Storage based on Phase Change Materials (PCM)
Selection of concepts

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

Report C1 of Subtask C

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Task 32
Storage

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Report C1 of Subtask C

Storage based on Phase Change Materials (PCM) Selection of concepts

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A technical report of Subtask C

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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 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".

The topic of PCM is not completely new for solar energy storage but the way Task 32 has handled it is new. From material to system and simulation, the process was application oriented: a solar combisystem has a target. Can PCM storage do better than water tanks ?

The report presents in a common reporting format a survey of the five projects investigated within Task 32 at its beginning and dealing with PCM. 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.

Jean-Christophe Hadorn

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

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Contents

1 INTRODUCTION

There are five PCM related projects included in Task 32:

Three projects deal with macro-encapsulated PCM containers in water stores. All of these projects include the development of TRNSYS models for the PCM stores:

- In Lleida University, Spain bottles of PCM material with graphite matrix for the enhancement of the heat conduction and increase of power input/output is tested. Applications are free-cooling and DHW tanks.
- In the Applied University of West-Switzerland in Yverdon les Baines/Switzerland a parametric study for the use of PCM in heat stores for solar combisystems is carried out.
- The Institute of Thermal Engineering at Graz University of Technology performs tests and simulations with different PCM materials encapsulated in plastic foils for stores for conventional boilers to reduce the cycle time.

The two other projects are slightly different

- In 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 performs tests and simulations with PCM-slurries of micro-encapsulated paraffins for stores for conventional boilers to reduce the cycle time. TRNSYS modules are developed for a store filled with slurry with various internal heat exchangers and flow/return pipes and an external heat exchanger with PCM slurry on one side.

2 Selected projects

2.1 Applied University of West-Switzerland (Jaques Bony, Stephane Citherlet)

A Project name: PCM storage

Starting date: November, 2004 Due Date: December 31, 2006
Institutions involved, industry partners country and persons
1. Applied University of West-Switzerland / HES-SO
Financed through: Federal Office for Energy

B Type of storage

Capacity / dimensions: 850 l
Features: Solar Combi-system
Availability on market: Yes (AGENA, Inc., without PCM)

Objectives:
1. Provide a TRNSYS type that can simulate PCM modules placed into a combi-system used in Task 26
2. Evaluate the simulation results with experimental data obtained with the combi-system
3. With a parametric study, evaluate the potential of using PCM in combi-systems.

C System description , goal, capacity, performances, targets

The combi-system includes two heat exchangers, one for the DHW and the second for the solar hot water. The tank water is used for the heating. PCM modules will be placed in the water tank. The effect of PCM volume and position will be estimated with a simulation model, after the latter has been validated with experimental data. The properties of various PCMs will be provided by the Lleida team.

D Current progress

Laboratory tests:
The test facility used during the Task 26 has been modified (construction, acquisition/control and heat evacuation) in order to test the effect of PCM.
In parallel, a basic water tank is in preparation in order to validate a new simulation model with experimental data obtained with simplified PCM configurations.

Simulation:
Modification of TRNSYS type 60 in order to take into account PCM modules plunge into the tank. Model is finished but has to be compared to experimental data. The data will be first provided by the Lleida University team and latter this year the model will be compared to experimental data provided by each team.

E Results:

Comparison between simulation results and experimental data will start soon.

F Open questions, problems

G Perspectives

In collaboration with the Lleida and Graz Universities a protocol has been set up, to evaluate the conformity of the simulation models developed by each teams. The goal is to compare experimental data obtained by each team (currently only the Lleida team has data) with simulation results to evaluate the conformity of each computer model.

2.2 University of Lleida (Luisa Cabeza)

A Project name: Implementación y análisis del almacenamiento de energía térmica con materiales de cambio de fase para dos aplicaciones concretas: free-cooling y depósitos de ACS (Analysis and implementation of thermal energy storage with phase change materials for two applications: free-cooling and DHW tanks)
Starting date: December 1, 2002 Due Date: November 30, 2005
Institutions involved, industry partners country and persons
1. University of Lleida, Spain
2. University of Zaragoza, Spain

Financed through: Spanish government

B Type of storage: PCM in water storage

Capacity / dimensions: 146 L water tank with PCM (from 2 to 6% volume)
Features
Availability on market
Objectives:
1. Compare performance to only water tanks
2. See performance in solar system
3. Test different PCMs
What is new compared to state of the art knowledge?

C System description, goal, capacity, performances, targets

D Current progress

Some experiments have been already carried out showing good performance. First TRNSYS simulations have been done.
More structured experimental test will be performed in pilot plant to validate TRNSYS model.

E Results

Preliminary results have already been published in several conferences

F Open questions, problems

G References

- Renewable Energy 28 (2003) 699-711
- Presentation at Eurosun 2002
- Presentation at the XVI Congreso Nacional de Ingeniería Mecànica, Spain 2002
- Presentation at Futurestock 2003
- Presentation at the 6th workshop Annex 17 – ECES IA – IEA, Sweden 2004

2.3 Department of Civil Engineering, Technical University of Denmark (Simon Furbo)

A Project name: PCM storage

Starting date: July 1, 2003 Due Date: December 31, 2005
Institutions involved, industry partners country and persons
1. Department of Civil Engineering, Technical University of Denmark

Financed through: Danish Energy Authority

B Type of storage: PCM storage

Capacity / dimensions: from 1 to 20 m3
Features: a seasonal strorage inPCM
Availability on market: only laboratory for the moment
Objectives:
1. demonstrate the concept by simulation
2. demonstrate the feasibility on small scale
3. scale up
What is new compared to state of the art knowledge ? the use of supercooling effect to keep the store quiet during many months

C System description

A tank with compartments is filled up with a PCM material (58 C transition phase). Each compartement can be loaded and triggered separately.
It is anticipated that a 12 to 20 m3 of storage can yield to a 100% solar fraction in a low energy house in danish conditions.

D Current progress

Calculations have been carried out by means of a new TRNSYS model for a solar combisystem based on a PCM storage utilizing super cooling.

E Results

Parameter analyses on differently designed heat storages are carried out.
The heat storage must be divided into a number of sections.
The charge strategy should aim on melting one storage section at the time.
Active use of super cooling will increase the thermal performance of solar combisystems with about 3%.

F Open questions, problems

Will the supercooling effect be observed in large bulk volume ?
Will it be possible to trigger parts of the storage ?

G References

Paper for the EuroSun 2004 Conference

2.4 Institute of Thermal Engineering, Graz University of Technology (Andreas Heinz)

A Project name: PAMELA

Starting date: 12/2001 Due Date: 11/2004
Institutions involved, industry partners country and persons
1. University of Ulster (Coordinator)
2. ISE Freiburg Germany, EIVD Switzerland, IWT TU Graz, Austria, Bulgarian Acad. of Science,
3. BASF Germany, Cristopia France, Tyforop Germany

Financed through: EU 5th framework

B Type of storage: PCM Storage

Capacity / dimensions about 200 litres
Features: Microencapsulated Slurry, 65 °C phase change point
Availability on market: No
Objectives:
1. Development of Material
2. Definition of applications and laboratory test of applications
3. Development of Simulation tools
What is new compared to state of the art knowledge ?

C System description

PCM slurries in tanks are investigated and compared to pure water tanks for heat storage

D Current progress

Laboratory tests for different immersed internal heat exchangers (in slurry tank) and an external heat exchanger with the slurry pumped around
Simulation tool for heat exchanger and storage tank developed

E Results

Slurry is quite stable but it is building a crust at the top after some days without movement. PCM paraffin with 65°C melting point has a melting range of about 15°C. No subcooling if it is not heated above 75°C. Higher viscosities compared to water. Therefore lower heat transfer coefficients both for natural and forced convection, higher pressure drop. Storage capacity compared to water can be much higher (up to 170 % with 50 % concentration) if used in a system with low temperature difference. The storage tank model and heat exchanger model are validated by experimental results.

F Open questions

Separation to the top, plugging of pipes which are not flown through for several days. High increase in storage capacity only occurs for low temperature differences around the melting range.

G Perspectives

2.5 Institute of Thermal Engineering, Graz University of Technology (Andreas Heinz, Peter Puschnig)

A Project name: PCM storage

Starting date: January, 2004 Due Date: December, 2005
Institutions involved, industry partners country and persons
1. Institute of Thermal Engineering, Graz Technical University
2. Polymer Competence Center Leoben
3. KWB (Austrian biomass boiler manufacturer)
4. Vaillant (Gas boiler manufacturer)
5. SOLID (solar company)
Financed through: Austrian Ministry of Science, Programme "Energiesysteme der Zukunft"
Specific Web site: www.**energiesysteme**der**zukunft**.at/

B Type of storage: PCM storage

Capacity / dimensions: 200 litre
Features
Availability on market: not available yet, research status
Objectives:
1. Same energy content with less than half the volume of a conventional water store
2. Application which cycles around melting temperature
3.
What is new compared to state of the art knowledge ?

C System description

A storage concept incorporating PCM modules with water as heat carrier flowing around is designed.
The PCM storage shall be used to reduce the number of starts and stops of boilers in order to reduce their emissions and improve their efficiency. The target is to significantly reduce the volume of the storage compared to a water storage concept

D Current progress

A TRNSYS model for the simulation of PCM storages incorporating PCM modules and/or PCM slurries has been developed. The model has already been validated against measurements with PCM slurries. A storage test stand was already built up into which the new PCM modules will be incorporated. Measurements will be carried out in order to validate the simulated results.

E Results

Planned results:
Measurements of the emissions and of the efficiency of a gas and a wood pellets boiler in continuous and start-stop operation.
Different measurements with the newly designed storage concept incorporating PCM modules and comparison with simulated data will be carried out.
Simulation of the possible reduction of boiler cycling and thus reduction of emissions by incorporating a storage tank into a defined system will be done.

F Open questions

Encapsulation of PCM and its durability is a problem.

G Perspectives

3 Conclusions

Five projects dealing with Phase Change Materials are investigated within Task 32.

For solar combisystems the most suited material appears to be Sodium acetate with its theoretical transistion temperature of 58 C.

Open questions that Task 32 will address are:

1. is this material suited for solar combisystems ?
2. what type of containment is the best ?
3. what are the thermal properties of the material ?
4. can the required power be injected into a PCM store ?
5. is the energy density enough higher than water to make a PCM store attractive ?
6. where to place the PCM in a tank ?
7. is a PCM slurry suited to storage ?
8. is the supercooling effect an advantage or a drawback ?
9. etc…

There are numerous open questions that Task 32 further reports will adress thanks to the cooperative work within Subtask C.