%, the temperature lift is not large enough to compensate for higher losses in heat exchangers, pipes and tanks. That means that the energy density of the material that can be used in a real application is much smaller than both the theoretical one and what has been measured under laboratory conditions. Therefore, a large quantity of material would be necessary which makes sense neither technically nor economically.

- The used material has been chosen because it is manufactured in mass production and therefore inexpensive. Up to now, there are very few research institutes that develop sorption material specifically for heat storage. In most cases, the focus is on heat pumps, cooling machines or gas separation and drying processes. Singular projects have shown that the development of sorption materials for heat storage is technically feasible. So far, these materials have been expensive or for example corrosive.
- A TRNSYS model for the sorption store including the evaporator/condenser heat exchanger has been developed and a TRNSYS deck has been set up for the Task 32 reference conditions.
- For the simulations reported in report B6, a different sorption material has been used to show the possibilities of the store/system concept. The system concept was similar to the one used in the field test system which was using the sorption store only for space heating and not for domestic hot water preparation. This was done because of the low temperature lift of the material pair silica gel / water. The temperature lift of the material chosen for the simulations is much higher. Therefore, domestic hot water preparation would be feasible. But in the simulations, the solar fraction was limited to a value below 100% even for very large storage volumes because of the mentioned system design.

More details can be found in the IEA-SHC Task 32 reports: B1, B3, B4, B5 and B6.2.

3.5 Monosorp (ITW, Germany)

The main findings of the studies on open adsorption storage designed for seasonal storage of solar heat, as reported by ITW in Germany, are the following:

- An effective sorption storage integrated in a conventional mechanical ventilation system has been developed in the Institute of Thermodynamics and Thermal Engineering (ITW), University of Stuttgart and was theoretical and experimental investigated
- For the first time, highly filled zeolite honeycomb structures made by extrusion of zeolite powder using thermoplastic polymers as plasticising aid and binder are used as adsorbent. Honeycomb structures have decisive advantages compared with fixed beds of spheres or other shaped bodies. They show excellent adsorption kinetics and generate low pressure losses along the process length. In open cycle processes low pressure drop is important to minimise the electric power consumption of the fans.
- Theoretical analysis has been carried out. Special attention has been given to precisely incorporate the appropriate physical and chemical processes that occur during adsorption and desorption, into the theoretical model; this will then reflect the proper performance of the proposed sorption system under real practical conditions.
- Simulation of the space heating for a residential building based on sorption storage was carried out using TRNSYS. The sorption process was evaluated using a 1-D two-phase model with heat- and mass-balance in a separate numerical routine.

- A prototype sorption storage tank integrated into a commercially available residential heating system has been built at ITW. The system has been scaled to achieve short cycles on a weekly basis, so that the system could be tested under varying conditions.
- Theoretical analysis shows that, compared to the adsorption period, the desorption process is more sensitive to several input parameters.
- Experiments have been carried out that demonstrate the technical feasibility of the proposed system under real operating condition. The experimental results concerning the thermal behaviour of the adsorption/desorption process and the achieved heat storage capacity are in good agreement with the theoretical analyses. Furthermore it has been shown that the solar thermal desorption under transient conditions using high performance CPC collectors performs well. Special attention was given to achieve the necessary high desorption temperature of 180°C inside the sorption store.

More details can be found in the IEA-SHC Task 32 reports: B1, B4, B5 and B6.3.

3.6 Two-Phase Closed Absorption Storage (EMPA, Switzerland)

The main findings of the studies on closed adsorption storage, as reported by EMPA in Switzerland, are the following:

- The heat capacity of the NaOH storage (2 stages) compared to a water storage is about 3 times better for domestic hot water (DHW) and about 6 times better for heating purposes (heating floor). The calculations are made for a building located in central Europe.
- The heat capacity of a one stage (one process unit per storage) system especially for DHW is insufficient. The above specified heat capacity is only given with a second stage.
- The storage is intended to be charged with solar energy with no auxiliary heater. To avoid too big storage volumes, the buildings must be built in low energy standard like “Passive House” or “Minergie” (Swiss standard).
- NaOH – lye as sorbent has a good cost benefit ratio. NaOH is a by-product of the PVC production and costs only about 250€/m³. The estimated volume of NaOH – lye for a passive house is about 5 m³. This figure depends strongly on the climate and the used solar collector area.
- The separation of the process units and the tanks into independent modules, leads to a simple control strategy. In the process unit, there are only small amounts of mass of the chemical process involved. This allows continuous operation.

More details can be found in the IEA-SHC Task 32 reports: B3 and B4.

4 Future work on the Subtask B topic

The work in Subtask B (and outside of it) has taken chemical and sorption storage further from theory to practice and commercialisation. However, there are a number of things that were planned for the Task but which were not completed:

- No simulations of short term sorption storage for heating and cooling were carried out with the Task 32 boundary conditions.
- No simulations of closed sorption acting as heat pumps together with a boiler were performed.
- Boreholes as heat sink and source were planned to be simulated for a number of systems, but the parameter values for Spanish conditions were not identified in time.
- Monitoring and documentation of prototypes and commercial stores in the field.
- Theoretical study and lab testing of two stage charge or discharge of the two-phase absorption store. This should increase the storage density by making it possible to discharge the store to lower concentrations at the cost of lower storage efficiency.

The work of Subtask B has shown that there are promising sorption storage solutions that should be further developed and tested at least in field trials. The work has also shown that current materials are a limitation for the processes that have been studied. The following areas are suggested for future work in the field, in addition to the studies listed above that were planned but not completed within this Subtask:

- Research in materials for seasonal storage. This is required for closed three-phase absorption, open and closed adsorption as well as chemical reactions. The current materials are either too expensive, do not have the correct properties, or have not yet been shown to work in prototypes with realistic boundary conditions. Fundamental materials research is needed to get a better understanding of the physicochemical mechanisms.
- The work on $MgSO_4.7H_2O$ shows it is has a very good potential for seasonal storage. However, the material needs to be tested in a prototype to check whether there are any practical problems with melting, cyclability and degradation in general as well as heat transfer.
- The numerical modelling of the heat and mass transfer processes in thermochemical materials is still very basic. Model improvement will result in new tools to better understand the dynamic behaviour of the TCM processes and assist the material development in this field.
- For short term storage, research is required to find suitable materials and operational conditions that give a suitable temperature lift for cooling and heating together with sufficiently high energy density for storage. The cost of the material is not as important as for seasonal storage, but it is still an important factor.
- Studies on sources of low grade heat for heat pumping using closed processes. The sorption (and chemical reaction) processes studied in this Subtask, all use water. This needs to be evaporated before it is recombined with the active substance. This energy has to be either extremely low cost or free, and additionally has come from a heat source of at least ~5°C.
- The Monosorp concept is very promising and is suited for a full scale field test. However, at present their is no commercial method for extruding the zeolite monoliths required in the store.

- Seasonal stores are not charged once and then discharged. During autumn and spring there are periods with both charging and discharging. The store operates at different temperatures for these two states. More study is required to understand how best to recover the sensible heat during these changes in store temperature and whether it is best to segment the store so that only smaller portions undergo theses changes.
- One focus for further development in this technology field can be on new materials – like ionic liquids or functional adsorption materials (H. Kakiuchi, Mitsubishi Chemical Group) – which will have a higher sorption mass ratio in the temperature range reachable by solar thermal collectors.

5 Management aspects of Subtask B

Subtask B was organized this way:

- The general aims of the Subtask were defined in the Task definition.
- In practice, all groups that wanted to participate and whose projects were within the scope of the Subtask were welcomed into it. One group was only active in Subtask B at the very end of the Subtask, that from EDF in France.
- Additionally, other groups have contributed to the chapters in the handbook and initial meetings, but have not received finance to participate fully.
- Subtask B meetings were held in the plenary sessions of the Task 32 experts meetings. At the first meetings, the majority of the time was devoted to presentations of recent studies, but towards the end more emphasis was put into discussions on inter-comparison and contents of reports.
- Additionally all members working with adsorption have attended a meeting on adsorption including other interested groups.
- The subtask leader visited several of the groups in order to gain a better understanding of their work.
- The members of the Subtask have had the opportunity of visiting most of the labs used in the studies during the course of the Task meetings.

What was efficient was the open exchange of information between groups. The presentations have led to productive formal and informal discussions. The people involved in the Subtask have a large number of years of experience and have been able to give constructive criticism and advice to one another. The quality of the work has been high. The fact that the whole Task has had a common goal and framework for simulations and inter-comparison has been appreciated by all. The discussions have been more focussed and it has been easier to put one's own work into perspective.

Seasonal storage has been the focus of most of the work in Subtask B. The fact that there has been a project working with seasonal storage using supercooling of phase change materials in Subtask C has added another dimension to the inter-comparison of possible technologies.

However, the Subtask has not resulted in any deeper direct collaboration or interchange of staff or resources between the participants. The different projects were essentially related to different processes requiring different approaches. Certain common elements were found, but these were not elaborated as the projects were in different phases. Additionally, not that much effort has been possible to devote within the individual projects for the inter-comparison work due to the fact that they have been funded nationally. Finally the funding has sometimes not been sufficient to provide time for system simulation even though the models are all available.

The nature of IEA-SHC is such that this picture is likely to be repeated, with the majority of the benefit being interchange of information between mostly independent projects with the possibility of inter-comparison based on common boundary conditions. However, the depth of these inter-comparisons is dependent on the individual funding of each project. It is suggested that common funding is applied for that will finance the central aspects of future Tasks, such as definition of boundary conditions, the exchange of experts between parts of a Task and the inter-comparison work. It should also finance the work required of a number of participants to produce the Task specific results from their ongoing individual projects. EC funded projects could provide a partial basis for the common funding of parts of a Task, but this contribution would probably be restricted to participants from EU countries. National counter-financing for non-EU countries is then a prerequisite to a balanced funding model. This touches the core of the present IEA model for Implementing Agreements. This model should be revisited on a higher level, taking account of the increasing importance of international collaboration in energy R&D and the decreasing future number of scientists available.

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7 Publications from Subtask B

7.1 Subtask reports

These are available from the IEA-SHC website at www.iea-shc.org under Task 32.

B1: Selection of Concepts. This report gives details of five projects involved in the Subtask. One project started after this report was published, that of EMPA in Switzerland, so is not included.

B2: Thermal Properties of Materials for Thermo-chemical Storage of Solar Heat. This is a short report giving details of properties of sorption materials. There is also a very short summary of an evaluation study of materials for chemical storage of solar heat. The contents of the report can also be found in the Task handbook.

B3: Laboratory Prototypes of Thermo-Chemical Storage Units. This report has been superceded by report B4 that has the same data as well as that for two other projects.

B4: Laboratory Tests of Chemical Reactions and Sorption Storage Units. This report describes the results of laboratory measurements on five store prototypes, including data for energy density and boundary conditions. A short inter-comparison of the prototypes is made. This report is the same as B3, but with two additional projects: that of Monosorp open adsorption store; and characterisation of the hydration and dehydration of $MgSO_4.7H_2O$.

B5: Store Models of Chemical and Sorption Storage Units. This report describes briefly the models developed within the Subtask and gives details of their validation. The full model description is not given, but is referred to in the text.

B6: Simulation of Chemical and Sorption Stores. This report has a short cover document giving details of the methodology and nomenclature as well as briefly describing the boundary conditions. The results for the three different systems that were simulated are given in separate appendices. Monosorp, Modestore, and compact chemical storage are the three systems that were simulated. The cover document and appendices are available as separate documents.

B6.1 System report: ECN TCM Model (Herbert Zontag, ECN, Holland)

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

B6.3 System report: Monosorp (Henner Kerskes, Karola Summer , ITW, Univ. Stuttgart, Germany)

B7: Final Report of Subtask B “Chemical and Sorption Storage”. This report summarises the work of Subtask B of IEA-SHC Task 32. The main results and conclusions are given as are suggestions for future work. A short discussion on management aspects of the SubTask is also given.

7.2 Journal Articles

Weber, R., Dorer, V.: *Long-term heat storage with NaOH*, Vacuum, 2007, doi:10.1016/j.vacuum.2007.10.018.

7.3 Articles in Conferences

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7.4 Other reports

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