009 - ADVANCED STORAGE CONCEPTS FOR ACTIVE SOLAR ENERGY

IEA-SHC Task 32 2003-2007

J.-C. Hadorn
Operating agent Task 32 for the Swiss Federal Office of Energy
Groupe Berney - BASE Consultants SA, Geneva, Switzerland
jchadorn@baseconsultants.com

Abstract

Storage is a key success factor for the large development of solar heat utilisation in mid climate.

IEA Solar Heating Cooling Programme started Task 32 in 2003. After 4,5 years Task 32 was completed in December 2007. The main objective of the Task was to contribute to the development of advanced storage solutions in thermal solar systems for buildings that lead to high solar fraction, and up to 100% in a typical 45N latitude climate.

The Task was organised in 4 Subtasks:

1. Subtask A: Evaluation and Dissemination (Subtask Leader: Switzerland / France Thomas Letz)
2. Subtask B: Chemical and Sorption (Subtask Leader : Chris Bales, Sweden)
3. Subtask C: Phase Change Materials (Subtask Leader: Wolfgang Streicher, Austria)
4. Subtask D: Water (Subtask Leader: Harald Drueck, Germany)

and gave valuable results and new information in all aspects of the 4 technologies that were investigated. This paper by the Operating Agent presents an overview of achievements and some of the main results. For detailed presentations of the scientific work, the reader can refer to companion papers from experts who participated in Task 32 and to the http://www.iea-shc.org/ web site.

Keywords: heat storage, cold storage, water tank, PCM, sorption, chemical reaction, solar

1. The prevailing situation

The most efficient way to collect solar energy for space heating purposes is to do it at low to medium temperature, between 20 and 80C. Storage in this range is done since centuries with water.

Water is a good heat storage medium. One m3 of water can store 70 kWh between 20 and 80 C, that is the production of about 20 m2 of good flat plate solar collectors during a bright sunny day.
Keeping this energy in a water tank for a few days can easily be achieved by insulating the container with classical insulation material 10 to 12 cm thick.
The sensible heat capacity (ability to store heat in a sensible form) of water is one of the highest. On top of this interesting physical property, water has four other very important advantages over other material: It is non toxic, it is ubiquous, it is cheap, it is a fluid.

To store cold energy, say around 0C, water is also a very good storage material ! Using its latent heat from liquid to solid (ice), water can store 91.6 kWh par m3 ! This, combines with the total reversibility of the process, makes clearly water the first choice when cold storage is needed for cooling purposes in building.

2. Advanced concepts

Figure 1 shows four ranges of solutions to store heat. Water over 70C, phase change materials (PCM), reactions based on sorption principle, and chemical reactions.

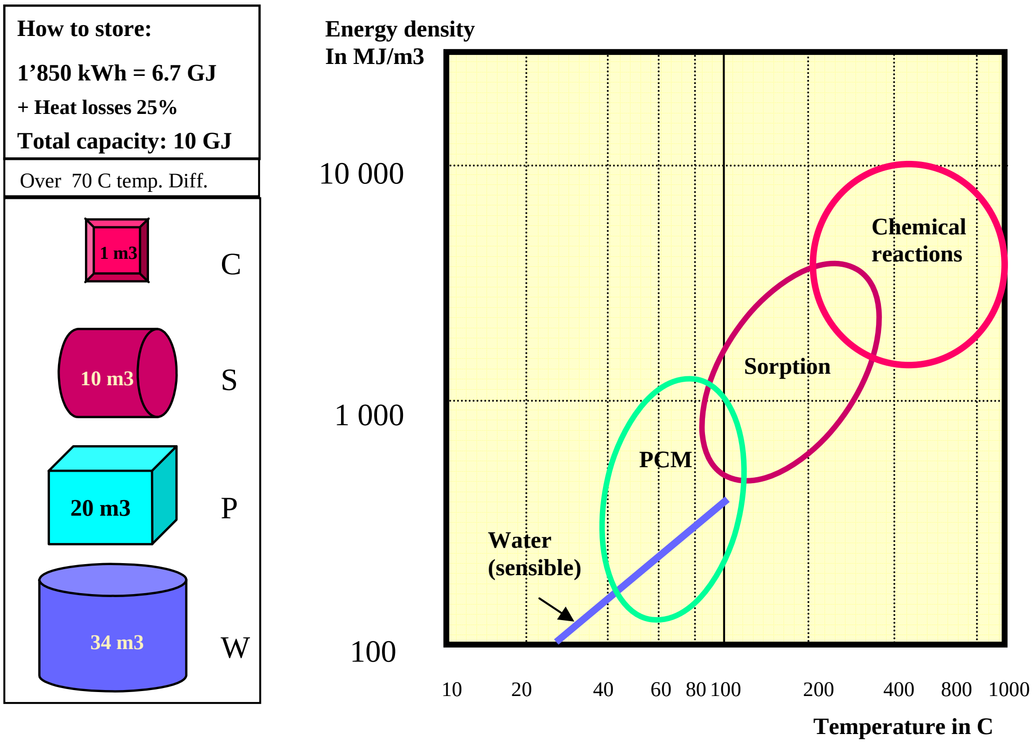

Fig. 1. Energy density vs temperature (log scale) and comparison of theoretical volume needed to store 10 GJ of heat based on four different principles [1].

The density that can be theoretically achieved is shown on the vertical axis where as the horizontal axis shows the temperature needed.
Water our best in class of today is still a low dense material compared to the other solutions and noticeably chemical reactions, where the storage volume for a seasonal store in a low energy house could be not bigger than 1 m3 compared to the 34 m3 of water we need today.

The IEA Solar Heating and Cooling Programme decided to investigate these 4 alternatives during 2003 to 2007 within Task 32 “Advanced storage concepts for solar and low energy buildings”.

3. Water tank storage

For solar combisystems, water tank storage is the state-of-the-art choice [2].

However there are ways to improve the efficiency of water tank stores and the overall performance of a water based combisystems. Several topics deserve R&D attention to be improved: stratification devices, heat losses, system integration.

Stratification devices allow better stratification of hot water in a tank so that less auxiliary will be needed to meet the peak load during DHW draw off for example. There are several solutions on the market but all are somehow complicated and expensive. Pervious fabrics have been investigated in Denmark and the best choice exhibits promising results compared to current devices. It is a two concentric layers system, where water can leave at any level depending on its temperature relative to Denmark investigated 3 configurations of combisystems whose only variation is the stratification scheme in the water tank (figure 2). The alternative with 2 stratification devices, one for the solar loop and one for the return loop perfoms best with a 20% improvement of the annual solar energy delivered to the load in the best case compared to the no stratification device case.

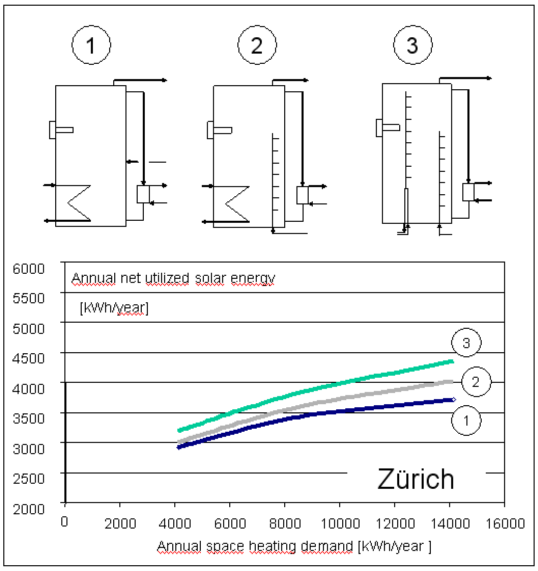

Fig. 2: In these detailed simulations from DTU, Denmark, the best performer in Zürich climate is clearly the double stratifier solution.

When there is no stratifier (figure 4), the internal heat exchanger solution performs best.

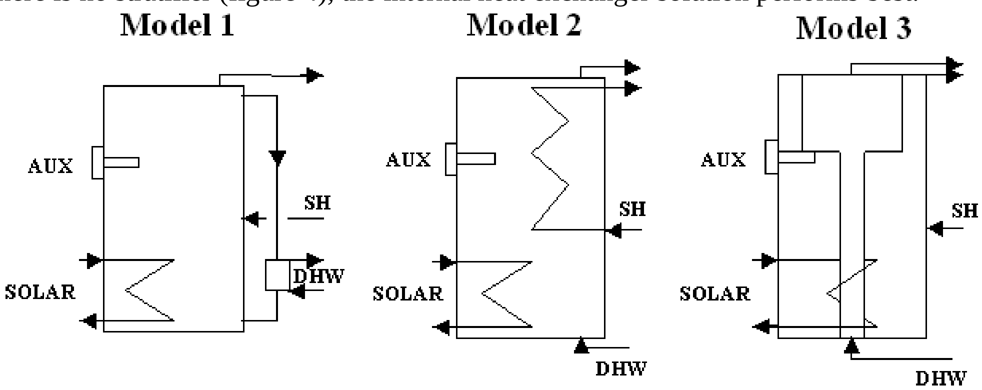

Fig. 3. Detailed simulation from DTU Denmark showed that model 2 showed slighlty better annual performance than the two others

4. Storage with phase change materials (PCM)

One way to improve storage is to use a material that can be more energy dense than water. If the transition temperature is adequately chosen, such materials exist. Task 32 worked with sodium acetate which exhibits a theoretical transition point at 58 C, ideally suited to solar combisystems.
Material caracterisation is a topic in itself and Task 32 developped a method to be able to assess the thermal properties of the material in a confident and repeatable way (figure 4).

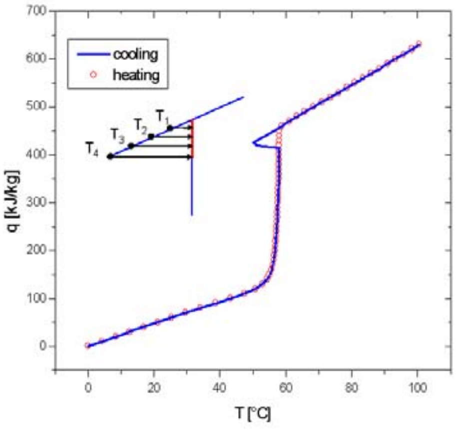

Fig. 4. Thermal properties of sodium acetate trihydrate with graphite, measured at IWT, Austria. The material supercooling effect is clearly visible. Hysteresis must also be precisely measured.

Modelling PCM in a storage is also a difficult item that has been adressed by Task 32. We have now models of sodium acetate in different configurations that can be used to predict the behaviour of solar combisystems with such PCM storages.

Simulation of several combisystems with PCM storage revealed that PCM storage show two unforeseen limitations: the volume of PCM that one can introduce into a water tank is limited to 20 to 30% of the whole storage volume, due to the necessary containment of the material and the heat extraction power from PCM to water is limited by the diffusion process inside the material. Sodium acetate did not show a decisive advantage over water in a combitank even if its density of energy is higher and if its heat conductivity is enhanced with graphite. Special system design were developped which showed better improvements but with a 35 C transition temperature material.

Fine tuning of the adequate PCM and the proper way to build an efficient heat exchange should remain on the agenda of international solar research. A new idea is being investigated in Denmark: using the supercooling effect of sodium acetate to build a seasonal store with limited heat losses.

5. Sorption storage

There are different sorption principles that can be used for heat storage. An absorption technique is used in a commercial device that can provide 20 kW of heat and 10 kW of cooling from a solar source, the TCA from company Climatewell in Sweden. Extensively monitored during Task 32, it is more a chemical heat pump than a true storage.

It can however store energy for a few hours and convert hot water to cooling and heating. The principle is that when using one tank containing water (evaporator), and an other one containing an hygroscopic salt (reactor), water will evaporate to the salt that absorbs the water. When the confined space is in a state of vacuum the water transport will be so high that the water will start boiling in order to produce vapour at the same speed as it is absorbed by the salt. Such evaporation requires energy. If the energy is not supplied from outside the system it will be taken from the water itself, which as a consequence gets colder

Other techniques based on adsorption principles tried to use silicagel or zeolite as a storage medium. After extensice search in laboratory in Switzerland and in an experimental house in Austria, both media showed limitations in terms of usable temperature lifts during discharge when used as particles in beds. A new way to use zeolite has being developed in Germany within Task 32. An extruded solid zeolite with air channels showed interesting properties at laboratory level. Simulation showed that a 8 m3 storage volume would be enough for 70% of the heating load of a low energy house. A laboratory prototype will deliver more information soon.

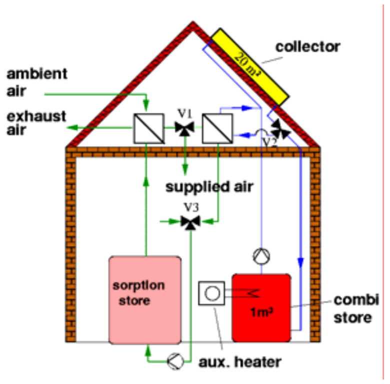

Fig. 7. The Monosorp storage concept from ITW, Germany is still a laboratory prototype but could lead to a dense seasonal storage solution for one family house.

At Empa in Switzerland, a prototype of storage unit based on the NaOH desorption at 150 C principle has been set up. First results show that the material can dry in summertime even better than anticipated (65% concentration reached) reducing the needed charging temperature to 120 C. The pilote installation will be monitored during 2 years and modelling will enlarge the scope of the results.

6. Storage using chemical reactions

The high density of storage with chemical reactions makes the topic attractive. However many difficulties must be overcome to get to a commercial solution.The choice of an adequate reaction has kept attention at ECN, The Netherlands. A promising material is magnesium hydroxide seven hydrates which could theoretically store 777 kWh/m3 at 122 C.

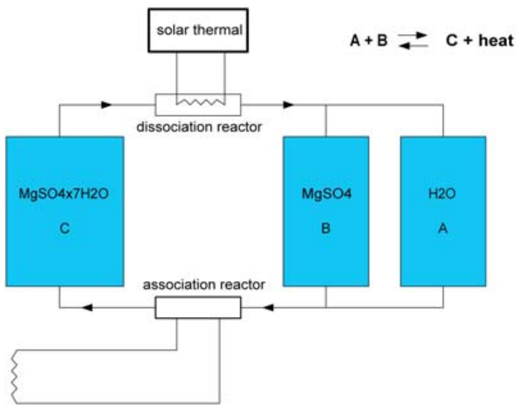

Fig. 13. Sketch of a future chemical heat store system with its three vessels, at ECN, the Netherlands (for a 12.2 MWh capacity, tanks volume could be: A 14 m3, B 5 m3, C 16 m3).

This is a temperature that high performance solar collectors can achieve in summer time. The principle is to dry the material in summer with solar heat and in wintertime rehydratation can deliver back the energy (figure 13). Work with this material and its abitlity to de-hydrate and re-hydrate has just started.

7. How to compare various storage technologies?

Several criteria can be considered for comparing storage technologies. Task 32 of IEA SHC prepared a detailed list. The first indicator concerns the energy performance of a combisystem with the storage technology. The value of Fsav the fractionnal energy saving has been selected as the best indicator and can be derived from the parameter FSC'.

FSC' is a dimensionless quantity simultaneously taking into account the climate, the building (space heating and domestic hot water loads) and the size of the collector area, in a way that doesn't depend on the studied combisystem. First developed within IEA SHC Task 26 [2], the FSC (Fractional Solar Consumption) has been improved in Task 32 to yield to FSC' which takes into account a possible cooling load also, and the ability of a store to be seasonal.

This means that it has been possible to show that Fsav is a function of FSC' even if FSC' is greater than 1.

Energy performance indicators	
NRJ1	Fractional energy savings Fsav as a function of FSC'
NRJ2	Comfort for heating and DHW load met without penalties
NRJ3	Comfort in cooling conditions
NRJ4.1	Heat storage material energy density kWh/m3
NRJ4.2	Bulk storage density kWh/m3
NRJ4.3	Storage efficiency
Economical indicators	
ECON1	Investment cost per kWh stored
ECON2	Operational costs per kWh discharged
Market introduction	
MKT1	1 if on the market, 2 if within 3 years, 3 in more than 3 years
Environmental indicators	
ENV1	Storage material risk (corrosion + toxicity + safety)
ENV2	CO2 saved by the system compared to a reference
System integration	
INT1	weight of material for the storage unit kg/kWh capacity
INT2	number of separate pieces
INT3	level of skills required to install the storage unit
INT4	need for technical maintenance

Table 1. Criteria considered for comparison of heat storage units within Task 32

In order to assess Fsav in comparable conditions it is necessary to set up a standard simulation framework that many different systems can use. Task 32 defined a complete set of parameters for TRNSYS simulations, for 3 different reference houses (a low energy house with only 30 kWh/m2 for space heating, 60 and 100 kWh/m2) in 4 different climates (Stockholm ,Zürich, Barcelona, Madrid). The entire deck of parameters is available through IEA SHC.

Storage technologies integrated into a solar combisystem can be compared using this new method.

8. Conclusion

Water is still the storage of choice for solar combisystems for the years to come. Some important findings for other materials have been discovered by Task 32. Models are now available for more optimisation analysis and for defining the best material a combisystem would need.

Several technologies for advanced storage concepts have been tested within Task 32. Table 2 summarizes them and their status at the end of 2007.

Future work on new materials for heat storage is important since we discover the limits of some promising components.

A new IEA Task will continue the work Task 32 has initiated, but will be more focused on material research.

Solar energy need a dense and long term storage solution if it is to used intensively for house heating.

References

[1] **Hadorn J.-C. editor,** (June 2005), Thermal energy storage for solar and low energy buildings - State of the Art, a IEA SHC Task 32 book, Printed by Servei de Publicacions Universidad Lleida, Spain, 170 pages ISBN 84-8409-877-X, available through Internet www.iea-shc.org Task32

[2] **IEA SHC Task 26** (2004)**:** Solar Heating Systems for Houses - A Design Handbook for Solar Combisystems, W. Weiss and al., James & James, 2004, 313 pages

[3] Task 32 reports are available at http://www.iea-shc.org/task32/publications/index.html

Principle	Material	Institute	Status 2007
Chemical reactions	--------------------------------	--------------------------------	--------------------------------
Closed 2 phase absorption	Mg SO_4 $7H_20$	ECN The Netherlands	Material investigation
Sorption	----------------------------	--------------------------	-------------------------
Open adsorption	Zeolite solid	ITW Germany	Laboratory unit
Closed adsorption	Silica gel particles in bed	AEE Austria	System in a house tested - stopped
Closed adsorption	Silica gel and Zeolite beds	SPF Switzerland	Material and bed tested - stopped
Closed 2 phase absorption	NaOH / H_2O	EMPA Switzerland	Laboratory unit runing
Closed 3 phase absorption	LiCl	SERC Sweden	commercial
PCM	--------------------------------	--------------------------------	--------------------------------
PCM seasonal storage using subcooling	$Na(CH_3COO)\cdot 3\ H_2O$	DTU Denmark	Simulation of concept – Prototype 135 liters
Macroencapsulated PCM in storage tank	$Na(CH_3COO)\cdot 3\ H_2O$ + graphite	Univ. Lleida, Spain	Lab prototype
Macroencapsulated PCM in storage tank with integrated burner	$Na(CH_3COO)\cdot 3\ H_2O$ + graphite	HEIG-VD Switzerland	Complete combisystem tested
Microencapsluated PCM slurry	Paraffin,	IWT-TUGraz Austria	Lab prototypes- Stopped for storage
Macroencapsulated PCM in storage tank	Paraffine, $Na(CH_3COO)\cdot 3\ H_2O$ with/without graphite	IWT-TUGraz Austria	Lab prototypes
Immersed heat exchanger in PCM	$Na(CH_3COO)\cdot 3\ H_2O$ without graphite	IWT-TUGraz Austria	Lab prototypes
Water	----------------------------	--------------------------	-------------------------
Simplified combisystem Maxlan system	Water	SPF Switzerland	Simulation proved
Water Stratifier	Fabrics immersed in water	DTU Denmark	Laboratory proved

Table 2. Storage technologies that IEA Task 32 has investigated between 2003 and 2007