# System Simulation Report of PCM Storage Units

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

**Advanced storage concepts for solar and low energy buildings**

## Report C6 of Subtask C

## March 2008


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Task 32 Storage

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

**Project Report C6 of Subtask C**

# System Simulation Report of PCM Storage Units

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A technical report of Subtask C

*This report has 4 separate appendices.*

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## Executive Summary

Due to the developed simulation modules for PCM stores of various kinds and the TRNSYS system simulations developed in IEA SHC Task 26 and Task 32 it was possible to carry out detailed systems analysis for the behaviour of PCM stores in different applications compared to water stores. The main application focused at in Task 32 was a solar combisystem, defined in Subtask A, Report A2. This system was used unchanged by HEIG-VD and the University of Lleida Spain and slightly altered ba the UDTI, Denmark. At Graz University of Technology the applications was a conventional heating system, were the PCM heat storage was used to reduce the boiler cycling rate.

- At the Applied University of West-Switzerland in Yverdon-les-Bains/Switzerland a parametric study for the use of PCM in heat stores for solar combisystems is carried out (details see Report C6.1 as Appendix 1).
- At the Department of Civil Engineering, Technical University of Denmark the use of super cooling of PCM materials for long-term heat storage is investigated with simulations (details see Report C6.2 as Appendix 2).
- The Institute of Thermal Engineering at Graz University of Technology performed simulations with different PCM materials encapsulated in plastic tubes and steel containers for stores for conventional boilers to reduce the number of start-stop cycles of the burner. ). A more detailed description of this work, including an analysis of the annual emissions caused by the start-stop operation can be found in (Heinz, 2007) (details see Report C6.3 as Appendix 3).
- At Lleida University, Spain, bottles of PCM material with graphite matrix for the enhancement of the heat conduction and increase of power input/output are tested. Applications are free-cooling and DHW tanks (details see Report C6.4 as Appendix 4).

Unfortunately the system simulations reported here showed only little or even no advantage for macro-encapsulated PCM modules in combistores and for PCM slurries for heat stores in solar combisystems. This is due to the fact that the improvement energy storage capacity is overcome by the temperature losses during high charge/discharge rates that result in switching on the auxiliary boiler due to too low temperature available. Even the immersed heat exchanger with high possible charging/discharging rates due to very small distances of the heat flow in the PCM had only little advantage against waters stores for the same applications.

Only the long term heat storage with subcooled liquid PCM shows (at least in the preliminary simulations) 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.

SOLAR HEATING & COOLING PROGRAMME
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# IEA Solar Heating and Cooling Programme

**T**he *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.

**T**he *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 21$^{st}$ Century* |

**C**ompleted 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 C
## "Storage with Phase Change Materials"

This report is part of Subtask C of the Task 32 of the Solar Heating and Cooling Programme of the International Energy Agency dealing with solutions of storage based on phase change materials or "PCMs".

This reports introduces the simulation studies done by 4 teams participating in Subtask C "Phase change materials" and presents the main results obtained.
A detailed report for each system studied is available separately.

Projects presented in this report reflects the knowledge of the participating body presenting the project.

The Operating Agent would like to thank the authors of this document for their implication in the search of future storage solutions for solar thermal energy, the key to a solar future for the heating and cooling of our buildings.

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# 1 INTRODUCTION

Based on the models described in Report C5 system simulations with the PCM stores and water stores were carried out. Four simulation studies were performed in Subtask C. Three of them were using more or less the reference conditions defined in Subtask A (Report A2). One of them dealt with a complete different application to reduce boiler cycling by introducing a PCM store.

- At the Applied University of West-Switzerland in Yverdon-les-Bains/Switzerland a parametric study for the use of PCM in heat stores for solar combisystems is carried out.
- At the Department of Civil Engineering, Technical University of Denmark the use of super-cooling of PCM materials for long-term heat storage is investigated with simulations.
- The Institute of Thermal Engineering at Graz University of Technology performed simulations with different PCM materials encapsulated in plastic tubes and steel containers for stores for conventional boilers to reduce the number of start-stop cycles of the burner. ). A more detailed description of this work, including an analysis of the annual emissions caused by the start-stop operation can be found in (Heinz, 2007).
- At Lleida University, Spain, bottles of PCM material with graphite matrix for the enhancement of the heat conduction and increase of power input/output are tested. Applications are free-cooling and DHW tanks.

A summary of these simulation projects is given in Table 1, some man results are presented in chapter 2 and the detailed results are given in the following appendices:

Report C6.1: HEIG-VD-W and HEIG-VD-PCM, Macroencapsulated PCM in Storage, HEIG-VD, Switzerland
Report C6.2: PCM with supercooling, DTU, Denmark
Report C6.3: PCM storage to reduce cycling rates for boilers, Graz University of Technology, Austria
Report C6.4: PCM-water store, University of Lleida, Spain

*Table 1 Summary of annual system simulation studies performed in Subtask C.*

| Type of Technology | Material | Kind of simulation | **Investigating Institute, Detailed Appendix** |
|---|---|---|---|
| Macroencapsulated PCM in storage tank with integrated burner | Na(CH3COO) ·3 H2O + graphite | Sensitivity analysis with seasonal simulations using the boundary conditions defined in Report A2 and Analysis according Report A3<br>Comparison to water storage | **Applied University of West-Switzerland (HEIG-VD), Switzerland Appendix 1 C6.1** |
| PCM seasonal storage using subcooling | Na(CH3COO) ·3 H2O | Sensitivity analysis for various parameters with seasonal simulations using the boundary conditions defined in Report A2<br>Comparison to water storage | **Technical University of Denmark (DTI), Denmark Appendix 2 C6.2** |
| Macroencapsulated PCM in storage tank | Paraffine, $Na(CH_3COO)\cdot 3\ H_2O$ with/without graphite | Reduction of cycling rates of boilers for various hydraulic systems, effect on biler efficiency and boiler emissions.<br>Comparison to water storage | **Graz University of Technology, (IWT-TU Graz), Austria Appendix 3 C6.3** |
| Immersed heat exchanger in PCM | $Na(CH_3COO)\cdot 3\ H_2O$ without graphite | Reduction of cycling rates of boilers for various hydraulic systems, effect on biler efficiency and boiler emissions.<br>Comparison to water storage | **Graz University of Technology, (IWT-TU Graz), Austria Appendix 3 C6.3** |
| **Macroencapsulated PCM in storage tank** | **$Na(CH_3COO)\cdot 3\ H_2O$ + graphite** | **Detailed analysis of impact of PCM on daily temperature and power course, sensitivity analysis for some positions of temperature** | **University of Lleida, Spain Appendix 4 C6.4** |

# 2 Results of simulation studies

The simulation results from **HEIG-VD in Yverdon-les-Bains, Switzerland** (Appendix 1) concerning the advantage of makroencapsulated PCM in solar combisystems are shown in Figure 1. It should be reminded that the proposed system has been analysed only from the simulation side, where a water tank storage filled only with water or filled with water + PCM (paraffin RT35) is compared.

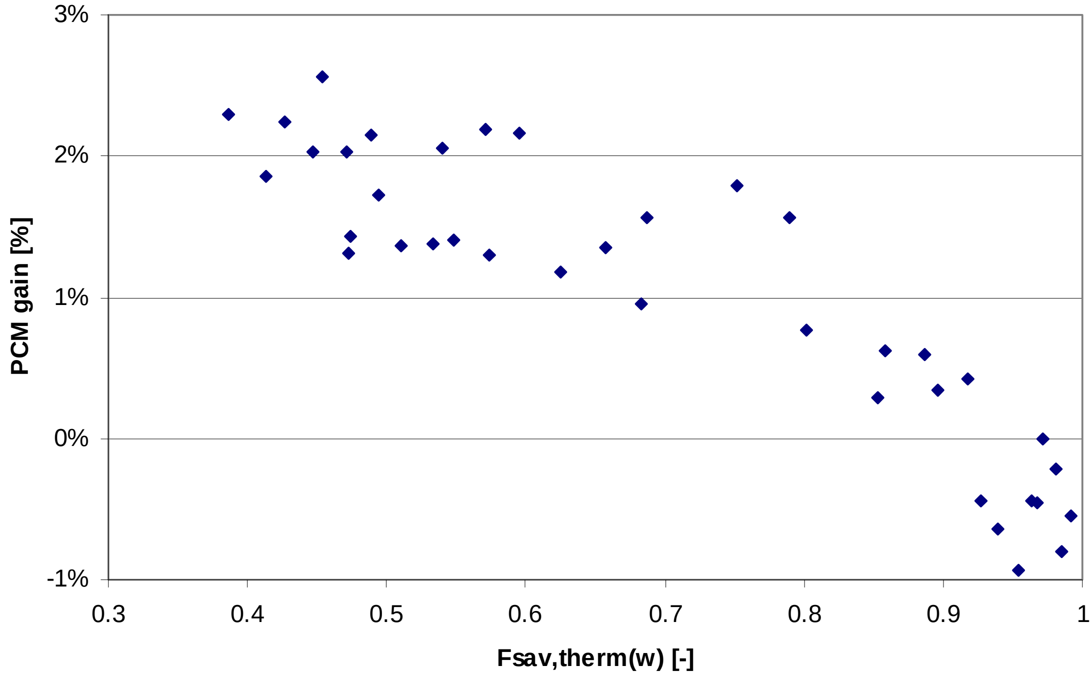



*Figure 1:. Difference between sole water and water + PCM system. The PCM gain =* $F_{sav,therm(W+PCM)}/F_{sav,therm(W)} - 1$

To evaluate the impact of the PCM on the performances, it is possible to define the energy gain between the $F_{sav,therm}$ for the tank with PCM ($F_{sav,therm(W+PCM)}$) and only with water ($F_{sav,therm(W)}$). If this gain is higher than 0, then the PCM brings an advantage. As it can be seen in Figure 1, the gain due to using PCM is low. A decrease of the ratio according to the increase of the $F_{sav,therm}$ can also be noticed. But it should be remembered, that when the $F_{sav,therm}$ is high, the solar installation is oversized. As it can be seen, adding a PCM becomes less interesting when the solar system is oversized. This is due to the fact, that when oversized, the storage of heating is less relevant.

According to the additional cost of adding the PCM and the environmental impacts results described in Report C3, this system with PCM does not show a substantial benefit compare to a storage tank filled only with water.

Only the long term heat storage with subcooled liquid PCM (**BYG DTU, Department of Civil Engineering, Denmark,** Figure 2, (Appendix 2)) shows the possibility to achieve 100 % solar fraction with PCM store volumes of about 10 m³ a 135 m² floor area passive houses (15 kWh/m²a space heating energy demand). Water stores have to be far bigger to achieve the 100 % solar fraction. 80 – 90 % solar fraction can be achieved also with water stores of 5 - 10 m³. Taking into account the long term heat losses of water stores the size reduction is far bigger.

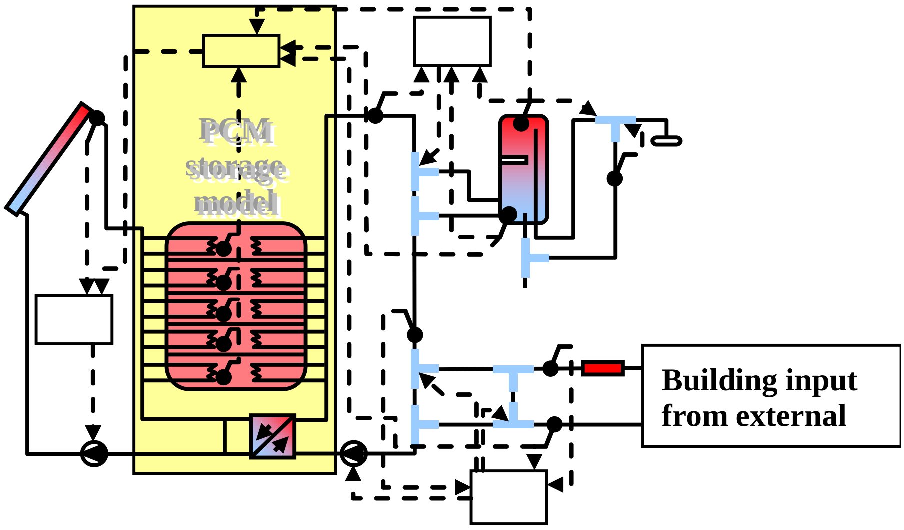



*Figure 2:Simulation model of BYG DTU, Department of Civil Engineering, Denmark*

At the **Institute of Thermal Engineering (IWT), Graz University of Technology, Austria** (Appendix 3) different hydraulic systems were investigated in terms of their ability to reduce boiler cycling operation. In the following a description of the hydraulic systems, which are used in the simulations, is given. Table 1 shows a summary of all simulated concepts.
The results for the system with sole water storage (G2a) and for systems with water storage with integrated PCM modules (G2b) are shown in Figure 3 for different storage volumes In comparison to the systems without buffer storage the number of start-stop cycles is reduced strongly. Even with the smallest volume of only 25 litres a reduction of about 70 % (set temp. 50°C) or 90 % (set temp. 65°C) can be achieved. With increasing storage volumes the number of cycles decreases, whereby the potential for a further reduction is low for volumes above 200 litres. Because of the lower utilized temperature difference the number of cycles is higher with a boiler temperature of 50°C in comparison to 65°C. On the other hand the higher temperatures decrease the annual efficiencies of the condensing boiler by 2-3 %.
The integration of PCM modules allows an enhancement of the storage capacity, resulting in a further decrease of the number of start-stop cycles especially with small storage volumes. There are only minor differences between the PCM volume fractions of 50 and 75 %. The integration of PCM modules hardly influences the annual efficiencies of the boiler and the system.

*Table 1: Summary of all simulated system concepts*

| system | type of boiler | type of buffer storage | type of DHW preparation | hydraulic integration and control of the boiler |
|---|---|---|---|---|
| **System Category 1: no buffer storage, DHW tank** | | | | |
| G1a | gas | no storage | DHW tank | boiler temperature controlled as a function of the ambient temperature, throttle control |
| G1b | gas | no storage | DHW tank | constant boiler temp., flow temperature control via mixing valve |
| G1c | gas | no storage | DHW tank | constant boiler temp., flow temperature control via mixing valve, hydraulic switch |
| P1 | pellets | no storage | DHW tank | constant boiler temp., flow temperature control via mixing valve, hydraulic switch, return temperature control |
| **System Category 2: buffer storage, DHW tank** | | | | |
| G2a | gas | water storage | DHW tank | constant boiler temp., flow temperature control via mixing valve, buffer storage |
| G2b | gas | water storage + PCM modules | DHW tank | constant boiler temp., flow temperature control via mixing valve, buffer storage |
| P2a | pellets | water storage | DHW tank | constant boiler temp., flow temperature control via mixing valve, buffer storage, return temperature control |
| P2b | pellets | water storage + PCM modules | DHW tank | constant boiler temp., flow temperature control via mixing valve, buffer storage, return temperature control |
| **System Category 3: buffer storage, instantaneous preparation of DHW** | | | | |
| G3a | gas | water storage | instantaneous preparation of DHW | constant boiler temp., flow temperature control via mixing valve, buffer storage |
| G3b | gas | bulk PCM tank | instantaneous preparation of DHW | constant boiler temp., flow temperature control via mixing valve, buffer storage |

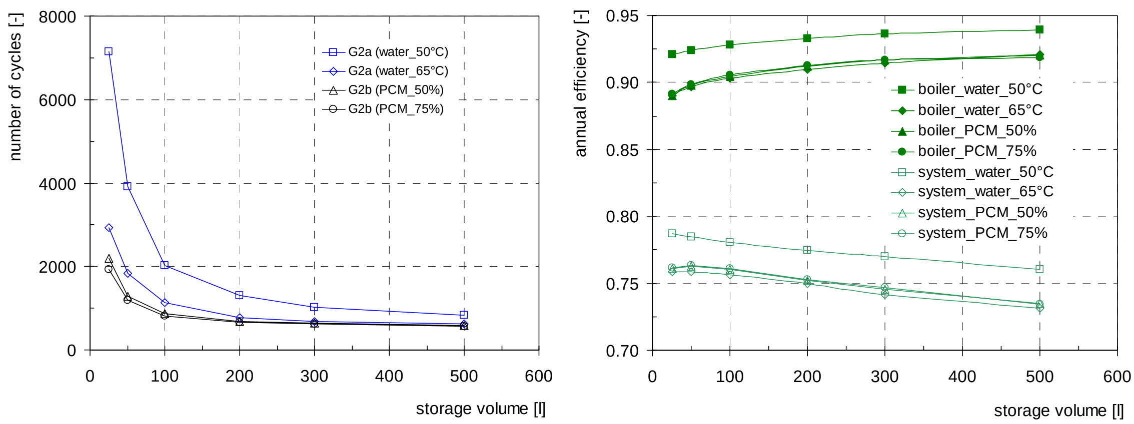
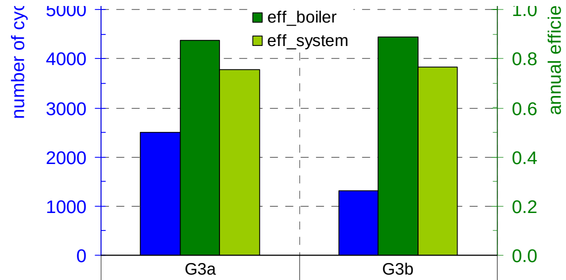



*Figure 3: Gas boiler: annual number of start-stop cycles (left) and annual efficiencies (right) for different storage volumes for systems with water storage (G2a) and for systems with water storage with integrated PCM modules (G2b)*

Figure 4 shows the number of start-stop cycles and the annual efficiencies for the system G3a (water storage) and the system G3b (bulk PCM storage). Due to the higher storage capacity of the PCM storage in system G3b the number of cycles can be reduced by 50 % compared to system G3a. The annual efficiency of the boiler is also slightly higher, which is a result of the lower amount of heat produced in start-stop operation due to the higher storage capacity.




| | G3a | G3b |
|---|---|---|
| n_cycles | 2503 | 1307 |
| Reihe4 | | |
| Reihe3 | | |
| Reihe5 | | |
| eff_boiler | 0.87 | 0.89 |
| eff_system | 0.76 | 0.77 |

*Figure 4: Annual number of start-stop cycles and annual efficiency for the systems G3a (water storage) and G3b (bulk PCM storage)*

At the **University of Lleida, Spain** (Appendix 4) the reference solar combisystem equipped with PCM containers in the top of the space heating store was simulated (see Figure 5). Detailed analysis was carried out concerning the correct simulation of the control algorithms. It was found, that a simulation time step of 1 minute was needed to simulate the functionality of the PCM correctly. Additionally a seasonal simulation with varying sensor and in/outlet positions for the PCM store in comparison to a pure water store was performed. There was no significant difference between the simulation of the pure water store compared to the store with the macroencapsulated PCM modules (Figure 6).

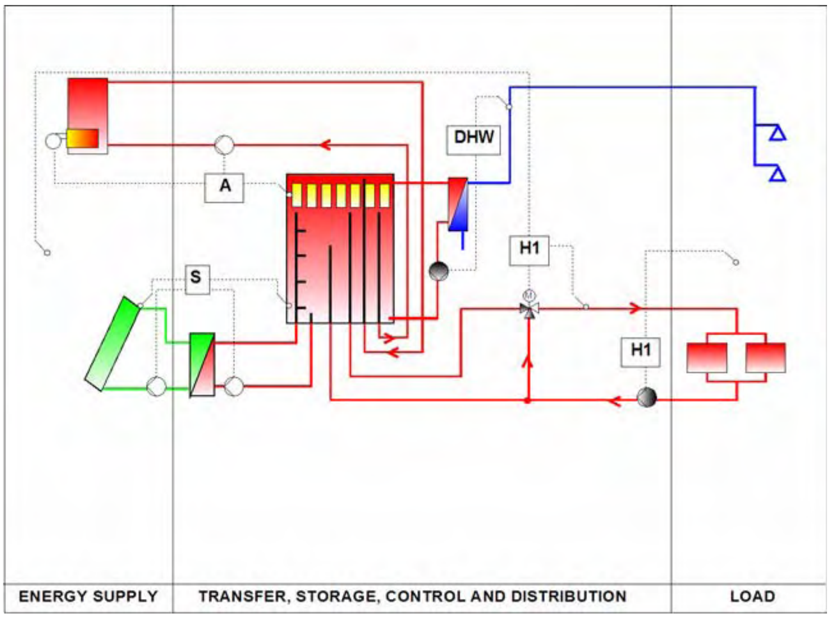



*Figure 5: Simulated solar combisystem of University of Lleida, Spain*

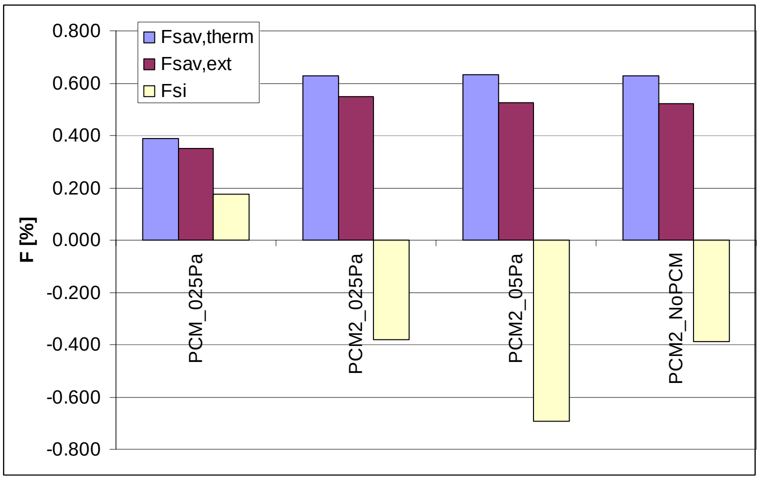



*Figure 6: Difference of heat storage with makroencapsulated PCM with various sensor and in/outlet positions and a sole water store.*

# 3 Final conclusions of simulation studies

Due to the developed simulation modules for PCM stores of various kinds and theTRNSYS system simulations developed in IEA SHC Task 26 and Task 32 it was possible to carry out detailed systems analysis for the behaviour of PCM stores in different applications compared to water stores. The main application focused at in Task 32 was a solar combisystem, defines in Subtask A, Report A2. This system was used by HEIG-VD and the University of Lleida Spain.

A revised solar combisystem system with seasonal storage of PCM due to subcooling was analysed at DTU, Denmark. The comparison to water stores is not as simple, because there are no heat losses of the subcooled PCM store. Compared to the theoretical heat storage of water without heat losses the PCM store can be reduce by about 30 %. Taking into account the long term heat losses of water stores the size reduction is far bigger.

At Graz University of Technology the effect of PCM storage and water storage on the cycling rate, efficiency and emissions of boilers for various hydraulic systems was analysed.

Unfortunately the system simulations reported here showed only little or even no advantage for macro-encapsulated PCM modules in combistores and for PCM slurries for heat stores in solar combisystems. This is due to the fact that the improvement energy storage capacity is overcome by the temperature losses during high charge/discharge rates that result in switching on the auxiliary boiler due to too low temperature available. Even the immersed heat exchanger with high possible charging/discharging rates due to very small distances of the heat flow in the PCM had only little advantage against waters stores for the same applications.

Only the long term heat storage with subcooled liquid PCM shows (at least in the preliminary simulations) 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.

# 4 References

**Subtask reports**

1. Report A2 "The Reference Heating System, the Template Solar System”.
2. Report A3 " Method of comparison of designs and criteria”.
3. Report C5 “Simulation Models of PCM Storage Units”.

**Articles in Conferences related to Subtask C and simulation developments**

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Appendix 1: Report C6.1
Appendix 2: Report C6.2
Appendix 3: Report C6..3
Appendix 4: Report C6.4