Method and comparison of advanced storage concepts

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

Report A4 of Subtask A

December 2007

Jean-Christophe Hadorn
Thomas Letz
Michel Haller

Task 32 Storage

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Method and comparison of advanced storage concepts

Jean-Christophe Hadorn,
BASE Consultants SA, Geneva, Switzerland

Thomas Letz
INES Education, Le Bourget du Lac, France

Contribution on method: **Michel Haller**
Institute of Thermal Engineering
Div. Solar Energy and Thermal Building Simulation
Graz University of Technology
Inffeldgasse 25 B, A-8010 Graz

A technical report of Subtask A

Base Consultants S.A.

BASE CONSULTANTS SA
8 rue du Nant CP 6268
CH - 1211 Genève

INSTITUT NATIONAL DE L'ENERGIE SOLAIRE EDUCATION

INES - Education
Parc Technologique de Savoie Technolac
50 avenue du Léman BP 258
F - 73 375 LE BOURGET DU LAC Cedex

Executive Summary

This report presents the criteria that Task 32 has used to evaluate and compare several storage concepts part of a solar combisystem and a comparison of storage solutions in a system.

Criteria have been selected based on relevance and simplicity. When values can not be assessed for storage techniques to new to be fully developped, we used more qualitative data.

Comparing systems is always a very hard task. Boundary conditions and all paramaters must be comparable. This is very difficult to achieve when 9 analysts work around the world on similar systems but with different storage units.
This report is an attempt of a comparison. Main generic results that we can draw with some confidency from the inter comparison of systems are:

- The drain back principle increases thermal performances because it does not use of a heat exchanger in the solar loop and increases therefore the efficiency of the solar collector.
- Stratifiers in the space heating loop bring only a limited improvement of thermal performances if the return temperature is maintained at a low level, and this improvement tends to decrease for high solar fraction systems.
- The use of an external heat exchanger in the collector loop instead of an internal one in the storage tank can lead to an increase of electricity consumption due to one additional pump, and compensates more or less the gain in solar energy collection.
- A high ratio storage size / collector area improves performances especially for high solar fraction systems: this means that if the collector area is chosen small compared to the load, a large storage does not make sense. This is mainly because the available solar heat is used immediately. On the other hand, if the collector area is large compared to the load, a bigger storage can really act as a time shifter for use during periods with no solar energy available
- Sodium acetate as a PCM in a storage tank must be looked at carefully , especially if the storage is working over a large temperature range: the improved heat storage capacity brought by the PCM when the phase change occurs (latent heat) is compensated by a lower sensible heat of the PCM compared to that of water it replaces in the tank. Until now, almost no differences in terms in annual energy performance have been found for the studied systems between those without and with PCM. More research on that topic is therefore needed since we do think that there must be better ways to use PCM for solar storage than the ones Task 32 could investigate.
- FSC' values reached by some systems are higher for chemical or sorption storages than those for water storages: these types of storage allow to consider larger collector areas and storage sizes, in order to enter into the seasonal storage category and let us hope that higher fractional energy savings could be reached even in less favourable climates if those systems become available on the market one day.

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 A

"Evaluation and dissemination"

This report is part of Subtask A of the Task 32 of the Solar Heating and Cooling Programme of the International Energy Agency dealing with evaluation of new storage concepts.

We propose in this report criteria that can be used to assess or compare heat storage techniques. We have tried to choose criteria both quantitative and qualitative that are relevant for choosing a storage technique to be part of a solar combisystem.

These criteria have been used in a first comparison of advanced storage techniques proposed by IEA SHC Task 32 experts.

An important indicator of a combisystem is its performance regarding solar energy delivered to the house. Using the new FSC' method described in other reports of our Task 32, we propose in this report a comparison of the different storage options for solar combisystems supposed to meet the same load.

This comparison is necessarily a first attempt since most advanced storage concepts Task 32 has dealt with are new and not totally optimized.
The goal of Task 32 was to reach this point where a first comparison, at least of simulation results, could be achieved. So that the tools for further optimisation would be available.

Comparing solar combisystems to evaluate the advantages of a new storage technology was one of the main challenges of Task 32 that some participants reached after 4 years of intense work and exchange.

We do believe Task 32 has reached this goal.

Jean-Christophe Hadorn

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

BASE Consultants SA - Geneva
jchadorn@baseconsultants.com

Contents

1 INTRODUCTION

Task 32 was aiming at comparing advanced storage concepts. Three types of solar combisystems (SCS) have been investigated in this Task:

- Storage concepts based on water storage (subtask D of Task 32)
- Storage concepts based on PCM (Phase Change Material) storage (subtask C)
- Storage concepts based on chemical reactions (sorption storages) (subtask B)

Detail reports for each system are available on the website:
http://www.iea-shc.org/task32/publications/index.html

Subtask A aims at comparing "systems" with advanced storage concepts. "Systems" are solar based systems that can produce heat and/or cold, and should be able to meet part of the load of a reference house defined in another document.

Criteria for comparing systems have been defined by Task 32 participants. They must be:

- relevant
- but simple to assess !

An effort to reduce the number of criteria has been made, but even with a limited number, participants in Task 32 still feel that for some advanced systems, they are difficult to quantify since the systems are still early prototypes.

One indicator is based on energy performance of the system. It is certainly a very important one. What is the "solar fraction" of my combisystem is a common question.

Methodology of deriving and comparing the energy performance indicator (the "solar fraction" in common language, the "fractional energy" savings in a more technical language) used in Task 32 has been taken from a method originally developped to compare solar combisystems in IEA Task 26 and presented in details in another report of Subtask A. The method has been modified to account for possible long term storage and is of particular interest to evaluate any type of solar combisystem with any storage capacity. It is called the FSC' method which stands for Fractional Solar Consumption.

NOTICE:

Views, findings expressed in this report do not necessarily represent the views or policies of the Task 32 experts who did work independantly on each system presented.

2 CRITERIA

2.1 Energy performance

- NRJ1 = Fsav = f(FSC') : Fractional energy savings as a function of the fractional solar consumption for heating and domestic hot water and cooling if the tested system does some cooling through the solar part of the installation. The methodology to assess FSC' is given in the report A1 of Subtask A (Letz T. (2007). FSC' is richer in relevant information than the simple well known SF Solar Fraction [1] which does not take into account the interaction between the solar part of an installation and the auxiliary. FSC' is an extension of the FSC method derived in IEA SHC Task 26 (Letz T. (2003)). A detail presentation of the FSC' method is given in (Letz, 2007), report A1 of IEA SHC Task 32.

- NRJ2 = Comfort for both heating and DHW are needed (2 temperatures are required: a room temperature and the temperature of delivered tap water). Using Task 26 simulation methods in TRNSYS, the penalty functions can be used to derive an indicator for both.

- NRJ3 = Comfort cooling. This criteria is based on a frequency histogram of indoor temperature (hourly values for instance), and measures the number of hours during a summer the indoor temperature is in a comfort zone.

- NRJ4 = Storage performance indicator that is:
  - NRJ4.1: Storage density of material: kWh/m3
  - NRJ4.2: Storage density of storage component: based on component bulk volume (occupied space) = kWh/m3
  - NRJ4.3 Storage efficiency = Energy out/Energy in over 1 or 365 days depending on the nature of the store (number of cycles per year). This ratio is a figure of merit of the storage, its loading and unloading process and its thermal losses.

2.2 Economics

- ECON1 = Investment in absolute term (material + installation), Euros per kWh

- ECON2 = Operating cost in absolute term, Euros per kWh (calculated at reference conditions, including the auxiliairy energy needed)

2.3 Market Availability (of storage and/or system)

- MARKT = is a value that is 1 if the system is on market, 2 if the storage will be on market within 1-3 year, and 3 if it is not anticipated to be market ready before 3 years. This is a measure of the time to market of the technology or the chance to have an industrial product within 3 years

2.4 Environnement

• ENV1 = Storage material Risk, Corrosivity + Toxicity + Safety (manipulation, flammability) measured by a grade:

0 = the risk is 0
1 = 0 to low risk,
2 = some material can be corrosive
3 = toxic or dangerous material.

• ENV2 (in 4 climates) = CO_2 equivalent emission per kWh of load / CO_2 equiv emitted by the reference system of the Task 32 (including the boiler cycling). A conversion factor for electricity is needed in some cases: 2.5 is taken. We take only the CO_2 during 1 year of operation, but not the CO_2 resulting from embodied energy in materials (very difficult to assess).

2.5 Integration in a system

For marketed systems, it is foreseen to use the following indicators of integration or ease of integration and operation:

- INT1 = weight of material (kgs of the total system delivery), is a measure of how massive is a system compared to another (think to a plastic storage tank compared to another one made of steel)
-
- INT2= number of separate pieces at delivery if known , is a measure of complexity to mount and of possible mistakes !

- INT3= level of skills required to install (1 = advanced, 0 = normal), is also a measure of ease of installation

- INT4= Need of system maintenance in normal operating conditions (1 = technically needed, 0 = free like a simple water tank storage system). This is an indication of operating costs as well.

2.6 SUMMARY of CRITERIA

	Energy performance	Economics	Market Availability	Environnement	Integration in a system
1	**FSC'** Solar energy delivered	**Total investment per capacity** €/kWh	**On market ?** 1, 2, 3 years from now ?	**Storage material risk**	**Storage unit weight**
2	**Ability to meet heating load temperatures** during the year without penalty	**Operating annual cost** €/year or €/kWh delivered		**CO2 or GWP** during year 1 of operation	**Number of components in a unit**
3	**Ability to meet cooling loads** during the year without penalty				**Level of skills to install**
4	**Storage performances** 1. Material density 2. Unit density 3. Storage efficiency				**Level of system maintenance**

Table 1: Summary of all criteria to compare storage concepts in Task 32

3 Comparison of systems on energy performance FSC’

A quantitative comparison of the performance of simulated solar combisystems will be presented, using the newly developed FSC' method described in report A1 of Subtask A (Letz T., 2007), and on the basis of the reference conditions established within Subtask A at IWT Graz (Heimrath R. Haller M., 2007).

For each system simulated, diagrams giving the thermal fractional energy savings ($F_{sav,th}$) or the extended fractional energy savings ($F_{sav,ext}$) are shown. A presentation of the different systems with hydraulic diagrams and the detailed characteristic curves for each system are available in report A3 of Subtask A (Letz T. et al, 2007).

Only simulation results corresponding to **system efficiency (the ratio between the annual thermal energy savings and the annual irradiation available on the collector area)** higher than 15 % have been taken into consideration to draw the characteristic curves of the systems. A value smaller than 15 % reveals that the system is not well dimensioned due to an oversized collector area compared to the load, or to an undersized storage capacity. This arbitrary value of 15% is chosen by comparison with the mean annual efficiency value of a PV system connected to the grid, and allows avoiding irrelevant values.

Warning

It must be pointed out that the proposed comparison is difficult and risky for several reasons:

- **For a fair comparison, the compared concepts should be on the same level of optimization. That is obviously not the case, because some concepts are at a very early stage of development while others have been worked on for a longer period.**
- **Since several parameters can differ between compared systems, the influence of one of them cannot be easily isolated.**
- **The analyst is not the same for all systems. We have had 9 experts working with the same framework but with independence.**

Our judgement is also based on limited available cases and on regression curves which implies implicit discrepancies. A sensitivity analysis should therefore be done.

The FSC’ method used in this comparison being new and the final curve chosen for each system very aggregated, the reader should refer to the detailed analysis of each case to draw more final conclusions. Therefore only global trends will be presented.

This work should be considered by the reader as an illustration on what can be done using the Fsav vs FSC' curves.

In report A3 of Subtask A, the characteristic curves showing the thermal and the extended fractional energy savings have been shown for each simulated system. It is important to note that each characteristic curve define a system completely over the whole range of FSC' for a given collector to storage ratio or "strategy".

With this precious information, a comparison between different systems can be tried, keeping in mind the important following assumptions:

- All simulations have been made using the same auxiliary boiler model in TRNSYS : type 370-Specific Type, data defined by Heimrath, Haller (2007)
- The type of solar collector used differs according to the type of storage (see paragraph 1.3 in report A4).

As a consequence, comparisons between systems **using the same solar collector type** give a **global** information on the influence of the following parameters:

- the layout design,
- the storage unit,
- the control strategy,
- and special design features

The influence of each parameter is not possible to evaluate with the proposed global method. Only trends can be derived.

On all diagrams, dot lines show the part of curves that has been extrapolated, as explained in report A4 of Subtask A (Letz T. 2007), when no simulation results passed the system efficiency criterion of 15% described previously.

3.1 *Solar combisystems with water storage*

3.1.1 Thermal fractional energy savings

Figure 1 shows the characteristic curves of the five systems simulated with a low ratio storage size over collector area, **between 33 and 50 l/m²**.

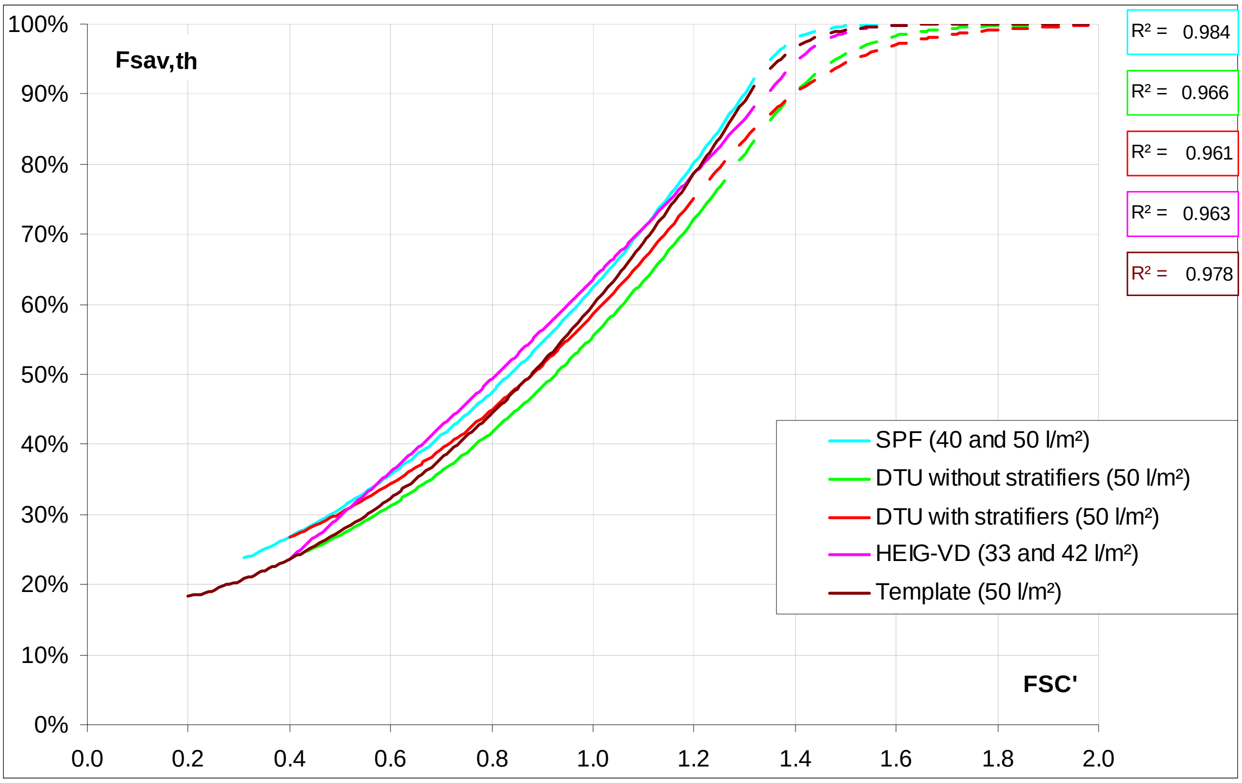

Fig. 1: Systems comparison for water storage
with low ratio storage size / collector area (thermal fractional energy savings)

<u>Comments</u>:

- SPF and HEIG-VD systems use the **drain back** principle, without a heat exchanger in the solar loop. This seems to provide an advantage compared to the Template solar system that does not use a drain back solution but a gylcol solar loop.

- DTU without stratifier lies under the Template Solar System, which includes a stratifier in the collector loop and an external plate heat exchanger. These two devices seem to provide a noteworthy improvement compared to an immersed heat exchanger without stratification device.

- DTU with stratifiers is very close to the Template Solar System, especially for intermediate values of FSC'. The only difference between this system and the Template Solar System is a stratification device on the return pipe of the space heating loop.

Differences appears for high FSC' values, but this seems more to be related to the fact that only few simulation results are available for the DTU system in this range of FSC' values, leading thus to a less accurate position of the characteristic curve. No clear conclusion can be derived at this stage.

- The effect of stratifiers can be seen by comparing DTU without stratifiers and DTU with stratifiers: **for low FSC' values, the effect of a stratifier is significant**, but the higher FSC', the lower the improvement due to the stratifiers.

Figure 2 shows the characteristic curves of five systems with a higher ratio storage size over collector area between **55 and 100 l/m²**.

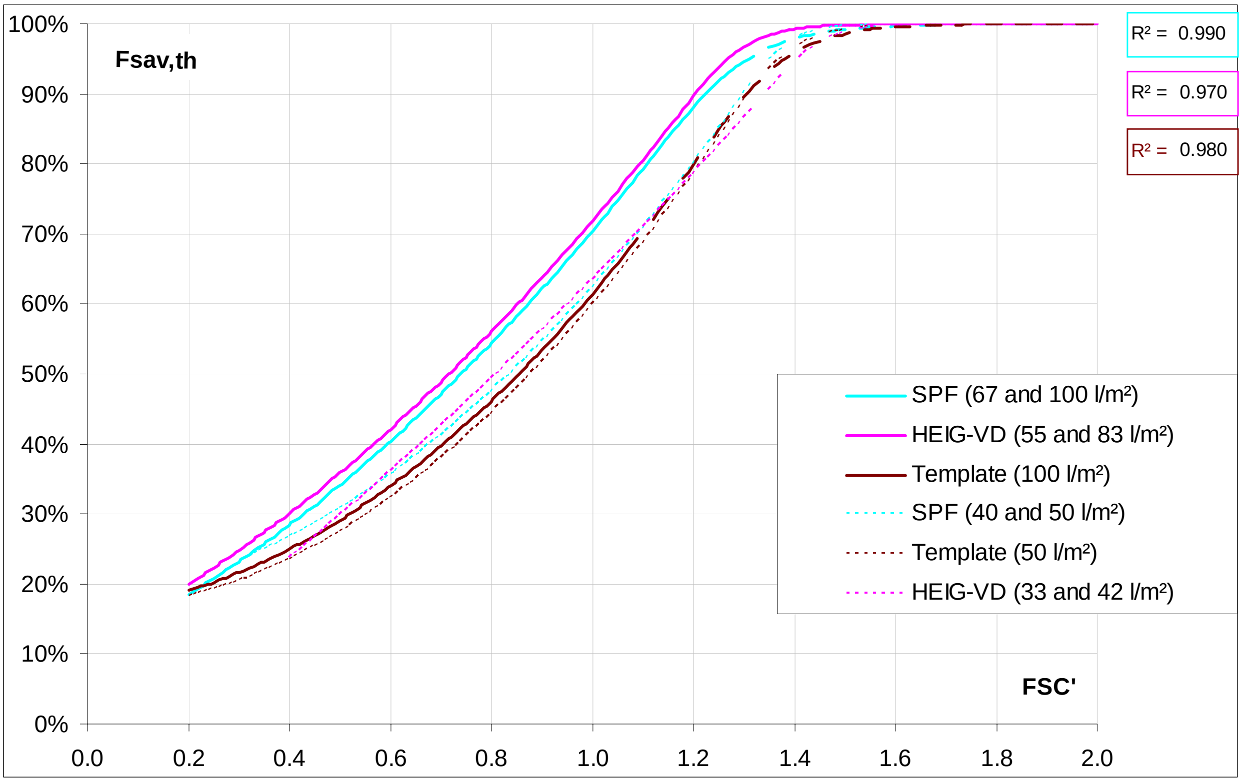

Fig. 2: Systems comparison for water storage
with higher ratio storage size / collector area (thermal fractional energy savings)

Comments:

- Here, performances of the SPF and HEIG-VD systems are much better than those of the Template solar system. One reason must be the use of the **drain back** principle.

- On the diagram dot lines represent curves for smaller ratio storage size / collector area: it can be seen clearly the improvement brought by a higher ratio, especially for higher FSC' and Fsav,th values. This means that **if the collector area is dimensioned with a low value compared to the load, a large storage does not make sense**, because available solar heat is used immediately. On the opposite, if the collector area is large compared to the load, a bigger storage can really act as a heat shift for periods without solar resource.

3.1.2 Extended fractional energy savings

Figure 3 shows the 5 water storage systems with low collector to storage ratio compared based on the extended fractional energy savings (Fsav, ext), that is included all parasitic energy in the system.

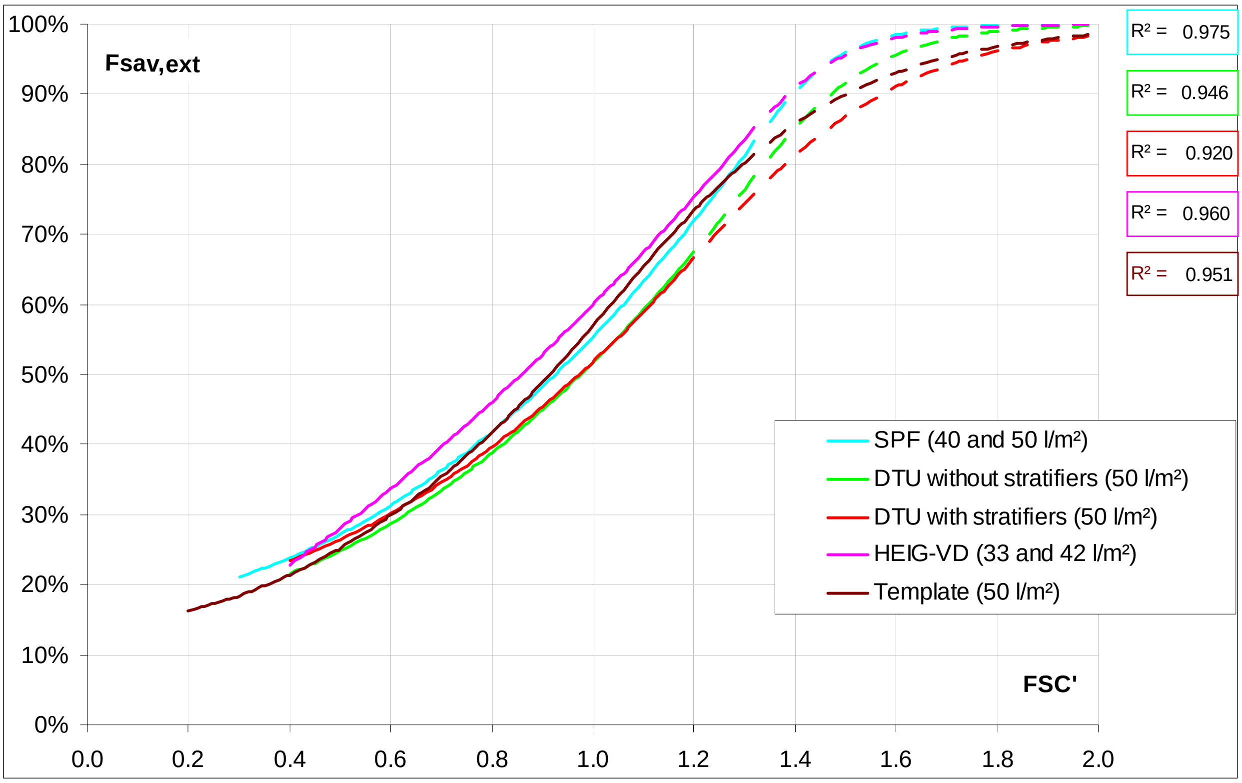

Fig. 3: Systems comparison for water storage with low ratio storage size / collector area (extended fractional energy savings)

<u>Comments</u>:

- Here, there are more differences between the SPF and HEIG-VD systems: the **HEIG-VD system seems to be a little thriftier with regards to electricity used** for pumps, valves, etc…But this should be analysed deeper with similar sets of parameters.

- The two DTU systems are very close: there is almost no difference between the two options with and without stratifiers, while there were some differences for the thermal only fractional energy savings. An explanation could be that the thermal efficiency improvement due to stratifiers, especially in the collector loop, is then lost because the improved system needs an external heat exchanger and one more pump, leading then to increased electricity consumption. This analysis shows that this way to present a synthesis of results in a global diagram allows to easily put in light some questions that have to be deeper analysed afterwards.

Figure 4 shows the 3 water storage systems with high storage to collector ratio compared based on the extended fractional energy savings (Fsav, ext), that is included all parasitic energy in the system.

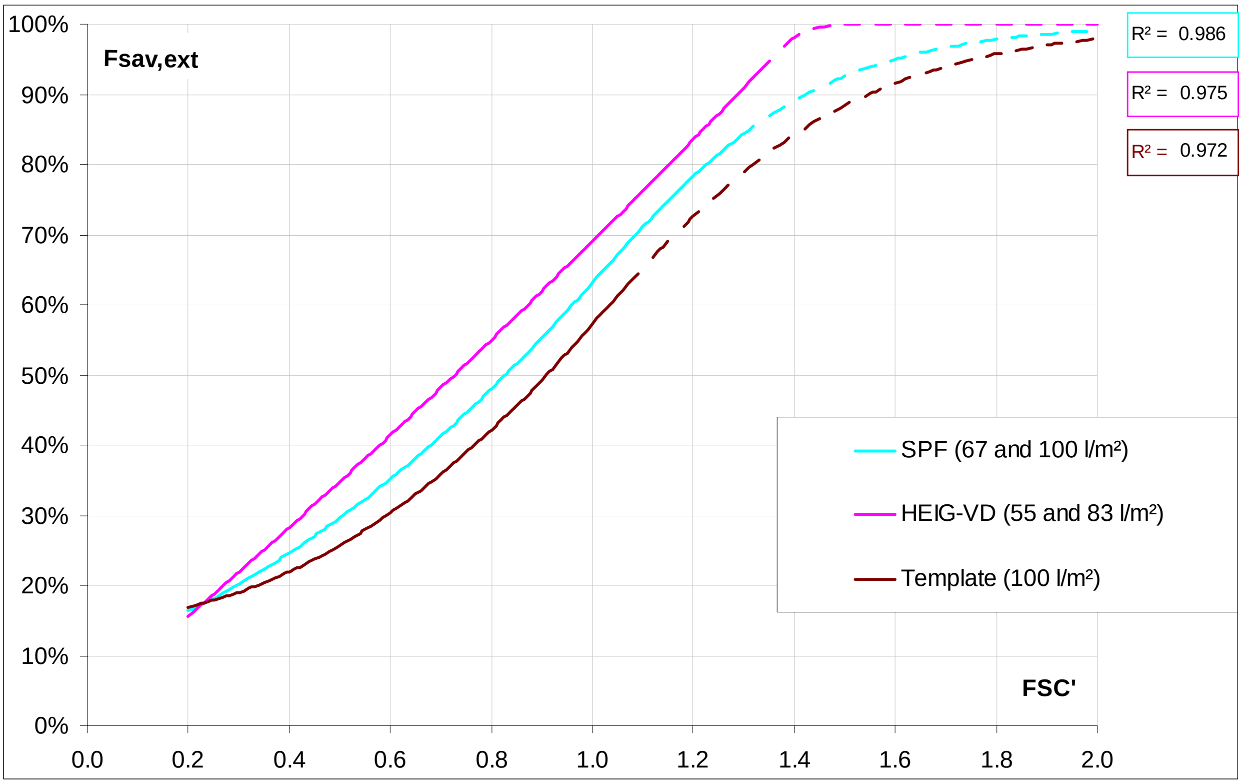

Fig. 4: Systems comparison for water storage with higher ratio storage size / collector area(extended fractional energy savings)

<u>Comments</u>:

- As before, performances of the SPF and HEIG-VD systems are much better than those of the Template solar system, due to the use of the **drain back** principle.

- But there is also a difference between the SPF and HEIG-VD systems: the HEIG-VD system **use less parasitic electricity** for pumps, valves, etc…But as explained in the previous paragraph, this has to be deeper analysed.

3.2 Solar combisystems with PCM storage

Only the HEIG-VD system has been simulated. So intercomparison with other systems using also PCM is impossible. But it is possible to compare the HEIG-VD system without and with PCM in the storage tank.

3.2.1 Thermal fractional energy savings

Figure 5 compares water and water+PCM storage concepts in terms of thermal fractional energy savings.

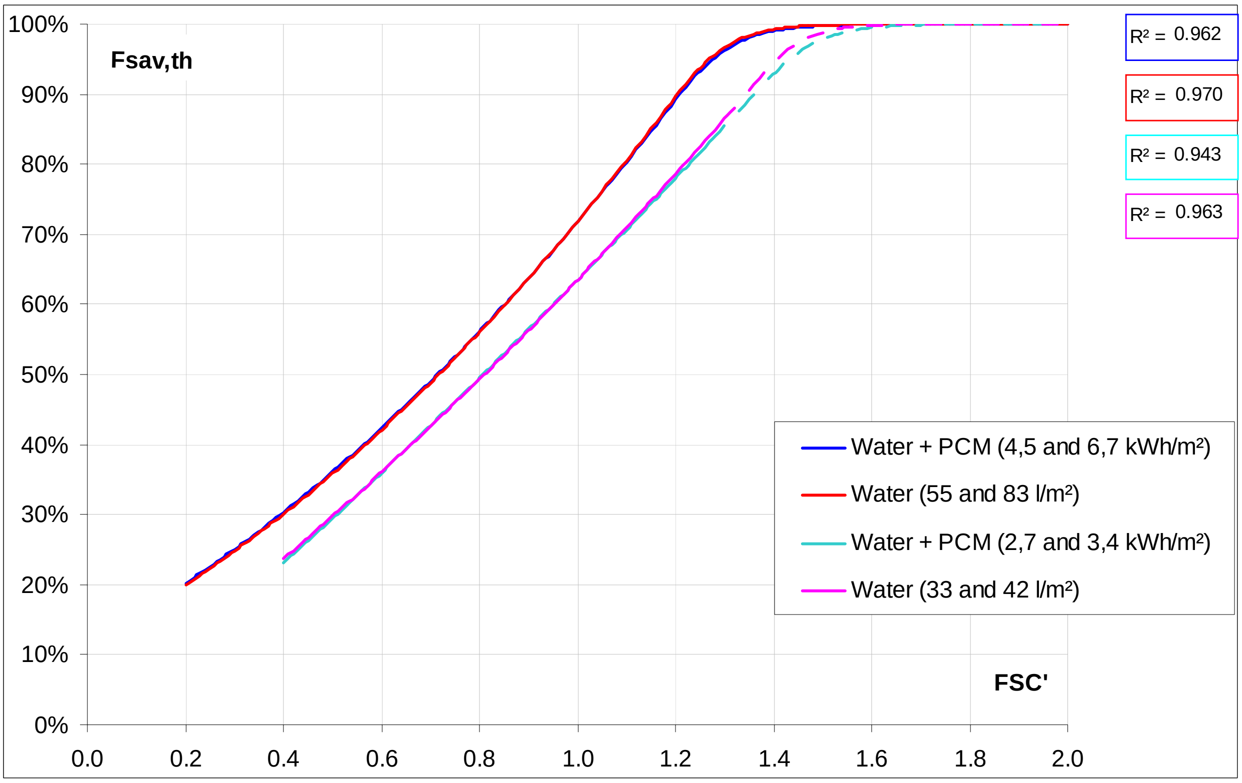

Fig. 5: Systems comparison for water and PCM storages (thermal fractional energy savings)

Comments:

- **A higher ratio storage size to collector area improves the performances**. About 6 to 10 points improvement is observed. For high FSC' values, this improvement is even greater because a high FSC' can be reached only with large storage volumes to overcome winter periods without sun.

- **Almost no differences are visible between systems without and with PCM**: the improved heat storage capacity brought by the PCM when the phase change occurs (latent heat) is compensated by a lower sensible heat of the PCM compared to the water. With a conventional temperature range of 70 °C [Letz T. (2007)], the heat capacity of this storage is exactly the same without and with PCM: 81 kWh/m^3.

- Previous conclusions applies for the studied system. It doesn't mean that PCM should never be used for storage in combisystems, but only that the performance improvement is very sensitive to the choice of the material used, and the dimensioning and the temperature lift of the storage tank.

3.2.2 Extended fractional energy savings

Figure 6 compares water and water+PCM storage concepts in terms of extended fractional energy savings, that is including auxiliary electricity.

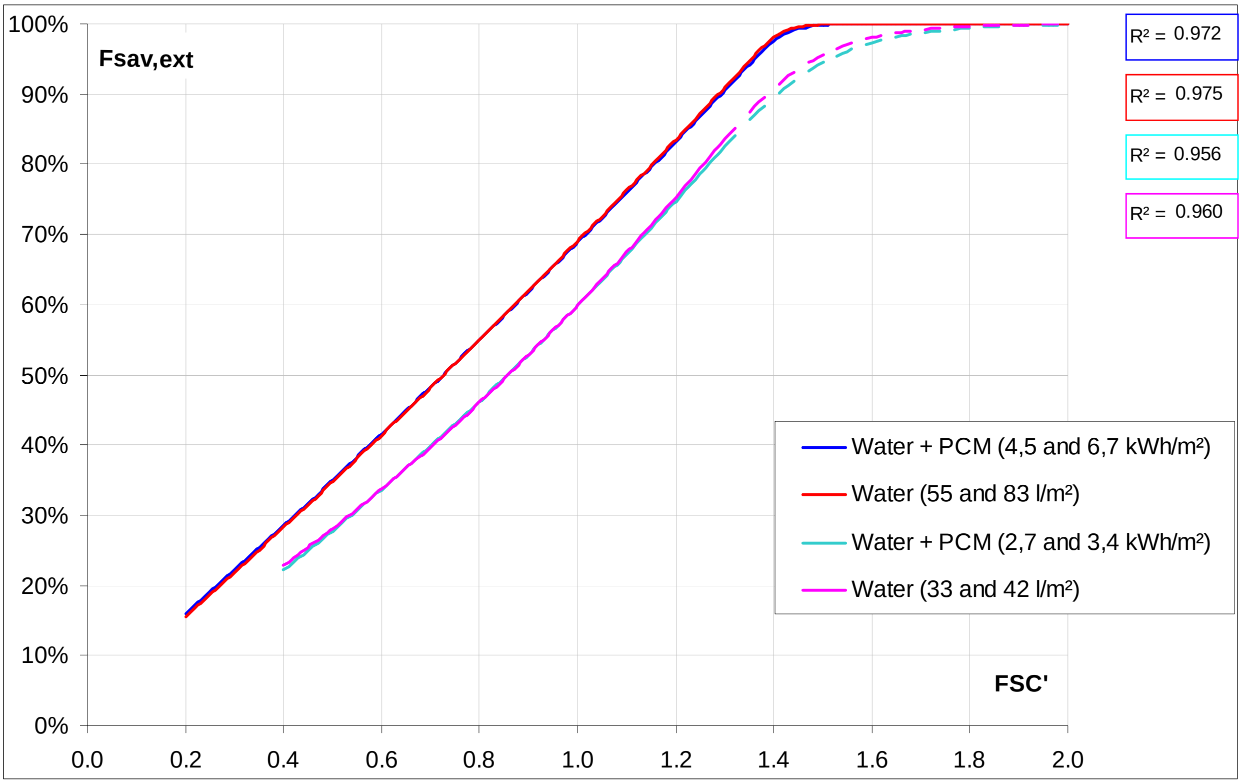

Fig. 6: Systems comparison for water and PCM storages (extended fractional energy savings)

Comments:

There is basically no difference with the previous case where auxiliary electricity was not considered. This means that the PCM storage does not require more parasitic electricity than the water only storage.

3.3 *Solar combisystems with sorption storage*

Three different systems have been simulated:

- AEE Intec system
- ECN system
- ITW system.

3.3.1 Thermal fractional energy savings

Characteristic curves of these systems are compared in figure 7 and 8, **although the ITW system uses CPC vacuum tubes instead of simple vacuum tubes like the other systems**.

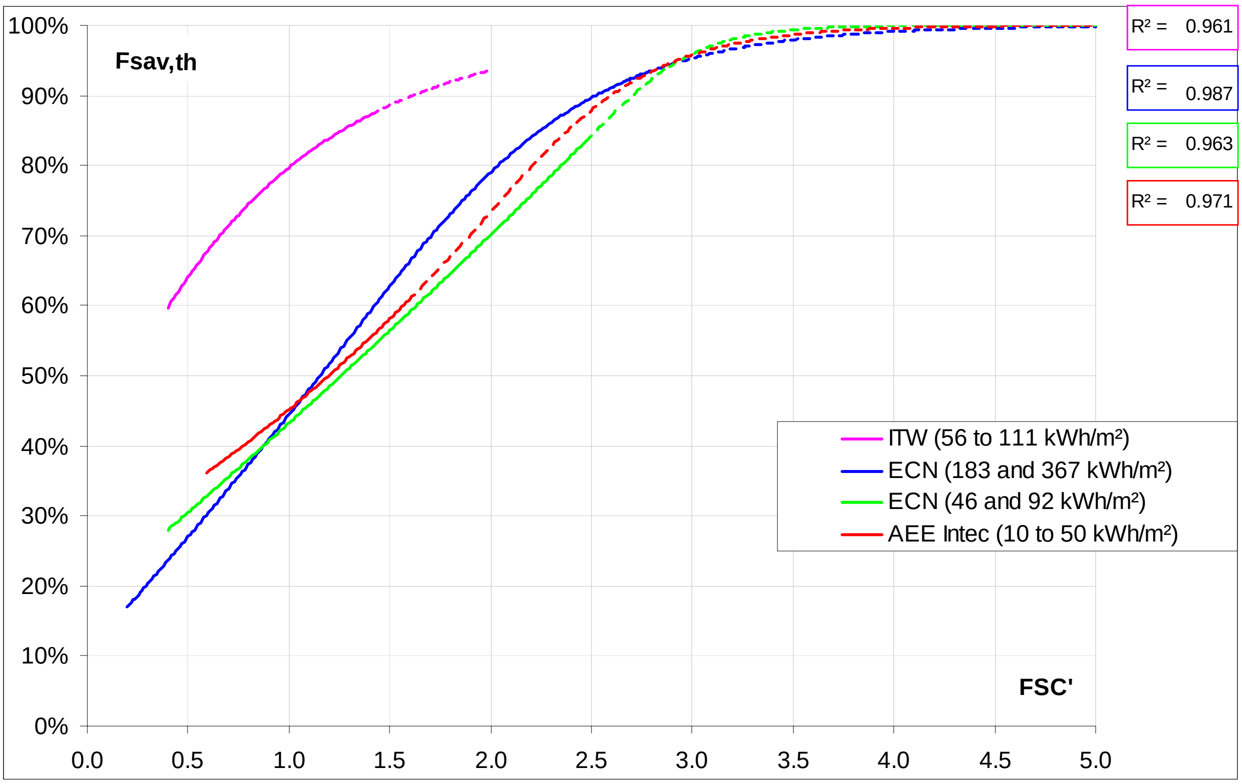

Fig. 7: Systems comparison for sorption storages
(thermal fractional energy savings)

<u>Comments</u>:

- The three systems using vacuum tubes solar collectors show similar performances.

- For the ECN system, the benefit of a larger storage capacity can be seen, but only with a large enough collector area: for "small" configurations (FSC' <1), the sorption storage can probably not be charged effectively and does not provide clear improvement of the performances.

- **The ITW system is very efficient** due to **more efficient collectors** that need also some tracking. It is not possible to determine which part of this good performance can be attributed to a more efficient storage concept, and which part simply to more efficient solar collectors. But going to higher temperatures in the solar loop in summertime tends to show some advantage if one can store this high temperature energy such as in a sorption storage. However comparing energy performance is also not a complete comparison: exergetic quality of each store should be carefully compared.

- A fair comparison is even more difficult because the ITW system (Monosorp) benefits also from a heat recovery system built-in that saves energy even without any solar input.

- Reached FSC' values are much higher than those for water storages: this means that **chemical or sorption storages allow to use larger collector areas and storage sizes, to go towards inter seasonal storage** and to target higher fractional energy savings even in less favourable climates.

3.3.2 Extended fractional energy savings

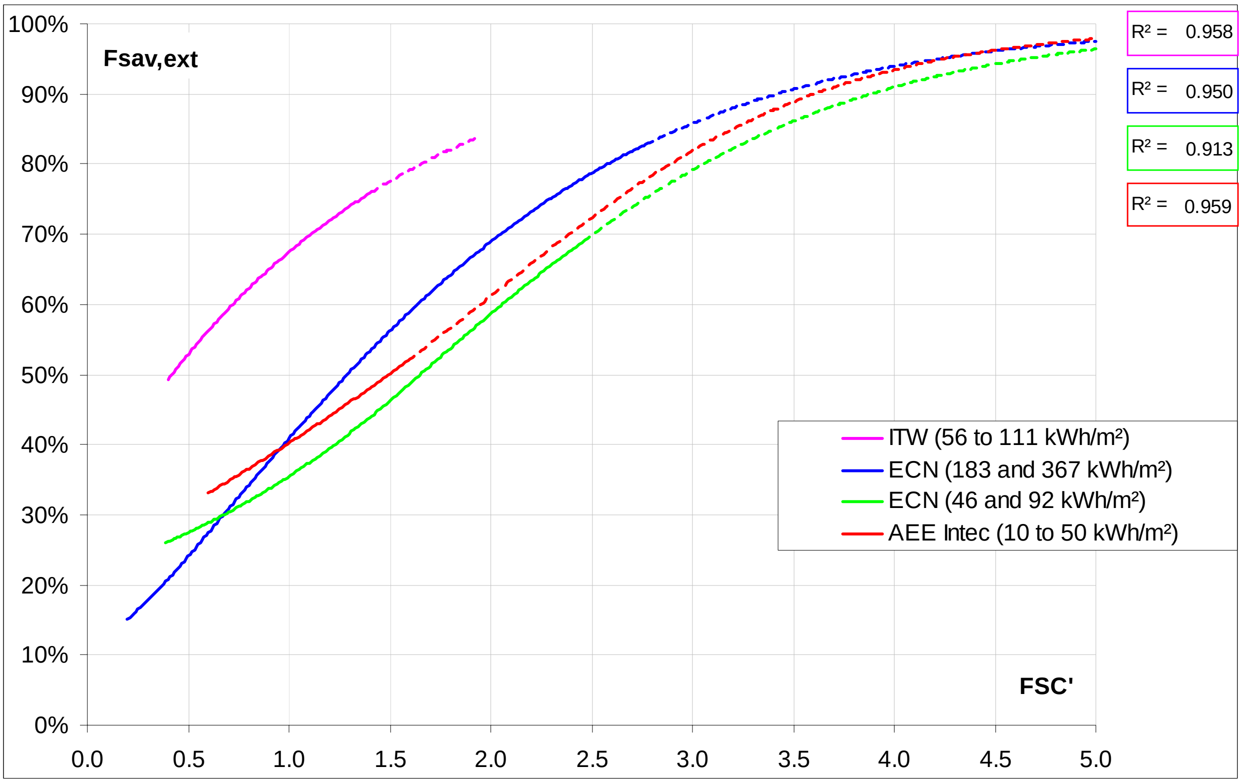

Fig. 8: Systems comparison for sorption storages (extended fractional energy savings)

<u>Comments</u>:

- There are no strong differences in conclusion when auxiliary electricity is accounted for.
- As a general conclusion when considering parasitic energy for pumps and control, a global trend seems to be that the difference between $F_{sav,th}$ and $F_{sav,ext}$ increases with FSC' .

4 Comparison on several indicators

The comparative analysis is done using the indicators defined in (Hadorn J.C., 2007). The list of indicators is:

Energy performance

NRJ1 = Fsav = f(FSC')

NRJ2 = Comfort for both heating and DHW are needed (2 temperatures are required: a room temperature and the temperature of delivered tap water). Using Task 26 simulation methods in TRNSYS, the penalty functions can be used to derive an indicator for both.

NRJ3 = Comfort cooling. This criteria is based on a frequency histogram of indoor temperature (hourly values for instance), and measures the number of hours during a summer the indoor temperature is in a comfort zone.

NRJ4 = Storage performance indicator that is:

NRJ4.1: Storage density of material: kWh/m3

NRJ4.2: Storage density of storage component: based on component bulk volume (occupied space) = kWh/m3

NRJ4.3 Storage efficiency = Energy out/Energy in over 1 or 365 days depending on the nature of the store (number of cycles per year). This ratio is a figure of merit of the storage, its loading and unloading process and its thermal losses.

Economics

ECON1 = Investment in absolute term (material + installation), Euros per kWh

ECON2 = Operating cost in absolute term, Euros per kWh (calculated at reference conditions, including the auxiliairy energy needed)

Market Availability (of storage and/or system)

MARKT = is a value that is 1 if the system is on market, 2 if the storage will be on market within 1-3 year, and 3 if it is not anticipated to be market ready before 3 years. This is a measure of the time to market of the technology or the chance to have an industrial product within 3 years

Environnement

ENV1 = Storage material Risk, Corrosivity + Toxicity + Safety (manipulation, flammability) measured by a grade: 0 = the risk is 0, 1 = 0 to low risk, 2 = some material can be corrosive, 3 = toxic or dangerous material.

ENV2 (in 4 climates) = CO2 equivalent emission per kWh of load / CO2 equiv emitted by the reference system of the Task 32 (including the boiler cycling). A conversion factor for electricity is needed in some cases: 2.5 is taken. We take only the CO2 during 1 year of operation, but not the CO2 resulting from embodied energy in materials (very difficult to assess).

CO2 emission for auxiliary energy (kg CO2/kWh) : gas

CO2 emission for parasitic electricity (kg CO2/kWh)

Integration of the system

INT1 = weight of material (kgs of the total system delivery), is a measure of how massive is a system compared to another (think to a plastic storage tank compared to another one made of steel)

INT2= number of separate pieces at delivery if known , is a measure of complexity to mount and of possible mistakes !

INT3= level of skills required to install (1 = advanced, 0 = normal), is also a measure of ease of installation

INT4= Need of system maintenance in normal operating conditions (1 = technically needed, 0 = free like a simple water tank storage system). This is an indication of operating costs as well.

The following table compares the features of the different systems studied. For most of them, some criterias are not available, because the systems are such in an early stage of development, either from a theoretical point of view (simulations), or from a practical point of view (test in lab) that values could not be assessed.

	Unit	Water storage				PCM storage			Sorption storage				
		DTU without stratifiers	DTU with stratifiers	Heig-Vd	SPF	Heig-Vd	University Lleida	DTU	AEE INTEC	ITW	SERC	ECN	EMPA
NRJ1		25.0 m² 2.8 m^3 102 kWh 55.4 %	25.0 m² 2.8 m^3 102 kWh 58.5 %	26.0/23.4 m² 1.9/3.5 m^3 84/152 kWh 63.6/72.0 %	26.0/22.5 m² 2.4/4.3 m^3 102/183 kWh 62.3/70.3 %	26.3/23.7 m² 1.8/3.2 m^3 79/142 kWh 63.4/71.7 %	n/a	n/a	16.0 m² 25 m^3 831 kWh 45.2 %	14.6 m² 9.5 m^3 1137 kWh 79.7 %	n/a	12.7m² 10.2 m^3 1833 kWh 43.9 %	n/a
NRJ2		>99.5%	>99.5%	100%	100%	100%		n/a	100%	yes	no	100%	
NRJ3		n/a	n/a	-	-	-		n/a	n/a	yes	no	n/a	
NRJ4											no		
NRJ4.1	kWh/m^3	81	81	81	81	81	?	128	n/a	160	253	420	500
NRJ4.2	kWh/m^3	36	36	44	43	44		75	n/a	120	85	180	200
NRJ4.3		0.81	0.82	0.75	0.85	0.75		0.51	0.29	0.75	no simulations	assumed ideal	0.55
ECON1	€/kWh	2.73	2.75	3.21	3.11	3.59		9.5	not available	26	no sims	n/a	27'500 €
ECON2	€/kWh	0.101	0.099	0.093	0.114	0.092		0.015	2292 kWh of aux fuel (gas), 1623 of electricity	0,769	no sims	n/a	250 €
cost of gas	€/kWh	0.121	0.121	0.068	0.058	0.068							
cost of electricity	€/kWh	0.239	0.239	0.093	0.145	0.093							
MARKT		1	1	2	1 or 2	3	3	3	3	3	1	3	3
ENV1		0	0	0	0	1	1	1	?	0	2	0	3
ENV2		??	??	Barc = 0.18 Madr = 0.24 Stock = 0.68 Zürich= 0.58	Barc = 0.23 Madr = 0.29 Stock = 0.69 Zürich = 0.63	Barc = 0.18 Madr = 0.23 Stock = 0.67 Zürich= 0.57		n/a	??	fsav = 70%	no sims	fsav=70% for Zurich, 15 kWh/m2	not available
gas	kg CO2/kWh			0.205	0.205	0.205							
electricity	kg CO2/kWh			0.120	0.12	0.120							
INT1	kg	557	557	230	88	630		7800	n/a	8000	740 kg for machine with 70 kWh storage	TCM = 8000 kg for 6.6 GJ (system weight not available)	17'000
INT2		tank + pump module + solar collector + solar collector loop	tank + pump module + solar collector + solar collector loop	1 tank	1 tank	1 tank in 2 parts + 154 PCM modul		2 -5?	n/a	10	1 TCA, 1 DHW store, 1 borehole + pumps and pipes between. TCA contains many valves	n/a	1 - 5
INT3		0	0	0	1	0	0	0	1	0	1	1	1
INT4		0	0	0	0	0	0	0	1	0	1	n/a	1

Tab. 2: elements of a first comparaison of systems

Comments on table 2

Energy performance

NRJ1: the reader should refer to the previous chapters

NRJ2: all systems achieved the comfort criteria imposed in the Task 32 framework for both indoor space temperature and domestic hot water minimum temperature at tap delivery

NRJ3: no system simulated had cooling capabilities in our case, but the Task 32 framework can handle cooling loads as well.

NRJ4: the storage density of material is to be compared to water (81 kWh/m^3 over 70 °C by convention in Task 32). ECN material and EMPA material (NaOH) have high densities. More important is the density based on occupied volume since some systems need 2 or 3 vessels to work. Even water tanks need twice the volume of the water to be operated.

NRJ4.2 shows that PCMs storage are not penalized on this criteria but not favored too, and that best sorption systems keep a clear advantage over water still by a factor 3 (ITW) to 5 (EMPA). New material candidates should target on this criteria to be at least twice better than water to get a chance to get to a competitive system in the end.

NRJ4.3 is a storage efficiency indicator. A measure of heat losses and exchange power capacity. Water tanks is around 80% for diurnal storage (1 to few days of storage). EMPA store is above 1.0 since energy in winter will also come from the low grade heat source to evaporate back water.

Economics

Economical factors are always difficult to assess, specially when comparing unique prototypes of systems ! We try here to give some directions. Figures for non water tank system should be taken as indicative.

Figures must be compared cautiously, because of the various purchase power parities (PPP) in the different countries, and because the costs of energy differ from a country to another. (We give in the table the level of energy costs taken into account in the evaluation). More information on the PPP can be found at www.oecd.org/std/ppp.

Water storage shows a 3 €/kWh investment cost and 0.1 €/kWh of operational costs. With a standard annuity rate of 10% on this 3 €, the cost of heat delivered during one cycle of storage is 0.31 €/kWh. To reach a zone where the storage cost is a small part of the total solar cost, the number of cycles per year should be at least 10 and more. For 100 cycles per year, the storage cost will then vanish to 0.031 cts/kWh delivered. Seasonal storages operate with 1 to 5 cycles a year in general. This put more pressure on the investment cost or on the density of the storage !

Market Availability (of storage and/or system)

Market availability shows that Task 32 worked mainly with prototypes except water storage and SERC.

Environnement

Environmental criteria are also difficult to assess for prototypes. We indicate here the values for water storage systems as a reference for a future work. The climate is of great importance for the performance of a solar system as can be seen.

Values of the ENV2 indicators depend on the emission of energy used. These values differ from a country to another, especially for electricity, because the CO_2 emissions depend on the way electricity is produced (renewable sources like wind or hydropower, low emission production like nuclear or high emission production like coal). We give in the table the level of emission taken into account in the evaluation.

Integration in a system

Is a store easy to handle ? Integration criteria show very diverse values for the total weight of a storage unit from 88 kg for a plastic water tank storage to 15’000 kg for a seasonal sorption store.

5 Conclusions

In the course of IEA SHC Task 26 "Solar combisystems", the FSC method developed in this framework revealed to be fruitful for comparing the performances of solar combisystems with very different conditions of climates, loads and system sizes. However a limitation of this method was that it could be handled only "small" systems, ie systems without long term storage.

For the special purposes of IEA SHC Task 32 dealing with all kind of storages, either small or large, a so-called extended "FSC'" method was developed in Subtask A.
This new method has been used in this report to evaluate and compare systems with very different designs. It has proved to be useful for the purpose of describing the performance of a combisystems with any storage size.

Several systems with advanced storage techniques have been simulated by Task 32 participants with the Task framework and the simulation models developed throughout the 4 years of the Task. The framework proved to work well. Each simulated system can be referenced with its characteristic curve Fsav vs FSC' which is independent of the climate and the load !

Using each system curve, it is possible to compare very different designs as this report explains and shows.

Following recommendations and trends can be given:

1. Drain back provide an improvement of performances compared to anti-freeze based systems

2. Stratifiers in water tank storage enhance thermal performances, but attention should be paid on the optimisation of parasitic energy used, in order not to impose a penalty the fractional extended energy savings.

3. Quick evaluation of performances of systems with fractional savings up to 100% can be obtained using their characteristic curve derived from simulations.

4. PCM storage (58 °C transition point) in Task 32 configurations (max 50% in volume) does not enhance system performances. Further optimisation is needed changing parameters such as the location of the PCM, its temperature range and its volume.

5. Only the long term heat storage with subcooled liquid PCM shows (at least in the preliminary simulations done at DTU) an advantage against water storage, when 100 % solar fraction for a 135 m² floor area passive house (15 kWh/m²a space heating energy demand) should be achieved.

6. System based on sorption storage need large storage volumes to reach good performances. But they open the way to real seasonal storage and high fractional energy savings even in less sunny climates.

7. A high temperature solar loop (with CPC collectors) and sorption storage is a promising solution towards a seasonal storage with affordable volume in a house. This is a way to further investigate.

Task 32 aimed at comparing new storage techniques in a global system as a solar combisystem. This goal was a challenge. Most of the participants in the Task 32 have made it possible to reach that goal.

Task 32 has set up a methodology to compare storage technologies with criteria and indicators. It is a first step towards better tools to analyze and compare heat storage options for solar combisystems.

Finally, we have not attempted to provide an intercomparison between storage technologies (water vs PCM or sorption). This is not recommended due to a number of assumptions made in the derivation of FSC' (empirical coefficient introduced based on preliminary results) and the limited number of simulations made for some technologies.
The proposed method requires more validation work and ajustments.

6 References

Duffie J. A., Beckman W. A. (1991) *Solar Engineering of Thermal processes*, 919 p. Wiley Interscience, New-York.

Hadorn J-C. (2007) : *Method of comparison of storage concepts, A Report of IEA Solar Heating and Cooling programme - Task 32 Advanced storage concepts for solar and low energy buildings*, Report A3 of Subtask A, December 2007, 13 p.

Heimrath R., Haller M. (2007): *The Reference Heating System, the Template Solar System, A Report of IEA SHC - Task 32 Advanced storage concepts for solar and low energy buildings*, Report A2 of Subtask A, May 2007, 55 p

Letz T. (2003): *Validation and Background Information on the FSC Procedure, A Report of IEA SHC - Task 26 Solar Combisystems*, December 2002, 23 p

Letz T. (2007): *The extended FSC procedure for larger storage sizes, A Report of IEA SHC - Task 32 Advanced storage concepts for solar and low energy buildings*, Report A1 of Subtask A, December 2007, 26 p

Letz T. et all (2007): *Evaluation of performances of solar combisystems with advanced storage concepts, A Report of IEA SHC - Task 32 Advanced storage concepts for solar and low energy buildings*, Report A3 of Subtask A, December 2007, 41 p

All reports of Task 32 are available on: www.iea-shc.org