International Energy Agency

Implementing Agreement on

Energy Conservation through Energy Storage

Annex 17

“Advanced Thermal Energy Storage through Phase Change Materials and Chemical Reactions – Feasibility Studies and Demonstration projects”

Final Report

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Summary

Annex 17 “Advanced Thermal Energy Storage through Application of Phase Change Materials and Chemical Reactions – Feasibility Studies and Demonstration Projects” was approved by the executive committee of the IEA Implementing Agreement on Energy Conservation through Energy Storage at their meeting in Hull, Canada on the 15\textsuperscript{th} to 18\textsuperscript{th} of June 2001. Three countries, Germany, Japan and Sweden participated in the annex.

Eight experts meetings and six workshops have been arranged during the course of the annex. The workshops have been arranged in Spain, Slovenia, Japan, India, Sweden, China and Turkey. Experts meetings have been arranged in connection to other events with implications on thermal energy storage in Germany (ZAE_Bayern Symposium) and Poland (Futurestock). Participants in the workshops also originated from countries not participating in the annex namely: Australia, Canada, China, India, the Netherlands, Slovenia, Spain, Switzerland, Turkey and the United Kingdoms. During the six workshops more than 100 presentations on ongoing research, development and demonstrations have been presented. The work in the annex has been divided into three sub tasks: Heating and cooling of buildings, Temperature control and Natural and waste heat utilization.

During the course of the annex the use of phase change materials for thermal energy storage purpose has increased rapidly and many products based on PCM have been introduced into the market. In other areas demonstrations have shown the technical feasibility of the applications.

New materials, both phase change materials and new sorbents, with improved properties or with physical properties related to the need of specific applications are on or near to the market. Standardized procedures for measuring and presenting physical properties of phase change materials are under development.

In the field of Heating and cooling of buildings systems utilizing PCM for peak shaving and/or utilization of natural and waste heat have been introduced. Floor heating systems, passive cooling of offices are examples of this technique. Building materials and components with PCM for increasing of the thermal mass are introduced or are near to be introduced into the market.

Sorption systems for heating and cooling of buildings utilizing waste heat as driving energy have been demonstrated. The demonstrations show both technical and economical feasibility.

Temperature control utilizing PCM for transportation of pharmaceutical goods or other temperature sensitive goods has become a common technology. Utilization of PCM for cooling or heating of the human body has been demonstrated both for personal comfort and for medical therapy. Several applications in different field of application are on the market. Passive cooling of buildings and of telecom cabinets are examples of the widespread applications.

Natural or waste heat and cold utilization both for domestic and for industrial use have been discussed and presented during the work of the annex. The use of night time cold for day time cooling is demonstrated in several countries as well as the use of the cold nights for cooling of telecom stations. Small scale use of the solar heat of the day for night time heating or for cooking of meals after dark have also been presented during the work shops of the annex.
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1. Introduction

1.1 A need for thermal energy storage

Thermal energy storage systems as such are lately gaining an increasing interest. This can mainly be attributed to:

- Rational use of thermal energy (i.e. primary energy saving)

  Thermal energy storage leads to a more efficient use of production units for heating and cooling. Machines working at a constant load close to design capacity have a higher efficiency. A chiller working without thermal energy storage facilities has a seasonal coefficient of performance 25 to 50 % lower than design value.

  The increased use of electrical energy for cooling and heating purposes has led to a large difference in energy consumption between peak hours and off peak hours. Due to an increased use of comfort cooling the seasonal electricity peak demand in southern Europe now is in summer time for cooling purposes instead of in winter time for heating. Thermal energy storage for cooling purposes will lead to a substantial peak shaving and thus less demand for investment in increased power capacity for electricity production.

  Natural sources for heat and cold could be utilized provided access and demand could be matched by thermal energy storage technologies. In this way the coldness of the night could be utilized for cooling during hot summer days and the heat of the day could be utilized for heating in the cold nights. Also seasonal storage from summer to winter could be foreseen.

- Effective use of waste heat from waste incineration and from industrial processes

  Waste heat at different temperatures is abundant. In order to be able to use the waste energy efficiently a match between demand and availability has to be created. Thermal energy storage is a way to create this balance.

- The growing interest of cogeneration of electricity and heat

  Cogeneration of electricity, heat and cold has become popular due to the high energy efficiency of such processes. However the demand for heat and/or cold does not always coincide with the demand of electricity. Thermal energy storage will overcome this drawback

- The growing use of solar energy

  Waste heat and solar energy is available at times not necessarily coinciding with the demand for heat or cold. Thermal energy storage is a way to match the supply and the demand of thermal energy.

1.2 A need for high energy storage density

The most common way for thermal energy storage is to utilize the sensible heat change with temperature. When water in tanks or underground in aquifers or rock or soil in borehole
storages change temperature it is an indication of that energy is stored into or extracted from the material. The advantage of such storage is the simplicity. The disadvantage however is that rather large volumes are required and that the energy is released at varying temperature. The large volume is especially true for cold storage where due to the limited temperature difference the storage density for sensible heat storage in water is in the range of 10 kWh/m³, whereas storage densities in the range of 30 to 100 kWh/m³ could be reached by using the latent heat technologies for storage.

1.2.1 PCM technology

The energy density in sensible heat storage is given by the heat capacity of the storage media and of the temperature range of the storage. The temperature range is depending on the application and is limited by the temperature of the heat source and of the delivery temperature from the storage. The energy density could be increased by introducing a substance having phase change temperature range within the temperature range of the storage.

Within a temperature interval $\Delta T = T_2 - T_1$ the stored heat is

$$Q_{lat} = \int_{T_1}^{T_2} c_p \cdot dT + \Delta H_{fs}$$

where $Q_{lat}$ is the sensible and latent heat stored and $\Delta H_{fs}$ is the heat of fusion at the phase change temperature $T_{fs}$.

The reachable temperature difference $\Delta T$ is determined by the charging temperature $T_C$, which is given by the heat source. A well known disadvantage of direct TES is the fact that they have to be at a higher (or lower) temperature as the ambience. Due to this temperature difference they are able to operate as heat (or cold) storage. A thermal insulation is necessary to avoid losses over the storage period.

Materials that melts within a given temperature range, phase change materials (PCM), are used for thermal energy storage. Waxes, eutectic salt mixtures and salt hydrates are the most commonly used classes for this purpose, but other classes are also considered.

![Figure 1: Available phase change materials](image)
Figure 1 shows the relation between melting temperature and heat of fusion for these materials.

1.2.2 Chemical reactions and sorption systems

Another possibility to reach high storage capacities is the utilization of reversible chemical reactions. An ideal reaction scheme is a reversible dissociation of a solid or liquid compound AB to a solid or liquid component A and a gaseous component B.

\[ AB \leftrightarrow A + B_g \]

The component B should preferably be gaseous because from the process engineering point of view it is much easier to separate a gaseous component from a condensed. This is necessary to prevent the reverse reaction and to provide thermal energy storage without degradation.

The energy density of the storage is defined as \( EV = \Delta H / (VA + VB) \). If \( VA << VB \) (because B is a gas) it can be simplified to \( EV = \Delta H / VB \). The reaction enthalpy \( \Delta H \) cannot be influenced, but the volume of B can be reduced by different processes:

- The gaseous component B can be condensed. Such a system, closed system, is shown in Figure 3
- The component B can be stored by a chemical condensation at a lower temperature. A storage medium like MgH2 (at 400 - 500 °C) is an example of such a system.

When the gas B is part of the atmosphere, like water vapor it can be stored in the ambience and its volume is not taken into account concerning the energy density. Such systems are called "open" systems (see Figure 2).

**Figure 2: Open system with the gaseous component B released to the ambience**
A sorption process on the surface of a porous material, like zeolite and other solid adsorbents, or within a concentrated salt solution, like LiCl and others, are examples for such chemical reactions for thermal energy storage.

1.2.3 Advantages of PCM

1.2.3.1 Higher storage density

Figure 4 shows how much the volume of tank would be reduced by latent heat of water. Although the reduction ratio depends on temperature difference for secondary system, size of the tank is reduced drastically for small ice packing factor, which is ratio of ice volume to tank volume. Since PCM has heat of fusion comparable to water, size of storage tank could be reduced almost as much as for ice storage tanks.

1.2.3.2 Constant temperature during phase change

During phase change the temperature of the material remains at a constant value. Compared to sensible heat storage where the storage capacity is depending on the temperature rise this is an advantage. The heat loss to ambient will be larger in sensible heat storage due to the higher temperature.

The correct choice of temperature for latent heat storage is important due to the fact that the COP (coefficient of performance) of the refrigeration machine is depending on temperature. For comfort cooling the commonly used ice storage lead to a lower COP compared to PCM with a melting temperature above 0 °C.
2. Annex work


2.1 Scope and objectives of annex 17

The objectives of Annex 17 are in general to solve technical and market problems for a better market opportunity for thermal energy storage systems utilizing PCM or chemical reactions in building systems and for temperature sensitive materials and waste heat utilization and to broaden the knowledgebase and disseminate information. In particular, research will be encouraged into system analysis in order to recognise market barriers for implementing the technology in residential, commercial, industrial and agricultural sectors. The action will be executed in close co-operation with manufacturers, utilities, users, governmental representatives and organizations involved in the dissemination of energy technologies.

An important task is to execute case studies and commence demonstration projects so that various promising practical applications of PCM and thermochemical technology can be highlighted (e.g. highly energy – efficient).

The Annex 17 shall result in accomplished/initiated demonstration projects related to potential fields of application. Furthermore it should give general recommendations for the energy industry and more application oriented R&D activities with increased participation of industry, manufacturers, etc.

2.2 Participating countries

Participants in this annex have been Germany, Japan and Sweden. The Operating Agent has been professor (emeritus) Fredrik Setterwall, (fredrik.setterwall@comhem.se) FSKAB
(former KTH) on behalf of the Swedish Council for Building Research (later Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning). Viktoria Martin from KTH (vmartin@kth.se) was the Swedish expert. Experts from Japan and Germany were Motoi Yamaha from Chubu University (yamaha@isc.chubu.ac.jp) and Andreas Hauer from ZAE-Bayern (hauer@muc.zae-bayern.de) respectively.

The annex has been opened to co-operation from researchers and companies in countries not officially participating in the Annex. The 10 countries thus having participated in the work of the Annex are Australia, Canada, China, India, Netherlands, Slovenia, Spain, Switzerland, Turkey and the United Kingdoms.

2.3 Reports to ExCo

8 progress reports have been presented, semi-annually, to the Executive Committee on the progress and the results of the work performed. These reports are found as appendices.

2.4 Expert Meetings (EM) and Workshops (WS)

Before the Annex was officially started, a kick-off Workshop was held in Lleida, Spain the 5 and 6 of April, 2001. At this event, the outcome of Annex 10 “Phase Change Materials and Chemical Reactions for Thermal Energy Storage” was presented, and a proposal for annex text and work program was discussed.

During the Annex, eight EM and seven WS were organized. Since many countries were interested in the work developed in the Annex, but they could not get official participation by their governments, the EM and WS were held alternatively in a member country and in a non-member country. Apart from the participating countries Work Shops and Expert Meetings therefore have been organized by entities in China, India, Poland and Turkey.

Details of Experts Meetings and Work Shops are presented in Table 1 and 2.

<table>
<thead>
<tr>
<th>EM/WS</th>
<th>Location</th>
<th>Date</th>
<th>Number of Participants</th>
<th>Participating countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick-off</td>
<td>Lleida Spain</td>
<td>2001-04-05--06</td>
<td>13</td>
<td>Germany, Japan, Netherlands, Spain, Switzerland, Sweden</td>
</tr>
<tr>
<td>1</td>
<td>Benediktbeuern Germany</td>
<td>2001-10-03--04</td>
<td>1)</td>
<td>Australia, Germany, Japan, Netherlands, Spain, Sweden, Turkey</td>
</tr>
<tr>
<td>2</td>
<td>Ljubljana Slovenia</td>
<td>2002-04-03--05</td>
<td>16</td>
<td>China, Germany, Japan, Slovenia, Spain</td>
</tr>
<tr>
<td></td>
<td>City</td>
<td>Date</td>
<td>Number</td>
<td>Participants</td>
</tr>
<tr>
<td>---</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>Tokyo Japan</td>
<td>2002-09-30—10-02</td>
<td>38</td>
<td>China, Germany, India, Japan, Spain, Sweden, Turkey</td>
</tr>
<tr>
<td>4</td>
<td>Indore India</td>
<td>2003-03-21--24</td>
<td>56</td>
<td>Germany, India, Japan, Sweden</td>
</tr>
<tr>
<td>5</td>
<td>Warsaw Poland</td>
<td>2003-08-31</td>
<td>1)</td>
<td>Germany, Japan, Spain, Sweden, Switzerland</td>
</tr>
<tr>
<td>6</td>
<td>Arvika Sweden</td>
<td>2004-06-07--09</td>
<td>50</td>
<td>Germany, India, Japan, Netherlands, Slovenia, Spain, Sweden, Turkey</td>
</tr>
<tr>
<td>7</td>
<td>Beijing China</td>
<td>2004-10-08--12</td>
<td>48</td>
<td>Canada, China, Germany, Japan, Netherlands</td>
</tr>
<tr>
<td>8</td>
<td>Kizkalesi Turkey</td>
<td>2005-04-18--20</td>
<td>36</td>
<td>Germany, India, Japan, Netherlands, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom</td>
</tr>
</tbody>
</table>

1) In connection with other events
Table 1: Details on EM and WS organized during the annex

<table>
<thead>
<tr>
<th>Country</th>
<th>Lleida</th>
<th>Bene</th>
<th>Diktbeuern</th>
<th>Ljubljana</th>
<th>Tokyo</th>
<th>Indore</th>
<th>Warsaw</th>
<th>Arvika</th>
<th>Beijing</th>
<th>Kizkalesi</th>
</tr>
</thead>
</table>

| Australia   |        |      |            |           |       |        |        |        |         |           |
| Canada      |        |      |            |           |       |        |        |        |         |           |
| China       |        |      |            |           |       |        |        |        |         |           |
| Germany     |        |      |            |           |       |        |        |        |         |           |
| India       |        |      |            |           |       |        |        |        |         |           |
| Japan       |        |      |            |           |       |        |        |        |         |           |
| Netherlands |        |      |            |           |       |        |        |        |         |           |
| Slovenia    |        |      |            |           |       |        |        |        |         |           |
| Spain       |        |      |            |           |       |        |        |        |         |           |
| Switzerland |        |      |            |           |       |        |        |        |         |           |
| Sweden      |        |      |            |           |       |        |        |        |         |           |
| Turkey      |        |      |            |           |       |        |        |        |         |           |
| UnitedKingdom |      |      |            |           |       |        |        |        |         |           |

Table 2 Country participation in WS and EM

2.5 Tasks

From the beginning, it was decided to divide the work in the Annex in sub-tasks. For each of these sub-tasks, a responsible person was appointed. Since the work in the Annex was mainly project oriented, each of these projects was assigned to one sub-task, and the responsible person was responsible to get all the available information about those projects.

The tasks were:

- Heating and cooling of Buildings
- Temperature control
• Natural and waste energy utilization

2.5.1 Heating and cooling of buildings

The aims of using thermal energy storage in connection to heating and cooling of buildings are to save energy both by decreasing the need of energy and to utilize natural energy sources and to decrease the peak loads thereby reducing the power needed. This subtask therefore was divided into three different subtasks: building materials, sorption processes and peak shaving. The responsible persons were Harald Mehling from Germany for building materials, Andreas Hauer also from Germany for sorption processes and Motoi Yamaha from Japan for peak shaving.

2.5.1.1 Building materials

The temperature inside a building depends among other things on the outdoor temperature and on the heat capacity of the construction material and on other components in the building (Figure 5).

![Figure 5: Temperature stabilizing effect by heat capacity of a building](image)

However in order to keep the weight low of the building most building materials exhibit a low heat capacity. Introduction of phase change materials into the building materials will considerably increase the thermal mass of the building. Figure 6 shows the amount of different building materials required to achieve the same thermal mass as that of 1 cm of PCM. By mixing of conventional construction materials with phase change materials the thermal mass of the building will increase without substantial increase of the weight of the material. Simulations have shown that peak temperatures during hot days can be reduced by 2°C to 3°C by introduction of PCM into the building materials. However night time ventilation is crucial to release the stored heat and regenerate the PCM.  

![Figure 6: Amount of material required for equivalent thermal mass](image)

The aim of the annex with respect to building materials is to construct and to evaluate different kind of construction material to be used in buildings for reduction of temperature fluctuations and utilization of natural heat and cold for energy conservation.
2.5.1.2 Sorption systems

The second part of the subtask “Heating and cooling of buildings” was dealing with sorption storage systems for the heating and cooling of buildings. This technology and its applications were discussed in the subtask.

An open or closed sorption system using solid or liquid adsorbsents can be used as a storage system for thermal energy. In this application during desorption the storage is charged, while it is discharged in the adsorption mode. Water vapor is the most suitable gas to be sorbed in these processes. High storage capacities can be expected, because the adsorptive will be stored in the ambience after desorption in open systems or be condensed in closed systems. The storage is not self-sufficient during adsorption. The system has to be connected to the ambience in order to get back the released water vapor, evaporate the condensed water respectively.

For the heating of buildings the heat of adsorption can be used in the adsorption mode. Depending on the used adsorbent and the desorption and adsorption conditions temperatures up to 200 °C can be reached. Under certain desorption conditions thermal energy can be delivered to the buildings heating system in the charging mode as well.

The application of open sorption systems can provide dehumidification by the adsorption of water vapour and sensible cooling by adiabatic humidification (after a cold recovery for the dried air) at temperatures between 16 °C and 18 °C. Using closed sorption storages, cold can be provided by the evaporation process during adsorption.

2.5.1.3 Peak shaving

Objectives of peak shaving

Thermal energy systems store heat and use it in different hours. They can balance between energy demand and supply. Figure 8 shows one example of energy demand of a building.
The partial load is treated by shortening operation hours

Considered cooling, the maximum load occurs in the afternoon on a warm day, but it appears only for few hours during a year. Often, the machine that produces cold has capacity to meet maximum load without thermal energy storage. The machine then is most of the time operated in partial load, which results in low efficiency. When cold is provided from TES at high demand, the machine can be operated at higher efficiency. This way, the system can adjust cold production by shortening operation hours for partial loads. Total capacity and cost of the system could be reduced.

In warm countries, such as Japan, USA and China, peak demand of electricity concentrates in the afternoon on warm day. It is told that a sensitivity of power demand to temperature rise is about 5 million kW/°C in Japan. Figure 9 illustrates the structure of electric power generation on the peak day in Japan. The electric demand of peak hours is twice as much as that of off peak hours. The growth of peak demand, which results in less load factor, causes inefficient management of power generation facilities and shortage of power supply. The governments and utility companies promote the application of TES to reduce peak load. One strategy of TES promotions is discount tariff in night time. Table 3 shows the electric tariff of Tokyo electric company in Japan. They offer 70% of discount in night time for TES contract. This policy gives users additional economical merits.
Table 3: Electric tariff in Japan

<table>
<thead>
<tr>
<th></th>
<th>Day time</th>
<th>Night time</th>
<th>Discount rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>11.08 JPY (0.15 EUR)</td>
<td>3.24 JPY (0.044 EUR)</td>
<td>0.707</td>
</tr>
<tr>
<td>Other seasons</td>
<td>10.07 JPY (0.14 EUR)</td>
<td>3.24 JPY (0.044 EUR)</td>
<td>0.678</td>
</tr>
</tbody>
</table>

Night time is from 22:00 to 8:00
100 JPY = 0.73 EUR (2004 Nov.)

Therefore peak shaving has the following advantages.

− Lower machine capacity
− Machines can be operated with high efficiency
− Reduce demand cost for facilities
− Leveling of power generation throughout a day or seasons

For heating, the discussion can be repeated with the same arguments with two differences:

− Power requirements even in small houses can be very high if domestic hot water is taken into account
− Matching the heating demand to the availability of waste heat becomes an important issue

2.5.2 Temperature Control

Temperature control is a very suitable application because there you can take advantage of the high capacity of PCMs in a small temperature range. In the case of transport boxes, PCM modules to keep the internal temperature constant within a few degrees for a long time have already penetrated the market. Further applications that are currently under development or in a first stage of market introduction are textiles and clothes, electronic equipment, medical applications, cooling of newborns, catering and even a laptop that includes PCM.

2.5.3 Natural and Waste Energy Utilization

According to IEA statistics, the world’s total energy supply was in 2002 over 10000 Mtoe. However, the world’s total primary energy use was only about 7000 Mtoe implying that about 30% of the energy supply is lost during energy conversion. This is what can be referred to as waste heat and this “energy resource” is hence enormous. Add to this waste heat the abundant natural energy sources such as solar, wind and geothermal energy and it is clear that by increasing their use, a path to a sustainable energy system is opened. However, in order to realize such an increased usage, thermal energy storage is a key system component.

Utilization of natural and waste energy falls as a research area partly into the subtasks mentioned above. Both for heating and cooling of buildings or of telecom applications and for temperature control purposes natural and waste energy are used extensively.

Examples of where thermal energy storage is required are: use of the cold of the night; or the heat of the day for cooling and heating of buildings or for domestic processes like cooking and comfort. Efficient use of intermittent industrial high temperature waste heat also requires thermal energy storage technology. The projects included into the annex therefore focus on the technology for these kinds of applications.
2.6 Information on the web

The work in the annex has been reported on www.fskab.com/Annex17.

The web site contains information on the 25 projects that are included in the annex. The final results of these projects are found as appendices to this report. Further the six workshops and the eight experts meetings are reported. All presentations during (~125 presentations) the workshops are found on the web site.

Physical properties of commercial available PCMs as well as other tested substances are available on this site. Information on commercially available PCMs is found as appendix.

This web site has been visited monthly by between 1500 and 2000 visitors originating from more than 70 different countries. More than 1 Gbytes of information have been downloaded every month.

The CD-version of the final report contains also the content of the web site.

2.7 International Cooperation

Within the activities of Annex 17 some international cooperation has started. The exchange of ideas and experiences during the Annex 17 workshops has developed new partnerships and project collaboration between the participating companies, universities and research institutes. Some examples of this outcome of the Annex work will be documented in the following paragraphs.

International cooperation that was strengthened because of Annex 17 is cooperation between PCM producers, and the fact that because of this Annex these companies could expand their market to new countries. For example, Climator is now the representative of Rubitherm in Scandinavia, and they are working very close today. We should highlight that all the companies participating in one or another way to the Annex (Rubitherm, Climator, TEAP, SGL Technologies) have been giving away free samples to researchers to be tested in their applications and projects.

One example of industry and university collaboration has been the corrosion tests made by the University of Lleida for TEAP hydrated salts.

During the course of Annex 17 a strong need for more reliable thermal data was discovered. To find out the accuracy of the current way of doing measurements, and finally to improve this, a ring test between institutes, universities and companies from different countries is being performed.

Within a research project funded by the New Energy Development and industrial Technology Organization, NEDO in Japan interest in a mobile latent heat storage system developed in Germany was expressed by Japanese companies in 2002. The latent storage system was developed by the German company Alfred Schneider GmbH and was commercialized as a complete system by the company TransHeat. In early 2004 SANKI Inc., KURIMOTO Inc. have decided to introduce a Trans Heat Container from PROJECT MANAGEMENT CONSULTANTS, Co LTD (Germany). The system will be investigated in Japan.

In the sorption storage field two collaborations have been started during the Annex 17 workshops. The first one is dealing with the development of a new adsorbent. First ideas have
been presented at the 3rd workshop in Tokyo in 2002 by Dr. Jänchen from ZeoSys GmbH in Berlin, Germany. Mitsubishi Chemical Corporation MCC has started to work in the same direction. During the following product development experiences with this new types of adsorbent have been exchanged. The new adsorbent was presented at the 7th workshop in Beijing, China in 2004 by MCC. The Bavarian Center for Applied Energy Research, ZAE Bayern and the Fraunhofer Institute for Solar Energy Systems, ISE were involved in the evaluation and integration of the new material into TES systems.

Collaboration between Mitsubishi Chemical Engineering Corporation, MEC, and the ZAE Bayern was initialized after the Tokyo workshop. An investigation of a liquid desiccant storage system using high concentrated lithium chloride was performed by the ZAE Bayern for MEC.

Another of the ways where this Annex has helped a lot to the researchers around the world is by networking. The best confirmation of this is the amount of exchange activities that have taken part during the length of the Annex.

Already the year 2001 Dr. Luisa F. Cabeza from the University of Lleida in Spain visited the ZAE Bayern in Garching, Germany for 3 months.

During year 2002 Dr. Luisa F. Cabeza from the University of Lleida in Spain visited again the ZAE Bayern in Garching, Germany for 3 months; Dr. Harald Mehling from the ZAE Bayern in Garching, Germany, visited the University of Lleida, Spain during 3 weeks; Dr. Uros Stritih from the University of Ljubljana, Slovenia, visited the University of Lleida in Spain for 1 week; and Dr. Che Jing from the Tianjin University of Commerce, Tianjin, China visited the Royal Institute of Technology, Stockholm, Sweden during 6 months.

Year 2003 was also very active in exchange of students, researchers and professors within Annex 17. Sayaka Takeda visited the ZAE Bayern in Garching, Germany during 3 months, and the University of Lleida for 2 months. Earlier in the year Dr. Luisa F. Cabeza and Dr. Miquel Nogués, both from the University of Lleida, Spain, visited the ZAE Bayern for 1 week. Dr. Harald Mehling from the ZAE Bayern visited the University of Lleida during 6 months. Finally, Muhsin Mazman from Çukurova University in Turkey visited the University of Lleida during 4 months.

In 2004, Dr. Luisa F. Cabeza from the University of Lleida visited the ZAE Bayern in Garching, Germany, during 1 week.

3. Materials, composites, encapsulations

3.1 Review on the state of the art

During Annex 10, a databank for materials investigated for use as PCM and for PCM on the market was produced. During Annex 17, it became clear that the databank was not complete with respect to investigated materials. Furtheron, data for commercial PCM were not up to date any more. Therefore, during the course of Annex, an update of this data has been performed and published (B. Zalba, J.M.Marin, L.F.Cabeza, H. Mehling, “Review on thermal energy storage with phase change: materials, heat transfer analysis and application”, Appl. Thermal Eng, 23, 251-283, 2003). In addition to the work done in Annex 10, now heat transfer, corrosion and thermophysical property measurement have been treated.
3.2 New PCM

Many of the projects within Annex 17 deal with cooling of buildings. At the beginning of the Annex, the main strategy to use PCM for this purpose was in passive systems as for example in building materials and building components. For that purpose, the melting point of the PCM has to be somewhat below 26°C, as this is in many countries the maximum temperature of the comfort range. On the other hand, to ensure reliable crystallization with night air ventilation, the melting point has to be significantly above 20°C. At the beginning of the Annex these requirements have almost exclusively been fulfilled by paraffins. Paraffins however can burn and are therefore subject to some restrictions when applied in buildings. Due to the work within Annex 17 it became clear that there is a strong demand for more PCM melting in the 20 to 26°C range, preferably salt hydrates. This demand has been realized by several companies during subsequent workshops and strong R&D-activities within these companies were initiated. Within the last years, Rubitherm, Climator and TEAP have developed a set of new PCM with melting points for passive building applications as well as for active applications, where slightly lower melting points are required. These PCM are available as product already.

3.3 New PCM-composite-materials

Composite materials are generally developed to change one or more properties of other materials. For PCM, usually heat transfer is a problem. In the past, the ZAE Bayern had developed a PCM-graphite composite based on a porous matrix of pre-pressed graphite.

The PCM is infiltrated into this matrix. Within the project “Innovative PCM-Technology” it was realized that this method does not work well with some salt hydrates. Therefore, a new composite that is produced by compounding was developed and patented by SGL Technologies. This compound has a somewhat lower thermal conductivity than the composite produced by infiltration into a pre-pressed graphite-matrix, however it is still more than 10 times better than the pure PCM. Both PCM graphite composites are available now commercially as Sigra-λ®.
3.4 Encapsulation

During the project “Microencapsulated PCM integrated into construction materials” BASF developed microencapsulated paraffin. Commercially microencapsulated PCMs are available with melting points 24 and 26 °C (Micronal®). It is available as dry powder or as emulsion and can be applied in building materials to increase their heat storage capacity as well as in PCM-slurries for heat and cold transfer in fluid pipes. The technology for microencapsulation will work in the range 0 – 90 °C.

Based on these microencapsulated paraffins, larger particles can be formed through flocculation forming FMC-PCM (Flocculated Micro Capsule – PCM)

![Flocculated Micro Capsules - PCM](image)

3.5 Improvement and Standardization of measurement methods

Reliable and comparable thermal data have been rare since the early investigations on PCM materials. For a long time it was not clear if different data for the same material were due to variability of the material or due to problems with measurement systems. As PCM approached the market stage within recent years, this state of unclear or even wrong data became more and more annoying. Work towards solving this problem started with two PhD thesis performed at KTH / Sweden (Bo He High-Capacity Cool Thermal Energy Storage for Peak Shaving - A solution for Energy Challenge in the 21st Century Diss. KTH 2004 ISBN 91-7283-751-9) and Zaragoza / Spain (Belen Zalba Thermal Energy Storage with phase change materials. Experimental procedure, Zaragoza (Spain) 2002). These works showed that there are at least systematic problems with the parameters in DSC-measurements.
Figure 12 Result for Cp from DSC-measurements with different heating rate and sample mass.

In 2004, Arcadis, BASF, Dörken, Emco, Rubitherm and SGL TECHNOLOGY decided to develop common standards for materials testing and finally create a quality logo for PCM. They contracted the ZAE Bayern and the FhG-ISE with the development of standards for materials testing and quality control. Currently, a ring test between many institutes, universities and companies is performed. Standards should be available in the second half of 2005.

4. Heating and cooling of buildings

4.1 Peak shaving: Cost consideration

One of the merits of peak shaving is cost effectiveness. PCM stores energy of discounted tariff or free one from natural environment. Savings by PCM should compensate the cost of installation, by using pay back years. Economic feasibility of a PCM storage system can be evaluated from a number of times of usage until the investment paid back. In this paper, the author calls this value Pay Back Cycle calculated from equation shown below.

\[ C = \frac{P}{L \times E_{\text{saved}}} \]  

(1)

where \( P \) is the price of PCM, \( L \) is the heat to store, and \( E_{\text{saved}} \) is the price of saved energy by system.

Figure 13 shows the relation from equation (1).

If the price discount were introduced, equation would be written as follows.

\[ C = \frac{P}{L \times E \times D} \]  

(2)
where D is discount rate, and E is the price of energy.

Figure 13: A chart among Pay back cycle, price of energy and price of PCM

Figure 14 shows the relation between Pay back cycle and discount rate for certain price of PCM. It is found that Pay back cycle decreases for small value of discount rate. If the price of PCM was low, low discount around 10 – 20 % would be effective.

Figure 14: A relation between pay back cycle and discount rate of energy

4.2 Phase Change Materials: System analysis

During recent years, different system designs were developed for cooling applications that are able to meet different requirements on efficiency and reliability of system performance.
One starting point was the idea to increase the thermal mass of lightweight buildings with PCM to give them the thermal performance of solid buildings. Simulations have shown that the peak temperatures can be reduced this way by 2°C to 3°C, and that night time ventilation is crucial to release the stored heat and regenerate the PCM (Figure 15 left). For night time ventilation a ventilation system is recommended. These systems are completely passive, that means they need no energy for operation. However they have two disadvantages, the small cooling power due to the low temperature difference to air and free convection and the fact that night time temperatures might not decrease enough to ensure regeneration of the PCM reliably. Further on, availability of different melting point strongly restricted the climates where this technology can be applied.

During the course of the Annex, new system strategies were developed.

These strategies use PCM with lower melting points (figure middle and right) and therefore give larger cooling power. Because of the low melting point, these systems can not be regenerated easily to night time air but in combination with evaporative or dry cooling towers or ground sources of cold water reliability can actually be increased compared to passive systems.

Another starting point of investigations has been cold storage in ice storage systems (Figure 16 left).
Their drawback has been the large temperature difference between melting point and outside temperatures. This reduces chiller efficiency, and, if sorption chillers are used, the restriction to ammonia-water as working fluid. During the Annex, the use of PCM with melting point between 4°C and 10°C has been investigated. These temperatures allow LiBr-water sorption chillers to be used and chiller efficiency is generally increased.

4.3 Case studies and demonstration projects

Light weight buildings often suffer from overheating in summer due to the lack of thermal mass as storage for the cold from the night. Therefore the basic idea of the project Phase Change Composites was to develop microencapsulated PCMs which are easy to integrate in building materials and may offer a good heat transfer from the construction material to the PCM thus enhancing the discharging process during the night.

![Figure 17 Building component with integrated PCM](image)

The project started with material screening and the numerical modeling of PCM walls in a building simulation program to identify the needed material parameters and useful applications. The next step was testing the encapsulated materials and then first wall test samples with integrated PCMs in a test apparatus. When these samples performed satisfying, real size testrooms have been equipped with PCM-products and have been monitored to quantify the effect of the PCM to energy consumption and comfort of a building. In a last step, demonstration projects were done. As a result of this project, microencapsulated paraffins are available from BASF as base product, several building products with integrated PCMs are on the market and first buildings are being set up.

Thermal storage performance of the building elements made of phase change composites, mainly paraffin or salt-hydrate absorbed in porous concrete, was analyzed by simulation. A mathematical model describing the energy balance of phase change storage elements allows operational simulation and also a prediction of building storage elements applicability. The numerical calculations in function of thermophysical properties, ambient and design parameters lead to the conclusion that solidification goes fully and the heat recharging process can be used only for the case of CaCl₂·6H₂O composite.

This idea of incorporating PCMs in concrete was also developed in another project, where PCM is incorporated after microencapsulation. First experiences with microencapsulation of PCM were performed during the first part of the project. For the demonstration project part, BASF Micronal® was used. Two cubicles were constructed and instrumented, one with 5% PCM in the concrete and the other without PCM. Comparison between both cubicles is underway, but preliminary results give a difference of 3°C in temperature. The concrete produced was tested for mechanical and thermal properties.
Wood-lightweight-concrete is a mixture of cement, wood chips or saw dust (less than 15 wt. %), water and additives. Advantages are variable properties in the thermal insulation, noise insulation, density and heat capacity. The reasons for the investigation on the combination of PCM with wood-lightweight-concrete were to increase the thermal storage capacity, and to get lighter and thinner wall elements with improved thermal performance. It was shown that PCMs can be combined with wood-lightweight-concrete and that the mechanical properties do not seem to change significantly.

The basic idea of passive solar home design is to invite sunlight into the house during the winter, and once it is inside the home, to hold it in and store it until nighttime. Conversely, the sun needs to be kept out during the summer. This possibility was studied in a project performed in India.

A new system where latent heat is stored in PCM that is embedded directly below OA floor boards in the form of granules with several millimeters in diameter was developed. The feature of the system was that heat exchange occurs through direct contact between the granular PCM and air serving as the heat medium. This allowed outstanding heat exchange efficiency and then increase of the TES capacity in the entire system. As a result of some trials, PCM granules named FMC-PCM were applied which consisted of microcapsules with a diameter of a several micrometers containing paraffin wax PCM. On the basis of these results, full scale experiments were conducted in a test room with a floor area of 9.2 m².
Free cooling applications with integrated PCMs suffer from two drawbacks: the wall to heat transfer coefficient limits the useable storage capacity in a 24h cycle and the only available cold source is the night air at dry bulb temperature. In certain climates and applications these two restrictions limit the market for PCM products. If it is possible to integrate water piping (e.g. capillary tubes) in the PCM-products, the heat transfer to the storage can be increased and the piping can be connected to any cold source, thus making the system independent from outside temperatures.

A project about innovative PCM technology was carried out to develop different PCM applications for heating and cooling of buildings. The suitable PCMs necessary for the project were searched, and different applications for heating and cooling of buildings were developed. Some examples are the use of latent heat store for heating of buildings, plaster and compound systems with high heat storage capacity, transparent insulation and daylighting elements, shading-PCM compound system, PCM in gypsum products, and PCM to buffer temperature variations in solar-air-systems.
A feasibility study on free-cooling was developed. The experimental setup used is a closed air circuit, with fans to move the air, a heating and cooling device to set the air at the right temperature and a thermal energy storage. Several PCMs have been tested during the presented work, but finally only two were selected. One was a molecular alloy with 34% C16 and 66% C18, with a melting temperature of 19.5-22.2°C, and the other one was RT25 from Rubitherm, with a melting temperature of 20-24°C. With the results from the study, a real installation was designed. The storage device was designed with a capacity of 3 kW, with an inlet temperature during night of 16°C for 4 hours, and an inlet temperature during day of 30°C.
The energy efficiency of many heating and cooling applications can be significantly improved by the replacement of the existing working fluids with phase change material slurries (PCMS). They require smaller storage capacity and reduce pumping costs. Slurries have similar general fluid properties and they offer the advantage of high latent heat storage capacity at a narrow temperature band corresponding to the phase change temperature. Selection of the correct phase change material and carrier fluid in conjunction with a selection of suitable systems will enable space and water heating, space cooling, systems cooling, industrial processes and refrigeration systems within buildings to be improved. Heating systems and building/air conditioning system uses of PCMS were also evaluated through system modeling and experimentation using laboratory sized evaluation of components and full systems.

Floor heating systems are increasingly being used in Japan. PCM floor heating is commercially available. Figure 27 shows proportions of floor heating in the area of Tokyo Electric Company. The total number of application was 45 and nearly one-third of the applications have utilized PCM.
Figure 27 Proportion of types of storage used in service area of Tokyo Electric Company.

4.3 Sorption Storage Systems

4.3.1 System Concepts

There are two types of sorption storage systems: Open and closed systems. Although both types are based on the same physical effect of ad- or absorption, their technical requirements are quite different. At the same time their properties concerning their performance lead to different applications. Open sorption systems are influencing directly the properties of an air stream, while closed systems are more appropriate to deliver heat and cold to liquid heat transfer media.

Open Sorption Systems

In an open sorption storage system air is transporting water vapor and heat in and out of the packed bed of solid adsorbents (see Figure 28) or a reactor where the air is in contact with a liquid desiccant. In desorption mode a hot air stream enters the packed bed or the reactor, desorbs the water from the adsorbent or the salt solution and exits the bed cooler and saturated. In adsorption mode the previously humidified, cool air enters the desorbed packed bed or the concentrated solution. The adsorbent or the solution (or absorbent) adsorbs (or absorbs) the water vapor and releases the heat of sorption. The air exits warm and dry. In case of a solid adsorption it can be very hot. In case of a liquid absorption the dehumidification of the air is the main purpose.
The desorption energy $Q_{\text{Des}}$ is the energy input to the thermochemical storage system, whereas the heat of adsorption energy $Q_{\text{Ads}}$ can be used for heating. The heat of condensation $Q_{\text{Cond}}$ can be additionally used, if it is available on a usable temperature level, which is depending on the inlet air conditions. The energy for evaporation $Q_{\text{Evap}}$ has to be available at a low temperature level, which can not be used otherwise (right scheme of Figure 28). The desiccant cooling process is based on the dehumidification of the air during the adsorption mode only.

Thermal energy storage is achieved by separating the desorption step (charging mode) from the adsorption step (discharging mode). After desorption the adsorbent can theoretically stay in this desorbed state, being referred to as charged in the following, without any thermal losses until the adsorption or absorptions process is activated.

**Closed Sorption Systems**

A closed sorption system is shown in Figure 29. It is based on the same physical effect. However the engineering is quiet different from open sorption systems. Closed system could be more precisely described as evacuated or air-free systems. The operation pressure of the fluid to be sorbed can be adjusted in these systems. In closed systems, components which do not exist in the atmosphere can be used, because there is no connection to the ambience.

Figure 29 is showing a closed sorption system using water vapor as adsorptive. The heat has to be transferred to and from the adsorbent by a heat exchanger. This holds also for the condenser/evaporator. Heat has to be transported to the adsorber and at the same time the heat of condensation has to be distracted from the condenser in order to keep up the water vapor flow from the adsorber to the condenser during the desorption. During adsorption the heat of adsorption has to be taken from the adsorber and the heat of evaporation has to be delivered to the evaporator. Is this not possible, the sorption process will reach thermodynamic equilibrium and the flow of water vapor comes to a stop.

The main problem in the system design is the heat and vapor transport in and out of the adsorbent. Advanced heat exchanger technologies have to be implemented in order to keep up
the high energy density in the storage, which would be reduced by the amount of "inactive" heat exchanger material.

4.3.2 Demonstration Projects and Case Studies

Air Conditioning and Cold Storage in Open Sorption Systems

ZAE Bayern and its partner are building a liquid desiccant cooling system, LDCS, providing cold water at about 15 °C for additional cooling of a jazz club in Munich. Return air of the building is dehumidified in an absorber by a concentrated hygroscopic LiCl-H₂O solution, supplied from a tank. Subsequent indirect evaporative coolers, supplied with the dry air, produce cold water for fan coil units in the jazz club and for the cooling of the absorber. The desiccant solution is diluted while dehumidifying the air and is stored in a separate tank. The jazz club needs cooling only at night. During the day the absorber and part of the air handling equipment regenerate the desiccant solution to its original concentration, using hot water at about 75 °C from a district heating system. The cooling capacity is about 20 kW, the regeneration capacity about 40 kW. A storage volume of 1.5 m³ provides solution for 9 hours of full load operation.

The major technical components of the system, the absorber/regenerator and the indirect evaporative coolers, are subject of development. New types of these components have been tested in advance. Currently the system is under construction and due to be set into operation in summer 2005.
Test of Thermochemical Storage of Heat with New Storage Materials

Tests of X type zeolites and mesoporous materials for thermochemical storage of heat in lab-scaled storage units show that solar energy applications inquire new microporous materials which keep a certain energy density and temperature lift but at lower charging temperature.

Aluminophosphate molecular sieves are potential candidates for those applications. Therefore, the adsorption properties of water in AlPO4’s were investigated. The storage density of the aluminophosphates is comparable with that of zeolites. Because of the differential molar heats of adsorption being between the zeolites and the mesoporous materials the temperature lift should be significant higher as for silica gels despite the fact that the desorption temperatures of AlPO4’s and silica gels are about the same.

Sorption Storage System using Zeolite for Heating and Cooling

An open sorption system based on the adsorption of water vapor on solid adsorbents using Zeolite 13X has been installed in a school building in Munich/Germany and connected to the local district heating net. A better power balance of the net can be achieved by off-peak charging of the zeolite storage. The system can be disconnected from the net during heat demand peaks and can deliver heat to the buildings heating system. To match the heat load of a school building in Munich/Germany the thermochemical storage has to contain 7000 kg of zeolite 13X. The system was originally planned for heating application only.

The zeolite system is under operation since the heating period 1997/98. Charging temperature supplied by the district heating system is about 130 °C. Under these conditions a thermal coefficient of performance (COPth) for complete sorption cycles of about 0.9 can be reached. The experimental achieved energy density related to the volume of the zeolite is 124 kWh/m³.

The system was expanded to a desiccant cooling system by adding a supply air humidifier and a cold recovery device. The sorption system was connected to the air conditioning system of a nearby jazz club with a permanent cooling demand. The best desorption temperature for the performance of the desiccant cooling system was found to be 80 °C. At that conditions a overall COP for air conditioning (including the cold recovery) of 86 % and a cold storage capacity of 100 kWh/m³ was measured.
Seasonal Storage using Silicagel

In the finished Project HYDES which had been funded by the European Union a high energy density heat storage system based on the adsorption process was developed and demonstrated. The adsorption characteristics of more than 40 commercial and non-commercial adsorbents were measured and resulting energy densities were calculated. During the project period several prototypes were built and tested under various conditions in order to find the system design with the best performance. At the end of the project two prototype systems were constructed and installed for different applications. A system installed in Austria is being operated in combination with solar collectors and a system in Finland is operated in a district heating network. Energy densities of up to 134 kWh/m³ have been achieved with the installed systems.

![Figure 31 Silicagel storage system in Austria](image)

Recently a follow-up project entitled ‘Modular High Energy Density Sorption Heat Storage’ (MODESTORE) was approved by the European Commission. The work in this project will start in April 2003 and will continue for three years. The main objective of the present project is to develop a second generation prototype of high energy density heat storage which is adapted to market demands in different European applications.

Absorption Storage System using LiCl for Solar Dehumidification

An office building of 5700 m² floors space has been built in Amberg, Germany, by architects Hart & Flierl for Prochek Immobilien GmbH. The innovative air conditioning concept using solar energy has been worked out by M. Gammel engineering consultants. The comparatively low heating (35 kWh/m²/a) and cooling demand (30 kWh/m²/a) of the building is covered by thermally activated ceilings, assisted by appropriately conditioned ventilation air.

Well water of 12-14 °C with a cooling capacity of 250 kW is used for cooling the ceilings in summer. A solar driven liquid desiccant cooling system, developed by ZAE Bayern, dehumidifies outside air by a liquid desiccant, a concentrated salt solution, LiCl-H₂O, with a capacity of 70 kW and cools 30,000 m³/h of supply air with a capacity of 80 kW by cold recovery from evaporatively cooled exhaust air. The liquid desiccant is regenerated by solar
thermal energy from a 70 m² flat plate collector array at 70 to 80°C with a maximum capacity of 40 kW. Solar energy for air conditioning is stored efficiently in about 10 m³ of desiccant solution. Summer air conditioning uses only solar energy, except from electricity for pumps and fans.

Figure 32 Installation of a LiCl absorber

4.3.3 Concluding Remarks

Thermal energy storage by sorption processes for the heating and cooling of building is a very active and promising field of research. At the moment a few demonstration projects are installed. In most cases the systems are in operation and the technical problems were solved. However sorption technology is expensive due to its high investment cost. This can lead to long pay back times compared to conventional solutions. But looking at the general development in energy markets sorption storage systems are sure a competitive option in the future.

Important for the next steps are careful feasibility studies, which include economic aspects. In this context the number of storage cycles is crucial. Interesting are especially hybrid applications, like heating and cooling, cooling and dehumidification. This is one possibility to raise the number of operating hours.

In the field of material research new ideas have been developed. At the moment these materials are in most cases far too expensive. This can change together with studies that quantify the potentials of emerging markets for sorption TES. The collaboration of adsorbent producers, basic and applied scientists and manufacturers of systems should be continued.

5. Temperature control

5.1 State of the art prior to annex work

Phase Change Materials can be used in Thermal Energy Storage technologies. In their application, the solid-liquid phase change is used to store high quantities of energy. The substances used can be organic – such as paraffins or fatty acids -, or inorganic – such as salt hydrates -; both show a single melting temperature when pure, or a melting range, when mixtures are used.
Phase Change Materials offer the possibility of thermal protection due to their high thermal inertia. This protection could be used against heat and against cold, during transport or during storage. Protection for solid food, beverages, pharmaceutical products, blood derivatives, electronic circuits, cooked food, biomedical products, and many others, is possible.

Here some of these applications are presented, specially looking for the ones that are already in the market and that emphasize the potential of Phase Change Materials.

5.1.1 General containers

The most known application of PCMs for transport or conservation of temperature of materials are containers with removal parts containing a PCM (usually water, nowadays many other products) that must be kept in the refrigerator before use, and that keep a low temperature in the container for a period of time. An example of such a device is the container commercialized by SOFRIGAM (www.sofrigam.com) and the PCM pads are presented in Figure 33 and Figure 34.

Some companies only commercialize the PCM pads, such us TCP RELIABLE, Inc. (www.tcpreliable.com) or PCM Thermal Solutions (wwwpcm-solutions.com). Such pads, presented in Figure 35 and Figure 36 can be used to keep products warm during shipment (the pad must be conditioned in oven and/or microwave oven) or cold (conditioning is done in the refrigerator).

5.1.2 Beverages
One application that has been commercialized is the so-called “isothermal water bottle”, specially developed for cycling, but that could be used by any other sporting person (Figure 37). It is a double wall bottle, with ALCAL® being the active part. The bottle has capacity for about 0.5 L has to be held in the refrigerator for the PCM to solidify and the whole container to hold the temperature of the refrigerator. When the bottle needs to be used, the PCM melts, keeping the liquid in the bottle at a quasi isothermal situation. The length of the process depends on the ambient conditions. Experiments show that with an ambient temperature of 25ºC, the interior temperature will be below 13ºC for about 3 hours.

This kind of recipient, also allows cooling down a liquid: one of these bottles is kept in the refrigerator full of water, it can be taken out of the refrigerator to an ambient temperature of 21ºC, emptied every 30 min and refilled with water at 18ºC. After the first operation, the water was cooled down to 8ºC (the melting temperature of ALCAL®), the second time, to 14ºC and the third to 15ºC, so the user could use 2 litres of fresh water. This product was commercialized by SOFRIGAM (www.sofrigam.com) but nowadays is not in the market, probably due to the bad election in the plastic container, which allowed a short life of the product.

This concept could be used in many other products, such as isothermal maintenance of fresh drinks (isothermal container for champagne, cava, wine, etc.).

Another concept that has been also successfully commercialized is a self-chilling beverage keg, the CoolKeg®, which uses the zeolite vacuum-adsorption technology (Figure 38). Zeolite, a natural mineral, absorbs under vacuum conditions the water contained in the fleece around the beer bellow. This physical reaction causes the freezing of the water left in the fleece. The hereby created heat emanates out of the zeolite layer to the surface. This product has been successfully commercialized by Cool-Systems Bev. GmbH (www.coolsystems.de).

5.1.3 Catering

In many catering applications, cooked meals are produced in one point and have to be transported to be eaten. Some examples are transport of cheese, salads, frozen deserts, confectionery, or fish. PCMs container could also be used to avoid breaking the cold chain
during transportation of precooked meals, foie gras, smoked salmon, milk derivates, ice-creams, and many others.

One example of such an application that has been already developed are pizza-heaters. The use of a container with PCM with the right melting temperature allows multiplying by three the length of time the food is kept above 65ºC. This has been studied by Cuevas-Diarte, and has been commercialized by Domino’s Pizza en the USA with the collaboration of Rubitherm (www.rubitherm.de). It is also one of the applications listed by the PCM developer Merck, KGaA (www.merck-ti.de). See Figure 39.

The same concept could be used for food distribution in hospitals, schools, etc., or in devices to heat up feeding bottles, and other food containers. Such containers have been commercialized by PCM Thermal Solutions (www pcm-solutions.com), and are presented in Figure 40 to Figure 42.

5.1.4 Blood products
A container was designed and produced to allow the transportation of blood and its by-products. Some products need to be transported between 20 and 24°C, others between 2 and 6°C, and others between −30 and −26°C. The purpose of this container was to allow the transport of such blood products between the hospital and the transportation vehicle (which is already conditioned at the right temperature), and between the vehicle and the final destination. This container is being commercialized nowadays by BIO TRANS in France (see Figure 43). The same kind of product is also commercialized by PCM Thermal Solutions.

5.1.5 Other medical applications

Another application for medical purposes is a mattress for operating tables. It would be used to avoid decrease of the body temperature during long operations, or during operations of burned people, for example. The mattress would be heated up electrically before its use (the PCM would be with a melting temperature about 37°C), and it would release the heat during the operation. This application is being tested as a prototype.

Another medical application are hot or cold pads to treat local pain in the body. These products are commercialized by many companies, such as Rubitherm (Figure 44 and Figure 45).

5.1.6 Electronic devices

This is one of the most developed and commercialized application of PCMs. For example, Cuevas-Diarte, presents a collaboration with FRANCE-TELECOM to protect electronic...
devices from heating up by solar insulation when installed outdoors. A PCM developed to change phase at 35ºC would absorb solar radiation during day, avoiding the electronic device to reach certain security temperature. The heat would be released during the night, allowing the cycling performance of the PCM. Nowadays, the company has a prototype which is being tested.

Many telecommunications equipment must be located outdoors and powered by batteries. Here is where another application of PCMs can be found. The company TEAP (www.teappcm.com), together with Power Conversion Products and MJM-Engineering, has developed a battery jacket that minimize the effects of peak heat loads in the day. The use of TEAP TH29 allows the heat loads to be absorbed in the daytime and released during night (Figure 46 to Figure 48).

A passive cooling system for communications equipment has been developed by Climator AB (www.climator.com), starting with a collaboration with Ericsson Telecom. This work lead to the production of ClimSel Cooling Systems that nowadays have been in operation for several years, with 100% function and no maintenance needs. This system has been installed in other sites and applications, with similar good results.

5.2 Work done within the Annex

During the development of the Annex some projects have been developed study the possibility of using new products for Temperature Control applications.

A new container to protect protein crystals was developed. Submitted to an external temperature of 25ºC, the XPS/Al container + MAPCM (5.1 liters) is able to maintain the temperature of the protein crystals at (20 ± 2)ºC for ~ 6 days.
In the catering sector a container for hot food transportation at controlled temperature between 70°C and 85°C and a container for ice-creams to be held below -8°C, were designed.

![Figure 50 Containers for transportation](image)

Also a safety transportation packing for effective temperature control of sensitive blood products, such as red blood cells (4 ± 2°C), blood platelets (22 ± 2°C), and plasma (-30 ± 2°C) was designed.

![Figure 51 Blood transportation](image)

Most hospital workers know that neonatal children get fever cramps or even sometimes die due to fever. Also, young children are getting brain injuries due to hypoxia. Young children can be treated in many ways, for example with cold towels, medicine, chilled rooms e.g. to keep the temperature down in hospitals. Hypoxia has been treated in different ways due to the knowledge of doctor, to minimize brain damage. During the work of this Annex a new product that could substitute traditional methods to treat these problems has started to be developed: a new mattress with PCM in it.

Heat can be a problem for professional athletes both in training and at competition. Heat can also be a problem for other people like elderly, people with some diseases and children. If the body-temperature can be reduced most people would feel more comfortable, perform better, be able to keep concentration better and for a longer time and the risks with dehydration and
fatigue is reduced. New products to address this problem were developed, such a wrist-cooler, a neck-cooler, a cap and a vest. All these products are being used by more and more athletes.

Figure 52 Cooling of the human body

Another problem studied and solved with PCM products is the overheating of laptop computers. One of the possible alternative methods to be used to avoid the noisy traditional fans is to add a PCM pad under the computer chassis. When the temperature of the computer chassis rises to the melting point of the PCM, the temperature of the computer will be kept close to this temperature.
At the end of the Annex, a new product to protect electronic devices was presented. A shelter for telecommunications with over 300 kg of PCM for thermal protection is commercialized in India (Figure 54).

6. Natural and waste energy utilization

The increased use of natural and waste heat is a key to a sustainable energy system. Natural heat includes for example solar heat, geothermal heat, and nighttime cooling. Waste heat is generated in large quantities in the process industry and in conjunction with large scale energy conversion. These abundant resources are, however, hard to utilize. To increase their use, advanced thermal energy storage technology is an essential system component since it enables supply and demand to be effectively matched.

Within the Annex 17, numerous projects that describe the use of advanced thermal energy storage to harvest natural and waste heat have been highlighted. These projects are briefly summarized below, and some concluding remarks are given.
6.1 Free Cooling

An installation where nighttime cold is stored in PCM (melting around 25-30°C) to be used for cooling during daytime has been presented by Zalba et al. (2002). In the set-up, flat plate encapsulation of the PCM was judged advantageous as compared to a shell- and tube heat exchanger. With the flat plate, one can easily control the heat transfer rate by varying the thickness of the encapsulation, melting and freezing becomes symmetrically, and the pressure drop is low.

Experimental investigation on the melting and freezing behaviour of the PCM eventually were used to design a real system with 3 kW cooling capacity. The thickness of the PCM capsules were selected to be 15 mm, charging temperature 16°C (at night) and discharging temperature 30°C, and the air flow rate 100 m³/h.

From an economic study, it was shown that the PCM material itself constituted 17% of the total system cost. The duct work was the most expensive – 21% of the total system cost. This is a very interesting way to present the costs – should be done more often in system studies.

Free cooling was also considered by Kuroki et al (2002) as they presented a numerical analysis of a forced ventilation system incorporating PCM as a storage media for nighttime cold to the daytime peak cooling hours. In this system, the ventilation air is brought through an underfloor channel where the PCM is located. Then it is released into the room to be conditioned. Simulations showed that the peak load could be reduced by up to 25% with a PCM load of 18 kg/m² floor area.
One installation incorporating PCM for free cooling has been done in the Stevenage Borough Council’s offices (UK) (Barnard et al, 2003). In their workshop presentation of the project, the “CoolDeck” system was described where night ventilation is circulated in “false” floor and ceiling voids to store nighttime cold in the thermal mass of the building material. In this CoolDeck, sheeting elements are attached to the slab to enhance the heat transfer. The installation also integrated PCM (salt-based with phase change temperature between 20 and 24ºC) with the CoolDeck elements in order to improve the thermal storage performance. A higher heat transfer rate of the design with PCM was reported. However, it was not established that the thermal mass actually increased due to the phase change of the salt. Thus, whether the phase change temperature range selected was appropriate is not known.

6.2 The Solar Way

Solar driven liquid desiccant cooling system is used for dehumidification of ventilation air in an office building in Amberg, Germany. This work was for example presented in the Indore-workshop in India 2003 (Laevemann et al., 2003). In the system, cooling capacity is efficiently stored in terms of 10 m³ regenerated liquid desiccant. By evaporative cooling the return air, and exchanging heat between this cold return and the supply, the system is made more efficient. The COP for the dehumidification unit (here defined as the enthalpy difference between outside and supply air divided by the thermal energy requirement for regenerating the liquid desiccant) is expected to be between 1.2 and 2. Cold well water provides sensible cooling to the building.

In order to increase the energy density and to improve the performance of stratified hot water storage tanks PCM modules were installed in the top of the tank. Initial simulation showed that short modules were the best solution, so it was implemented in a full solar system. Various PCMs with melting temperatures around 55ºC were tested (RT54, fatty acids, and sodium acetate). Since thermal conductivity is essential to get the right power, sodium acetate mixed with graphite was chosen. Experiments showed that the addition of only about 6% of volume of PCM increase the energy density of the tank by about 40%, and that water was kept at usage temperature a longer period of time.

Figure 56 Domestic hot water tanks including PCM modules
6.3 Storage Concepts for Combined Heat and Power Generation

Kato (2002) considered a chemical heat pump using the reversible reaction hydration of magnesium oxide. The concept was designed to enhance a power cogen plant. This was such that the dehydration of Mg(OH)\(_2\) into MgO first was conducted using surplus heat from e.g. an engine. The temperature requirement for this step was around 300\(\,^\circ\text{C}\). The water was condensed. This was labeled "storage mode". Later, in the "heat output mode" heat around 70-90 \(\,^\circ\text{C}\) was used to first evaporate the water such that the reversed reaction could take place releasing heat at temperatures over 100\(\,^\circ\text{C}\). The concept is illustrated in Figure 57.

![Figure 57 Principle of a magnesium oxide/water chemical heat pump; (a) heat storage mode, (b) heat output mode. (Kato, 2002).](image)

The heat storage density was found to be four to seven times that of a sensible water storage between the temperatures 70 and 90 \(\,^\circ\text{C}\).

Another heat pumping concept that could be used to upgrade approximately 90 \(\,^\circ\text{C}\) heat was that described by Saito et al (2002). Here, the conversion of approx 90\(\,^\circ\text{C}\) heat to 200\(\,^\circ\text{C}\) heat via a catalyst-assisted chemical heat pump was considered. A key chemical reaction was the low temperature, catalyst-assisted dehydrogenation of 2-propanol forming acetone and hydrogen gas. In the "discharging" mode, the heat is recovered around 200\(\,^\circ\text{C}\) by hydrogenation of acetone. Catalysts considered were carbon-supported platinum-iron and platinum-ruthenium. The conversion efficiency appears to lie within 5-25%.

With the aim of better utilizing the waste heat from co-generation, fuel-cell co-gen in particular, experiments have been carried out on mixtures suitable for PCM storage in the temperature range 60-90 °C (Nagano et al., 2002). The material is a mixture of magnesium nitrate hexahydrate with varying amounts of magnesium chloride hexahydrate to change the temperature. Many thermal characteristics experiments were reported. In particular, one can mention the charging/discharging tests carried out in a vertical heat exchanger unit. These experiments showed the storage density to be between 2 and 2.5 times that of a sensible water storage in the same temperature range.

6.4 Cost-Effective Waste Heat Driven Cooling Production

Several presentations on a system where absorption chillers (AC) run on industrial waste heat has been presented throughout the annex (Rydstrand et al., 2002, 2003 and 2004). On such chiller is installed at Chalmers University of Technology (CTH), Gothenburg, Sweden. This system has been simulated revealing that if the cooling demand increases in the near future, the system’s cooling capacity can be increased by 50 percent by using PCM for cooling.
storage. The investment cost of PCM storage has been calculated to be 1/3 that of investing in new absorption chiller capacity to meet the increased demand for cooling. In relation to the topic here, "natural and waste energy utilization", a cold storage thus is shown to make waste heat driven AC systems more competitive as compared to conventional electrically driven chillers.

Concluding Remarks

With regards to the natural and waste heat utilization, the annex has managed to attract projects ranging from laboratory scale and chemical reactions’ simulation stage to demonstration stage at full-scale. This is unique in that the demo-projects show the readiness of the technology today, and the labscale/simulation projects highlight the potential for making significant improvements in future systems.

The demo-projects have mainly been launched within the annex time period and for the future it would be of extreme interest to follow these projects, collect the experience, and synthesize a "best practice" for a variety of applications. The labscale/simulation projects hint at various ways of accomplishing improvements to the storage systems and they should be important for the advancement of state-of-the-art. An evaluation of this advancement should be continuously performed.

Within the annex work, the examples described above indicate that advanced thermal energy storage can play a role in natural and waste heat utilization. However, only a limited number of demonstration projects have been discussed in this annex. It is very likely that there are more natural and waste heat utilization projects going on around the world, perhaps implementing more traditional sensible storage technology, and that these projects have not reached the workshops of this particular annex. For future annexes a thorough ”search” around the world should be conducted by e.g. the expert group supporting the annex.

In addition to "finding" good example projects for each annex topic area, it should also be the aim for the annex to, based on the material presented at the workshops, construct model projects for annex participants to bring back to their respective national research arena.
7. Appendixes

I  Progress reports to the Executive Committee: Energy Conservation through Energy Storage

i Progress report fall 2001


Officially the Annex has three members, Germany, Japan and Sweden. Strong interest in participation has been shown by Australia, Canada, the Netherlands and Spain. Further countries that have been interested in the work of the annex are Finland, France, New Zealand, Poland, Slovenia, Switzerland, United Kingdom and United States.

The first Expert Meeting was held in Benediktbeuern, Germany on the 3rd of October 2001 followed by a symposium jointly arranged with ZAE – Bayern. 20 presentations were made during this symposium. The expert meeting was attended by three member countries (Germany, Japan and Sweden) and four observing countries (Australia, the Netherlands, Spain and Turkey). According to the work plan the first phase was intended to be a project definition and finanziation phase. More than 15 projects have been defined to be part of the Annex. The projects fall into three categories (responsible countries and persons in bracket):

- Heating and cooling of buildings (Germany and Japan )
  
  “Energy storage in the CREA building (Lleida)”

  “PCM module to improve stratified water tanks”

  - Building materials: ( Harald Mehling)
  
  “PCM wallboard containing PCM penetrated with cross-linked polyethylene”
    “Encapsulated PCM in building technology”

  “PCM in composite bridge decks”

  “Mixture of wood, PCM and concrete”

  “PCM wallboards”

  - Sorption systems: (Andreas Hauer)
  
  “Air conditioning and cold storage in open sorption systems”,

  - Peak shaving: (Motoi Yamaha)
  
  “HVAC with PCM storage in it”
“Simulation of PCM storage system”,
“Cityhall with PCM heater”
- Temperature sensitive materials : (Spain, Luisa Cabeza)
  “Blod transportation”,
- Waste heat utilization: (Sweden, Fredrik Setterwall)
  “Absortion chillers and energy storage”
  “Cold transportation in liquid dessicants”
  “PCM applications in industry”
  “Thermal management of solid oxide fuel cell systems”
  “PCM slurry systems”

In order to facilitate the cooperation between industry and research institutes, two experts from each country will participate in experts meetings, one industrial and one from the research world.

A home page for the annex will be constructed. Companies will be invited to sponsor the updating of the home page. When sponsoring they will be listed in the data base on companies active in the field and their products together with properties of said products will be published in a data base updated once every three month.

In order to attract new countries the experts meetings and work shop will be located to countries that either have difficulties to attract enough attention on thermal energy storage within the country or are not members of IEA. In this way the cooperation and collection of information will be spread outside the members of the annex.

Upcoming meetings
- Slovenia, April 2002, provided they agree. The backup country being Australia.
- Japan, 30 Sept to 2 Oct 2002, after the International Sorption Heat Pump Conference, that will take place in Shanghai.
- India, spring 2003, provided they agree. The backup country being Turkey.
- Poland, autumn 2003, after the Futurestock Conference.

**ii Progress report spring 2002**


Officially the Annex has three members, Germany, Japan and Sweden. Strong interest in participation has been shown by China, the Netherlands, Russia, Slovenia, Spain and Switzerland. This interest is manifested by registration to the 2nd expert meeting and workshop held in Slovenia on the 3rd to 5th of April year 2002. Further countries that have been interested in the work of the annex are Australia, Canada, Finland, France, Ireland, New Zealand, Poland, United Kingdom and the United States.

The second Expert Meeting was held in Ljubljana, Slovenia on the 3rd of April 2002 followed by a two days workshop and a technical visit to the cogeneration plant of Ljubljana. The expert meeting was attended by three member countries (Germany, Japan and Sweden) and four observing countries (China, Slovenia, Spain and Switzerland). The main points of the expert meeting were discussion on cooperation between Annex 17 and other organizations inside or outside of IEA, actions to be taken for recruiting more countries to the Annex, new annex on fuel cells and report on the ongoing projects.

Cooperation has been suggested between annex 17 and the Solar Heating and Cooling Program. Especially Task 26 within the SHCP have suggested a new task on utilizing thermal energy storage for reaching higher solar fraction for low energy buildings utilizing solar energy for heating and cooling (including tap water). A meeting in Oslo for Task 26 in the SHCP on the 9th of April was attended by the Operating Agent in order to express the views of the Annex 17 experts. The experts in Annex 17 think that the storage part should be dealt by a joint task between the two organizations with a major input from ongoing or finished work inside Annex 10 and 17. Further discussions between Task 26 and Annex 17 should be performed before the joint meeting of the executive committees of ECES and SHCP in November this year.

The working party on ice-slurries within the International Institute of Refrigeration was represented by Peter Egolf and Osman Saari from Switzerland as observers in the expert meeting. The aim of this is the need for dynamic thermal energy storage at temperatures different from zero. The working party on ice-slurries has discussed to include slurries of PCM as a task of the group. In this field the knowledge of the experts in Annex 17 is required. The Operating Agent will participate in the next meeting of the working party to be held in Stockholm on the 30th to 31st of May this year to discuss the possible cooperation between the two groups.

The 6th framework program within the European Union will consist of forming networks of researchers and research groups aiming at a common goal. It was decided that Annex 17 together with the working party on ice-slurries shall try to form such a network. A letter of intent should be given to the commission before the end of June this year. It was delegated to Fredrik Setterwall and Peter Egolf to formulate and send in such a letter. The networks already existing inside Annex 17 and IIR ice-slurry will be requested to state their interest in participation in such a work.

Many researcher groups and industrial groups have expressed interest in joining Annex 17. There are however some bureaucratic and some financial problems involved in entering an annex. Researchers are often not aware of the procedure necessary for participation. The financing bodies in different countries are not always aware of the benefit of participation. It was therefore decided that on the homepage of Annex 17 should be available information on how to join an annex. Also should the budget for the annex be available to show the marginal cost for attending compared to the value of the information that is shared within the annex. Further the experts and the Operating Agent should devote time to help candidate countries to join the work in the annex.
During the workshop two papers on fuel cells and energy storage was presented. One paper dealt with PEMFC (Proton exchange membrane fuel cells) for keeping the temperature of the fuel cell in a vehicle at a temperature suitable for starting even if the vehicle is subjected to very low temperatures. This application is on a temperature level of 100 °C whereas the second paper on SOFC (Solid oxide fuel cells) treats temperatures around 800 °C. The first problem has to be solved if fuel cells are to be used for vehicles. There are options for solving the problem apart from PCM energy storage. The second problem is more general and is more concerned with high temperature thermal energy storage and not necessarily coupled to fuel cells. The feelings were towards withdrawal of the suggestion of an annex on storage and fuel cells. An annex on high temperature energy storage, which most probably will mean chemical reaction energy storage, might be a suggestion for a new annex.

The status of the projects included in the annex is as follows

- Heating and cooling of buildings

  “Energy storage in the CREA building (Lleida)”
  - The architects are working on the building

  “PCM module to improve stratified water tanks”
  - Reported in the 1st workshop. Report available on the homepage showing an increase in energy density by 20 – 45% and an increased time above a certain required temperature of 50 - 200%. The technique is considered to be close to market.

- Building materials: (Harald Mehling)

  “PCM wallboard containing PCM penetrated with cross-linked polyethylene”

  “Encapsulated PCM in building technology”
  - Report presented at the 2nd workshop. The report is available on the homepage showing that the most promising area is reduction of high temperatures in the summer. The night time ventilation is very important for the result. Experiments will take place in full scale.

  “PCM in composite bridge decks”

  “Mixture of wood, PCM and concrete”
  - Report presented on the 2nd workshop. Report available on the homepage showing that the mechanical properties do not change significantly by introducing PCM into the material. The project continues by finding more suitable PCM and by testing the thermal performance of the material.

  “PCM wallboards”

- Sorption systems: (Andreas Hauer)

  “Air conditioning and cold storage in open sorption systems”

- Peak shaving: (Motoi Yamaha)
“HVAC with PCM storage in it”

- Report presented at the 2nd workshop. Report available on the homepage showing that for Japanese conditions 200 kg of PCM with melting temperature between 17 and 21 °C will be sufficient to eliminate chilled water supply during peak hours. An heat exchanger with fins inwards the PCM facilitates heat transfer.

“Simulation of PCM storage system”,

“Cityhall with PCM heater”

- Temperature sensitive materials : (Spain, Luisa Cabeza)

“Blood transportation”,

- Waste heat utilization: (Sweden, Fredrik Setterwall)

“Absortion chillers and energy storage”

- Report presented on the 2nd workshop. Report available on homepage showing preliminary results of feasibility study. For the demand curve chosen from Chalmers Institute of Technology the power of an absorption chiller could be reduced by 1/3 by introducing thermal energy storage. The cost of the storage is substantially less than the cost of a chiller with higher power. The project continues with experimental verification of the findings and search for client for demonstration project.

“Cold transportation in liquid dessicants”

“PCM applications in industry”

“Thermal management of solid oxide fuel cell systems”

- Report presented on the 2nd workshop. The report available on the homepage shows possible applications and potential for thermal energy storage in combination with SOFC. The project will now enter an experimental phase.

“PCM slurry systems”

- Will be treated together with IIR working party on iceslurries In general it was found that little work is performed to compare thermal energy storage techniques with other techniques fulfilling the same goal. More emphasize on feasibility of the suggested techniques is the general recommendation. This can be performed in student projects or diploma works. Therefore a list of suggested topics will be put on the web for use of teachers in their work.

Upcoming meetings

- Japan, 30 Sept to 2 Oct 2002, after the International Sorption Heat Pump Conference, that will take place in Shanghai.

- India, spring 2003, provided they agree. The backup country being Turkey.

- Poland, autumn 2003, after the Futurestock Conference.
iii Progress report spring 2003


Officially the Annex has three members, Germany, Japan and Sweden. Strong interest in participation has been shown by India. This interest has been manifested by participation in the fourth Expert Meeting and Work Shop held in Indore, India on the 21st to 24th of March 2003. Further countries that have been interested in the work of the annex are Australia, Canada, China, Finland, France, Ireland, the Netherlands, New Zealand, Poland, Slovenia, Switzerland, Turkey, Russia, Spain, United Kingdom and the United States. This interest is shown by having participated in previous meetings in Leida (Spain), Benediktbeuern (Germany), Ljubljana (Slovenia) or Tokyo (Japan).

The 4th Expert Meeting was held in Indore, India on the 21st of March 2003 followed by a Work Shop perfectly organized by Devi Ahilya Vishwa Vidyalaya University. 25 papers were received for the Work Shop. More than 50 persons attended the Work Shop. The industrial participation was large as well as representation from local government, governmental research institutes and universities.

The expert meeting was attended by three member countries (Germany, Japan and Sweden) and one observing country (India). During the expert meeting the progress of the projects of the Annex was discussed and new projects that will be presented during the time frame of the Annex were introduced. (See further below)

The discussion meeting on new annexes held in Munich on the 20th of February was reported and discussed. The proposals are

High Temperature Energy Storage

Transportation of Thermal Energy Utilizing Thermal Energy Storage Techniques.

Annex legal texts and workplans will be presented at the 54th ExCo meeting in Bergen in May 2003.

It was suggested to encourage cooperation with other organizations namely

Solar and heating Program within the International Energy Agency (SHC)

Working Party on Ice-Slurries within the International Institute of Refrigeration (IIR)

Application for a co-ordination action (CA) on Energy Storage and Transportation (ESTNET) within the 6th Frame Work Program has been delivered to the European Commission. Annex 17 will continue to follow the development of the application and participate in the CA
This cooperation will be in the form of joint projects or tasks (SHC). Annex 17 is invited to a planning meeting of Task 32 to be held in Amsterdam on the 9th of May 2003.

Invitations to planned activities in Annex 17 and information will continuously be sent to the chairman of the Working Party on Ice-Slurries within IIR.

Co-operation with other Implementing Agreements like, District Heating and Cooling, Heat Pumping Technologies, Fuel Cells is foreseen in the future.

The budget of the work in the annex was discussed. The cost of the research and development foreseen to be presented within the Annex exceeds 10 million Euro whereas the cost for the actual work in the annex (25% of the expert time plus traveling cost) in total is less than 400 000 €. The budget will be updated and presented as an argument for countries to join the international cooperation in IEA.

Due to the fact that many projects that are a part of the Annex will not be finalized during the originally stated time frame it was decided to ask the Executive Committee for an extension of Annex 17 until 30th of June 2005, e.g. one year extension. Japan and Sweden seems to be in favor of an extension whereas the formalities for Germany are not clear.

There is a strong interest from India to join Annex 17. The OA will send information about the formalities to Dr D. Buddhi.

In order to facilitate the spreading of information from the annex work it was suggested to form national teams for thermal energy storage in the way that Japan is presently doing. Dr D. Buddhi volunteered to start such a group in India. It was decided to bring up the question for discussion in the Executive Committee meeting in order to formalize an organization for this purpose. Also countries not members of the Implementing Agreement are welcome to form such groups in order to make the spreading of information more effective also to those countries. The formation of a group might be the first step to join IEA and their different IAs.

Report on ongoing projects

- Heating and cooling of buildings (Germany and Japan)
  - “Energy storage in the CREA building (Lleida)”
    - The building will be finished in December 2003
  - “PCM module to improve stratified water tanks”
    - Reported in the 1st Work Shop in Benediktbeuern in Germany. The technique is now commercially available in Japan. Is tested in Spain and will be presented in Futurestock in a solar system. Diplomathesis will be finished December 2003
- Building materials (Harald Mehling)
  - A report was given during the 3rd Work Shop in Tokyo, Japan. In short it is reported about a new PCM with a melting range of 20 – 24 °C, PCM in building materials and on PCM in windows and shadings
    - “Encapsulated PCM in building technology”
      - Reported during the 2nd Work Shop in Ljubljana, Slovenia
      - Final report 2003/2004
    - “Mixture of wood, PCM and concrete”
      - Reported during the 2nd Work Shop in Ljubljana, Slovenia Will be finished 2003/2004
    - “PCM wallboards”
    - "PCM in concrete"
Started April 2003 for two years. Posterpresentation in Futurestock.

MOPCON

- **Sorption systems:** (Andreas Hauer)
  - “Air conditioning and cold storage in open sorption systems”
    - Reported during the 4th Work Shop in Indore. A demonstration building in Amberg, Germany with 5700 m² floor area is being built. The cooling system will be demonstrated during the cooling season 2003. Presentation at Futurestock
  - “Heating and Cooling with zeolites”
    - This is a new project. The project was presented at the 3rd Work Shop in Tokyo, Japan. Finished
  - “Silica gel in a Closed System”
    - This is a commercial project run by the company Sortech. Demonstration plants will be erected in the Netherlands, Austria and in Germany. Andreas Hauer will visit the demonstration plant in Austria and report during the next Expert Meeting. HYDES project

- **Peak shaving:** (Motoi Yamaha)
  - “HVAC with PCM storage in it”
    - A report was given during the 2nd Work Shop in Ljubljana, Slovenia. Presentation of different applications of PCM for air conditioning has been given at the 3rd Work Shop in Tokyo, Japan. This includes ventilation systems for energy savings, thermal storage in ceiling systems, floor supply air conditioning systems. No new funding. Will be presented during Futurestock
  - “Simulation of PCM storage system”
  - “Cityhall with PCM heater”
    - Is working.
  - Stevenage Borough Council’s offices
    - Passive cooling utilizing cold night time air for comfort cooling. A joint English/Swedish project was reported during the 4th Work Shop in Indore. The cost for installation of the passive system for night time ventilation was estimated to 40€/m² as compared to 180€/m² for a conventional air conditioning system. Will be presented during Futurestock
  - “Peak Shaving combination UTES and PCM” Will be presented during Futurestock (Annex 14 project

- **Temperature sensitive goods:** (Spain, Luisa Cabeza)
  - Report on the state-of the art on PCM for temperature sensitive materials given during the 2nd Work Shop in Ljubljana, Slovenia. A project was reported on transportation of fine art performed at ZAE-Bayern in cooperation with the German company Va-Q-Tec
  - “Blood transportation”
    - This is a project of Rubitherm GmbH. Results will be given at the end of the year 2002.

- **Temperature sensitive goods:** (Sweden, Viktoria Martin)
  - “Absorption chillers and energy storage”
    - A first report was given during the 2nd Work Shop in Ljubljana, Slovenia. Now work is performed on a system study and on erecting experimental equipment. Will be presented at Futurestock
  - “Cold transportation in PCM”
    - A system utilizing sodium acetate tri hydrate for increasing the energy density in transportation of heat has been introduced by the company TransHeat. More information could be found on [www.eurecaag.de/Trans/index.htm](http://www.eurecaag.de/Trans/index.htm)
  - “PCM applications in industry”
    - A report on this project is available, but only in the German language.
  - “Thermal management of solid oxide fuel cell systems”
    - This project is finished and a report will be given later
  - “PCM slurry systems”

- **Waste heat utilization:** (Sweden, Viktoria Martin)
  - “Absorption chillers and energy storage”
    - A first report was given during the 2nd Work Shop in Ljubljana, Slovenia. Now work is performed on a system study and on erecting experimental equipment. Will be presented at Futurestock
  - “Cold transportation in PCM”
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  • Usually in built environment space is as much a restriction as is money and technology. A feasibility study on introduction of thermal energy storage for increase of the capacity of an existing cooling net work is performed in Sweden with a case in Gothenburg

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Upcoming meetings
- Warsaw, Poland, fall 2003, in connection with Futurestock Conference.
- Beijing, China, fall 2004
- Turkey, spring 2005

**iv Progress report fall 2003**

*Progress report on Annex 17 to the Executive Committee of the Implementing Agreement on Energy Conservation through Energy Storage, Paris, 2003 - 12 - 04 - - 05*


Officially the Annex has three members, Germany, Japan and Sweden. Countries that have been interested in the work of the annex are Australia, Canada, China, Finland, France, India, Ireland, the Netherlands, New Zealand, Poland, Slovenia, Switzerland, Turkey, Russia, Spain, United Kingdom and the United States. This interest is shown by having participated in previous meetings in Leida (Spain), Benediktbeuern (Germany), Ljubljana (Slovenia), Tokyo (Japan) or Indore (India).

The 5th Expert Meeting was held in Warsaw, Poland on the 31st of August 2003. After the expert meeting the Futurestock conference was arranged. A large number of papers concerning the field of the Annex were presented. Some of the presentations at the conference constituted report on Annex projects (see further below)
The expert meeting was attended by three member countries (Germany, Japan and Sweden) and three observing countries (Spain, Switzerland and Turkey). During the expert meeting the progress of the projects of the Annex was discussed. Activities for formation of new annexes on High Temperature Energy Storage and Energy Transportation Utilizing Thermal Energy Storage Technology were reported.

It was suggested to encourage cooperation with other organizations namely Solar and Heating Program within the International Energy Agency (SHC). It was decided to try to arrange a joint meeting between Annex 17 in the Storage Implementing Agreement and Task 32 of the SHC Implementing Agreement in connection with next annex meeting in Arvika, Sweden 2004-06-07—09.

The application for a co-ordination action (CA) on Energy Storage and Transportation (ESTNET) within the 6th Frame Work Program did not receive any funding. It was however decided to continue to find opportunities for formation of larger net works. In order to make decision makers aware of the importance of thermal energy storage not only for saving of thermal energy but also for conservation and safety of electrical energy systems it was decided that Andreas Hauer and Fredrik Setterwall together should write an article on the subject. It is important to point out that Energy Storage is equally important for thermal and for electrical energy purposes. .

Invitations to planned activities in Annex 17 and information will continuously be sent to the chairman of the Working Party on Ice-Slurries within IIR.

Co-operation with other Implementing Agreements like District Heating and Cooling (DHC), Heat Pumping Technologies, Fuel Cells is foreseen in the future. The Executive Committee had a joint meeting with DHC in their meeting in Bergen 2003-05-12—14 and will on their spring meeting 2004 meet with the Heat Pumping Technologies Executive Committee.

The budget of the work in the annex was discussed. The cost of the research and development foreseen to be presented within the Annex exceeds 10 million Euro whereas the cost for the actual work in the annex (25% of the expert time plus traveling cost) in total is less than 400 000 €. The budget will be updated and presented as an argument for countries to join the international cooperation in IEA.

The extension of the Annex until 2005-06-30 has been approved by the Executive Committee on their meeting in Bergen 2003-05-12—14.

In order to facilitate the spreading of information from the annex work it was suggested to form national teams for thermal energy storage in the way that Japan is presently doing. Dr D. Buddhi volunteered to start such a group in India. It was decided to bring up the question for discussion in the Executive Committee meeting in order to formalize an organization for this purpose. Also countries not members of the Implementing Agreement are welcome to form such groups in order to make the spreading of information more effective also to those countries. The formation of a group might be the first step for non-member countries to join IEA and their different IAs.

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    The building will be finished in December 2003
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  A diploma thesis from the university in Lleida, Spain will be finished December 2003

- Building materials: (Harald Mehling)
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  (47. Peter SCHOSSIG, Hans-Martin HENNING, Thomas HAUSSMAN, Alexandandra RAICU: Encapsulated Phase-Change Materials integrated into construction materials)

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Report on the state-of the art on PCM for temperature sensitive materials given during the 2nd Work Shop in Ljubljana, Slovenia.

A project was reported on transportation of fine art performed at ZAE-Bayern in cooperation with the German company Va-Q-Te

• “Blood transportation”

This is a project of Rubitherm GmbH. Results will be given at the end of the year 2002.

- Waste heat utilization: (Sweden, Viktoria Martin)

• “Absorption chillers and energy storage”

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- Sweden, Arvika 7th to 9th of June 2004.
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The 6th Expert Meeting and workshop is to be held in Arvika (Sweden) on the 7th to 9th of June 2004. To this meeting until now (3rd of May) 36 participants has been registered coming from 13 different countries. (Australia, Austria, France, Germany, Japan, the Netherlands, New Zealand, Spain, Sweden, Switzerland, Turkey and the United States)

During the expert meeting the progress of the projects of the Annex is to be discussed. After the workshop kick-off workshops of the two new suggested annexes on Optimized Industrial Process Heat and Power Generation with Thermal Energy Storage and Energy Transportation Utilizing Thermal Energy Storage Technology are to be held.
A joint meeting with Task 32 in the Solar Heating and Cooling Programme will be held before the expert meeting of Annex 17. During this meeting the activities of the two working groups will be discussed and plans for future cooperation between researchers in the two groups will be made up. Task 32 will arrange a work shop in parallel to the Annex 17 work shop.

On the 4th and 5th of March 2004 ZAE-Bayern in Munich arranged a symposium on Heat and Cold Energy Storage utilizing Phase Change Materials. (www.muc.zae-bayern.de/zae/specials/symposium_2004.htm) Many projects presented during this symposium are in fact a part of Annex 17. Many products within the field of introduction of PCM into building materials are now available. The performance of these materials was described during the symposium and the presentations could be found on the web-page.

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• compensated for heat losses from the tank and thereby allowed a longer storage period
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<table>
<thead>
<tr>
<th>EM/WS</th>
<th>Location</th>
<th>Host</th>
<th>Date</th>
<th>Number of participants in the work shop</th>
<th>Participating countries</th>
<th>Observer countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick-off</td>
<td>Lleida, Spain</td>
<td>University of Lleida</td>
<td>5-6 April 2001</td>
<td>13</td>
<td>Germany, Japan, Sweden</td>
<td>The Netherlands, Spain, Switzerland</td>
</tr>
<tr>
<td>1</td>
<td>Benediktbeuern / Munich, Germany</td>
<td>ZAE Bayern</td>
<td>3-4 October 2001</td>
<td>Together with ZAE-Bayern</td>
<td>Germany, Japan, Sweden</td>
<td>The Netherlands, Turkey, Australia, Spain</td>
</tr>
<tr>
<td>2</td>
<td>Ljubljana, Slovenia</td>
<td>University of Ljubljana</td>
<td>3-5 April 2002</td>
<td>16</td>
<td>Germany, Japan, Sweden</td>
<td>China, Slovenia, Spain, Switzerland</td>
</tr>
<tr>
<td>3</td>
<td>Tokyo, Japan</td>
<td>Heat Pump &amp; Thermal Storage</td>
<td>30 Sept. – 2 October 2002</td>
<td>38</td>
<td>Germany</td>
<td>China</td>
</tr>
</tbody>
</table>
The work in the Annex has been divided into three subtasks:

- Heating and cooling of buildings
  - Building materials and components
  - Sorption processes
  - Peak shaving
- Temperature control
- Utilization of natural and waste energy sources

New materials and physical properties
The interest has been focused on storage of cold energy. The reason is that phase change materials are more competitive in this area since the temperature range for storage is smaller and thus the energy density for sensible heat storage is low. Commercially available materials for this area are based on salt hydrates or mixture of paraffin hydrocarbons. The former usually have a low heat of fusion whereas the later exhibit a melting temperature range leading to that in some applications the total heat of fusion can not be utilized. New materials based on other organic or inorganic compounds have been presented during then annex.

Measurement and presentation of PCM physical properties differs between different suppliers. Reliable data for among others melting temperature, heat of fusion and heat conductivity are essential to a correct design of a storage based on these materials. This has clearly been shown in presentations given during the annex work shops. In Germany has been decided to standardize measurement and presentation of such data. The suggested standard was presented during the latest work shop in Beijing.

PCM usually has a low thermal conductivity which has been considered a drawback for the technology. By additives to the material or introduction of PCM into a matrix of conductive material the conductivity has been drastically improved. One such matrix is expended carbon which by the high porosity of the matrix leads to a high energy density with a very high thermal conductivity.

**Building materials and components**

Introduction of PCM into building materials increases the thermal mass of the building without changing the physical mass. By the increased thermal mass the external temperature variations will to a lesser extent be transferred to the interior of the building thereby creating a more comfortable indoor climate. The relative temperature constancy of the building also leads to a smaller moisture precipitation thereby avoiding damage to the building.

Building materials for different applications are now commercially available as presented during the latest work shop in Beijing. Plaster, fiber- and gypsum boards as well as introduction of PCM into concrete are examples of available materials. Also different building components as windows have been introduced to the market.

**Passive cooling of buildings**

The coldness of the night could be stored in PCM for air conditioning in day time. Such systems were presented during the work shop in Indore, India. The electrical power for the fans introducing the cold night air into the building corresponds to an electrical COP (Ratio between the produced cold and the required electrical energy) of approximately 20. The most important result however is not the energy savings but the reduced cost for installation compared to a conventional system. The air handling units will be substantially simpler with the passive cooling system.

Systems for passive cooling of buildings have been demonstrated in Germany, Sweden and in the United Kingdom.

**Sorption processes**

Demonstration projects in Germany show the feasibility of both cooling and heating of buildings utilizing district heating water for storage. In the project for heating low prized heat during the week ends is stored to heat a school building during the week. The cooling project concerns a jazz club with practically no cooling load during day time but high cooling power demand during show hours in the club.
Temperature control

Temperature control is needed in many cases

- Transportation of temperature sensitive goods
- Electronic equipment
- Personal comfort during extreme temperature conditions
- Medical applications

Presentations during the annex of products in this area are for instance

- LapTopCooler for keeping low temperature of the computer for avoiding burning and for safer running of the computer
- CoolWest for athletics in the Olympic Games. The west has also been used by fire man to prolong the stay in the fire area and by personal working with the light in theatres.
- Garment for medical doctors working with SARS-patients in order to keep a comfortable temperature even when dressed to avoid direct contact with the patients
- Cooling of new-borns for decreasing the risk of brain damage when subjected to oxygen deficiency.

Waste heat utilization

The Swedish project in the annex is about thermal energy storage in connection with absorption chillers. Especially in the case of district heating based on waste incineration it is important to be able to utilize the heat even in summer time when the heat load is small. Since absorption chillers are expensive, especially using low temperature energy as driving energy, the importance of thermal storage is obvious; by constant high load the peak power of the chiller could be held lower than the peak demand, thus decreasing the investment cost.

Further, an absorption chiller in a trigeneration system (producing simultaneously cold, heat and power) will, if operated continuously, lead to an increased electrical energy production and thus a more economical system.

Another project presented during the annex concerns utilization of high temperature energy but low duration from the steel industry. When the steel is cooled down in a batch process the energy is difficult to utilize for production of electricity without storage. When stored the energy could be used for a continuous production of electricity although the supply of thermal energy is intermittent.

New annexes

Discussions during the course of the annex show the need of more information in high temperature thermal energy storage and in the field of energy transportation.

Dr Rainer Tamme from Germany has taken the task to prepare for a new annex in the field of high temperature thermal energy storage.
Transportation by trucks, railways or ships of PCM as well as pumping high density energy carriers is a way to transport energy from the place where it is available to a place where it is needed. Two discussion meetings have been held during the annex. Dr Viktoria Martin took on the responsibility to arrange those meetings. However due to the financial and political situation in Sweden the situation about the future of this work at the moment is unclear.

**Information**

The web site of the annex, [www.fskab.com/annex17](http://www.fskab.com/annex17) is visited by more than 700 visitors each month originating from around 60 different countries.

On the website information from all the experts meetings and work shops are given. Thus more than one hundred presentations are found on the web site and also found are addresses and names of more than one hundred persons working in the field of thermal energy storage utilizing PCM or chemical reactions.

Also found are data sheets of the physical properties of commercially available PCM as well as of more than three hundred compounds used by and suggested by researchers for use for thermal energy storage.

**II Projects**

**i Heating and Cooling of Buildings**

**i:i Innovative PCM Technology**

**Title:** Innovative PCM Technology

**Classification:** Heating and Cooling of Buildings; Demonstration Project

**Country:** Germany

**Time table:**

Start: July 1999

End: June 2004

**Finance:**

German Ministry for Economics

Total cost 6.000.000 € 48% Funding

**Description:**

**Technical goal:** Innovative use of PCM-technology to reduce energy consumption for heating and cooling of buildings

**Strategic goal:** To build up an industrial stucture for PCM products in Germany

**11 industry partners, 2 universities, ZAE (project coordination), 1 trade-association**

Industrypartners:
7 subprojects to develop new PCMs and PCM based products

1. PCM development
2. Latent heat store for heating in buildings
3. Plaster and compound systems with high heat storage capacity
4. Transparent insulation and daylighting elements
5. Shading-PCM compound system
6. PCM in gypsum products
7. PCM to buffer temperature variations in solar-air-systems

The subprojects 2 to 7 deal with different applications for heating and cooling of buildings. The goal of subproject 1 was to develop suitable PCM for subprojects 2 to 7. The different subprojects and their results are now discussed.

Subproject 1: PCM development

**Partners:** Merck KGaA (subcontractor TU Bergakademie Freiberg)

**Goal:** development of PCMs (eutectic, anorganic) for subprojects 2 - 7

**Results:**

**Calculation of phase diagrams of new PCM**

Goal of this project was to develop new PCM for subprojects 2 to 7. In collaboration with the TU Bergakademie Freiberg new theoretical models were developed to predict the melting point and enthalpy of new salt hydrates and mixtures. Especially the temperature range from 20°C to 30°C was investigated as this temperature range is most interesting for building applications and at the start of the project only few anorganic PCM were available. The following table shows a few examples of the simulation results.

<table>
<thead>
<tr>
<th>Substance (formula)</th>
<th>Melting point [°C]</th>
<th>Enthalpy [J/g]</th>
<th>Subcooling [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiNO₃·3H₂O/LiNO₃/NaNO₃</td>
<td>27/25/222/31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiNO₃·3H₂O/Mg(NO₃)₂·6H₂O</td>
<td>27/26/60/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiNO₃·3H₂O/Zn(NO₃)₂·3H₂O</td>
<td>21/no crystallisation</td>
<td>no crystallisation</td>
<td>no crystallisation</td>
</tr>
<tr>
<td>LiNO₃·3H₂O/Ca(NO₃)₂·4H₂O/LiNO₃</td>
<td>18/no crystallisation</td>
<td>no crystallisation</td>
<td>no crystallisation</td>
</tr>
</tbody>
</table>

The results were then experimentally tested and simulation results verified. As an example, a new PCM with melting point of 25°C and high melting enthalpy was found.
Development of a high throughput method to search for nucleators

For the newly developed PCM and also for already known PCM it was tried to find new nucleators that show only small subcooling and high temperature stability. As there is to date no reliable theoretical model to predict nucleation performance of arbitrary substances, an experimental method that allows high throughput of a large amount of substances to test for their nucleation performance was developed.

The result of the investigations was that new nucleators for NaOAc·3H₂O, LiNO₃·3H₂O and PCM containing LiNO₃·3H₂O were found.

Microencapsulation of salt hydrates

A mayor way to apply PCM in buildings is mixing them with building materials. Therefore, it is necessary to microencapsulate the PCM.

A search for already known technologies for microencapsulation was performed, but did not give suitable results. Own experiments with different new ideas did also not lead to positive results. Generally, it was found that microencapsulation of salt hydrates is technically more difficult than for paraffins. The reason is that the water molecules in salt hydrates are much smaller than paraffin molecules and therefore it is more difficult to get a diffusion tight encapsulation shell.

Subproject 2: Latent heat store for heating in buildings

**Partners:** Robert Bosch GmbH, SGL TECHNOLOGIES GmbH, BEHR Industry Mylau GmbH, ZAE Bayern (subcontractor SHK Bayern)

**Goal:**

The project started with a comparison of different potential application fields for heat storages in buildings. The following table shows the two most important ones with some of their main characteristics.

<table>
<thead>
<tr>
<th>Storage for</th>
<th>space heating</th>
<th>domestic hot water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Increased storage capacity (1 day)</td>
<td>Increased storage capacity (1 day)</td>
</tr>
<tr>
<td>Temperature interval</td>
<td>= 20 K</td>
<td>= 40 K</td>
</tr>
<tr>
<td>Necessary storage power</td>
<td>low</td>
<td>high (20 kW)</td>
</tr>
<tr>
<td>Necessary stored heat</td>
<td>medium (20kWh)</td>
<td>medium (20kWh)</td>
</tr>
<tr>
<td>Safety constraints</td>
<td>low</td>
<td>high (drinking water)</td>
</tr>
</tbody>
</table>

Because of the lower requirements for power and safety constraints, it was decided to focus on the development of a heat storage for space heating. Especially the low safety constraints for drinking water in that case are important.

Development of simulation models for heat stores
One of the first tasks within the project was the development of suitable simulation methods. Different analytical and numerical methods were investigated and also a commercial software was tested.

- Analytical models are useful for general considerations and for very simple problems. Usually they neglect sensible heat and are therefore only useful for very small temperature swings. In most cases they treat a semi infinite space, which means they are only useful for short simulation times. The geometry is usually 1-dimensional, radial or spherical.

- A combination of numerical and analytical methods was developed and tested and eliminated some of these constraints.

- Numerical explicit models were most suitable for storage simulation. They are flexible with regard to geometry, enthalpy-temperature relation and other aspects. Figure 58 shows a comparison of a simulation and a measurement on a real storage.

The agreement is very good. A problem with numerical simulations, especially commercial software, is the connection to a program simulating a building for getting demand and supply data for the storage. Conventional methods and the commercial software have not been useful at all for this problem. They automatically create a very large number of knots for the numerical model that leads to difficulties in simulation time. Within the project, a new method was developed to reduce the number of knots significantly. This method has not been published jet, but will probably be published in summer 2005.

- Subcooling can currently not be treated in numerical simulation models as there is no method to deal with the nonequilibrium aspect of subcooling known. As measurements on the developed storages have shown, this is no restriction for the development of a storage for space heating as the typical degree of subcooling can be neglected with regard to the temperature difference between the phase change and the outlet.

**Development of different PCM-graphite composites**

To reach sufficiently high heat transfer within the storage, it was decided to use a PCM-graphite composite as heat storage material. The investigations started based on a patent of the ZAE Bayern. In this patent, it was shown that the infiltration of PCM into a highly porous graphite matrix leads to a composite with high heat transfer and heat storage capacity.
Different ways to infiltrate organic and inorganic PCM into the graphite matrix have been investigated and proved to be successful. However, for reasons still unclear, it was not possible to infiltrate the most suitable PCM for the space heating application, NaOAc·3H₂O.

Due to this, SGL developed and patented a new method to form a composite between PCM and graphite. In this method the graphite is not prepressed to form a mechanically stable matrix with high thermal conductivity, but is mixed with the PCM. This way of forming a composite seems to work with all kinds of PCM and is more flexible in filling complex geometries with the storage material. Compared to the matrix, the thermal conductivity is smaller; however it is still about 10 to 20 times higher as for the pure PCM:

\[
\text{infiltration}
\]

\[
\text{PCM} \rightarrow \text{graphite matrix} \quad \lambda = 20 - 30 \text{ W/mK in plane direction}
\]

\[
\lambda = 5 - 9 \text{ W/mK perpendicular to plane direction}
\]

\[
\text{mixing}
\]

\[
\text{PCM} \rightarrow \text{graphite compound} \quad \lambda = 4 - 5 \text{ W/mK in all directions}
\]

The different PCM-graphite compounds are already commercially available from SGL as product under the product name ®SIGRAL. Direct information can be found on the website from SGL.

Storage concept

The concept for the storage is shown in Figure 59.

![Figure 59: Concept for the storage](image)

The storage consists of a heat transfer pipe in a storage container which is filled with NaOAc·3H₂O-graphite compound. The concept is flexible with respect to storage size, power, and geometry. Basically, as the compound can be formed with any arbitrary PCM, the concept can also be used to build latent heat storages for other applications as long as the heat transfer medium is still a liquid.

Storage modules
Based on this concept different storage modules were built and tested. Figure 60 shows two modules connected in series on a fully automatic test stand.

![Automated test stand](image)

**Figure 60: Automated test stand**

The modules have been loaded and unloaded for several months, currently more than 1300 cycles have been performed. The recorded temperature-time curves show no systematic change in storage performance.

**Outlook**

It is planned to apply the developed storage concept in different applications. Potential installations for demonstration projects are currently investigated.

**i.ii.iii Subproject 3: Plaster and compound systems with high heat storage capacity**

**Partners:** Follmann & Co., Remmers Baustofftechnik GmbH

**Results:**

**PCM in internal plaster of lightweight buildings**

Simulations have shown that peak temperatures in summer can be reduced by about 2-3 K. Suitable microencapsulated PCM for product development however have not been available.

**PCM in external plaster of well-insulated walls**

A potential application has been seen in the reduction of supercooling and the condensation of water connected to this effect on the outer surface of a building wall. The problem caused by condensation of water is that well-insulated walls are susceptible to biological growth after only a few years. Figure 61 shows such an external wall.
Figure 61: External wall with biological growth

The algae growth occurs when a wall is often wet or moist for an extended period. The effect on composite insulation walls is more pronounced than on homogenous walls (with the same U-value), as the outer insulation stores only little heat and therefore cools down significantly faster.

External plaster with micro-encapsulated PCM

Figure 62 shows the cross section of a test wall with $U = 0.2\, \text{W/(m}^2\text{K)}$

![Diagram of test wall with micro-encapsulated PCM]

On this test wall, different alternative plasters were tested:

Normal plaster (no PCM),

Plaster with PCM1 and PCM2 with 30 weight % PCM, enthalpy approx. 20 – 40 J/g

Results of a measurement of surface temperatures from October 2003 are shown in figure 45.
During the time indicated by the arrow, the plaster equipped with PCM1 does only slightly go below the dew point temperature. The plaster with no PCM as well as the plaster with PCM2 show a significantly lower surface temperature than the dew point temperature and therefore condensation on the wall surface will occur in these cases.

Simulations for the case of retrofit of an existing wall with the following layer structure

wall + composite insulation + old plaster + new plaster with PCM

have shown a significant increase in heat capacity by adding new plaster (mass and PCM). The duration and amount of condensation on the wall are reduced. A light plaster coating (0.8 kg/dm³) with PCM is better than a heavier plaster coating (1.8 kg/dm³) without PCM. Approx. 20% reduction in duration and amount of condensation over the year was observed. Further potential for improvement is expected in

- Increase in the amount of PCM in the plaster,
- Increase in the thickness of the plaster coating.

**Outlook**

As Figure 64 shows, Remmers plans to make the developed PCM plaster commercial for combating biological growth on composite insulation facades

---

**Figure 63: Measurement of surface temperatures**

**Figure 64: Comparison of plaster with and without PCM**
i.i.iv Subproject 4: Transparent insulation and daylighting elements

**Partners:** Glaswerke Arnold GmbH & Co. KG, Warema Renkhoff GmbH, Merck KGaA

**Goal:**

As shown in Figure 65, the goal of the project was to develop two different PCM applications for building facades:

A solar wall, where the PCM substitutes a massive wall as heat storage element

A daylighting element, where the PCM transmits part of the incident solar radiation for daylighting, absorbs the other part and stores the absorbed energy as heat.

---

**Figure 65: Two applications of PCM for building facades**

**Solar wall with PCM**

The Figure 66 on the left side shows an experimental storage board with PCM (TEAP)

**Figure 66: Board for storage of solar energy**
The experimental results on the right side show that the PCM storage board was able to buffer temperatures significantly and store most of the absorbed solar heat as latent heat. It was found that LiNO$_3$·3H$_2$O (heat-resistant up to 100°C) would be an optimized PCM, however there is no manufacturer at the moment. The tested macroencapsulation allows easy handling, but thermal stability must be improved.

**Day lighting element with PCM**

For the daylighting element, in addition to thermal parameters one of the key parameter is the optical performance of the PCM with respect to spectral transmittance and absorbance. Further on, for architectural reasons, no macroscopic effects should be visible from the inside of the building, as this might disturb people in the room. These additional requirements have made the development of technically working systems difficult.

Many different concepts were investigated. Figure 67 shows two examples

- a double skin sheet with pure PCM (Dörken), it is form stable and allows easy handling. Dimensions are currently limited to 60cm x 60cm

- a PCM-compound (Rubitherm). The PCM-compound prevents leakage, but is not form stable and max. dimension are 40cm x 40cm

![PCM-compound (Rubitherm, left sample) and double skin sheet with pure PCM (Dörken, right sample)](image)

**Figure 67: Daylighting elements with PCM**

**i.i.v Subproject 5: Shading-PCM compound system**

**Partners:** Warema Renkhoff GmbH, Merck KGaA

**Idea:**

Solar blinds are preferably installed on the inner side of windows because, if installed on the outside, strong winds require high mechanical stability. A drawback of the installation on the inner side however is that the solar radiation absorbed on the surface of the blind heats up the blind very fast. The blind then acts as a solar heater and is known to cause significant problems in contributing to overheating of the room. Therefore, it was tried to put PCM into
blinds to increase their heat storage capacity. This can delay the temperature rise to the late afternoon hours and then the stored heat can be ventilated to the outside easily.

![Diagram of conventional sunshading system and sunshading system with PCM](image)

**Figure 68: Solar blind with PCM**

**Experiments**

Figure 69 shows two experimental solar blinds with PCM which were investigated within the project.

![Images of experimental solar blinds](image)

**Figure 69: Experimental solar blinds**

The measured temperatures shown in Figure 70 demonstrate that with PCM, the temperature of the blind can be kept close to the air temperature within the room and therefore prevent the blind from acting as a heat source.
Generally, the sun shading system with PCM developed and tested in laboratory scale showed very promising experimental and simulation results:

- significant decrease in max. blind temperature (≈ 10 - 15K)
- significant decrease in operative temperature (≈ 3K)
- time shift of heat gains from noon to evening
- improved thermal comfort during working hours

**Outlook**

A new demonstration project for PCM-systems will start mid 2005. The development of a sunshading system with PCM to prototype stage and the test of system performance in various demonstration buildings under realistic conditions are planned.

**i.i.vi Subproject 6: PCM in gypsum products**

**Partners:** Knauf Gips KG, Merck KGaA

**Problem:**

Figure 71 shows a simulation of a standard room constructed in three different ways with different thermal mass. The variation of temperature during one week in August can be reduced using PCM to the level observed in a massive building.
Wallboards with PCM

Knauf is one of the leading producers of gypsum wallboard. Within the project, gypsum wallboards with 35 wt.-% micro-encapsulated paraffin in the plaster board were developed. The PCM-wallboard can be produced within the conventional production process. The handling for installation is the same as without PCM. Technical data of the PCM wallboard are:

- board thickness: 15 mm
- amount of paraffin: 3.3 kg/m²
- enthalpy: 366 kJ/m²
- flamability: B2 (classified in DIN 4102 part 1)

Thermal data of the wallboard with PCM with respect to mass are:

\[ C_p = 1.2 \text{ J/(g·K)}, \]
\[ \Delta H = 35 \text{ J/g} \]

That means, the latent heat increases the heat storage capability of the board for a temperature swing of +/-2° 7 times (35/(4·1.2)=7). This effect is visualized in the experiment shown in Figure 72.

![Cooling down of several gypsum plaster boards reported by an infrared camera](image)

**Figure 72: PCM increases the heat storage capability**

Outlook

A demonstration project is planned for the Bundesgartenschau 2005 in Munich. The installation will be in the “Haus der Gegenwart” and will be accompanied by thermal measurements.

**i.i.vii Subproject 7: PCM to buffer temperature variations in solar-air-systems**

**Partners:** Grammer Solar GmbH, Merck KGaA
**Subject:** Solar-air systems (Figure 73) are well suited for heating the fresh air circulated into buildings in an energy-efficient manner.

However, solar-air-systems are strongly influenced by the temporal difference between heat demand and solar heat availability. A possible solution was seen in using PCM to buffer demand-supply differences.

**Investigated possibilities**

The application of PCM in connection to solar-air systems was tested for different locations to apply the PCM:

- collector absorber
- ventilation pipes (double pipe with PCM in the partition)
- hypocaust (hot-air floor heating with a PCM layer as heat storage)
- storage block (hot-air storage connected to the collector)

The result from testing different functional models was that the storage block appears to be the most promising application.

**Prototype of a storage block**

A prototype has then been designed and built and has been in operation at Grammar for heating parts of the company building since February 2003. The storage shown in Figure 74 on the left

- is charged via a 20 m² solar-air-collector
- air flow is 180 - 300 m³/h
- approx. 4.1 kWh latent heat can be stored
Figure 74: Storage block prototype

Figure 74 on the right shows an example of the temperature of the air circulated into the room. The temperature is above 20°C for several hours and no overheating is observed. The prototype is being monitored and the data regularly evaluated. The thermal batteries (Climator: Climsel32) are all in perfect working order to date (March 2005).

Outlook

There is still room for improvement in the arrangement of the batteries with respect to heat flow optimization. The system could also be tested with a different PCM to achieve a cooling effect in summer.

Further prototypes will be tested in different buildings within the framework of a follow-up project.

It should definitely be possible to manufacture a marketable heat-storage system at a feasible price.

i:ii Thermal Performance Studies of a Test Cell having a PCM-Window in South Direction

The basic idea of passive solar home design is to invite sunlight into the house during the winter, and once it is inside the home, to hold it in and store it until nighttime. Conversely, the sun needs to be kept out during the summer. Passive solar systems, with suitable designed an selected storage, can offer a very significant reduction of energy costs. Storage of solar thermal energy in phase change materials enable solar heat to be stored isothermally, at the temperature of reversible phase change (usually melting / solidification process). Solar heat is stored as latent heat of phase change when outside temperature is higher than the temperature of phase change. When outside temperature is lower the stored heat is released. In that way temperature is controlled automatically by the phase change process, provided that the materials and designs are appropriate and heat losses minimized.


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### i.iii Phase Change Composites

Thermal storage performance of the building elements made of phase change composites mainly paraffin or salt-hydrate absorbed in porous concrete, is analyzed by simulation. A mathematical model describing the energy balance of phase change storage elements allows the operational simulation and also a prediction of building storage elements applicability. The numerical calculations in function of thermophysical properties, ambient and design parameters lead to the conclusion that solidification goes fully and the heat recharging process can be used only for the case of CaCl$_2$·6H$_2$O composite. Optimization of the phase change building elements by thermal simulation would improve the thermal storage process and the energy gain in building constructions.

**Literature:** H. Kitano, K. Sagara, M. Hadjieva, R. Stoykov Simulation Approach for Applicability of Phase Change Composites in Architectural Field IEA IA ECES Annex 17 3rd Work Shop Tokyo 2002 09 30 – 10 02

**Contact:** H. Kitano . Mie University, Dep. of Architecture, Faculty of Engineering 1515 Kamihama, Tsu, Japan **E-mail:** kitano@arch.mie-u.ac.jp

**Partners:** Bulgarian Academy of Sciences, Central Laboratory of Solar Energy and New Energy Sources, 72 Tzariigradsko Schosse blvd., 1784 Sofia, Bulgaria,

### i.iv Mixture of Wood, Concrete and PCMs for Buildings

Wood-lightweight-concrete is a mixture of cement, wood chips or saw dust (less that 15 wt. %), water and additives. Advantages are variable properties in the thermal insulation ($\lambda$ between 0.15 and 0.75 W/mK), noise insulation, density ($\rho$ between 600 and 1700 kg/m$^3$) and heat capacity ($cp$ within 0.39 to 0.48 kJ/kg°C at $\rho$=1300 kg/m$^3$). Composites of wood-lightweight-concrete show new options in the field of construction with reduced demand of resources. Potential applications are the building interior, outer wall construction, storey buildings, and generally prefabrication. The reasons for the investigation on the combination of PCM with wood-lightweight-concrete were
- to increase the thermal storage capacity
- to get lighter and thinner wall elements with improved thermal performance

The focus was to find out if organic PCMs can be combined with wood-lightweight-concrete. Therefore, different materials from RUBITHERM, GR 40, 1 -3 mm and GR 50, 0,2 -0,6 mm were added to wood-lightweight-concrete with $\rho$=600kg/m$^3$ and $\rho$=1270kg/m$^3$.

**Figure 75 Surfaces of different mixtures.**
It was shown that PCMs can be combined with wood-lightweight-concrete and that the mechanical properties do not seem to change significantly.

**Literature:**
H. Mehlng, R. Krippner, A. Hauer, 2nd workshop of IEA Annex 17 in Ljubljana
Roland Krippner, Untersuchungen zu Einsatzmöglichkeiten von Holzleichtbeton im Bereich von Gebäudefassaden; PhD-thesis

**Contact:** Dr. H. Mehlng, ZAE Bayern, Mehlng@muc.zae-bayern.de

**Partners:** Technical University Munich/ Prof. Herzog (architect), Bavarian Center for Applied Energy Research ZAE Bayern, Rubitherm GmbH and Bayern Zement mbH.

**Funding:** EUR 50,000,00 (governmental grant from the Bavarian Ministry of Economics)

**i:v Air Conditioning and Cold Storage in Open Sorption Systems**

Driven by low temperature heat, e.g., solar or waste heat, open cycle desiccant cooling systems, DCS, provide cool and dehumidified air. Thereby DCS cover efficiently the ventilation load and the dehumidification load of a building. Furthermore, liquid desiccant cooling systems, LDCS, can store energy efficiently in the liquid desiccant and decouple energy demand and supply in time and location [1]. In large buildings, however, cold water, is used to remove the heat load from inside of the building. in addition to the ventilation air.

ZAE Bayern and its partner are building a LDCS providing cold water at about 15 °C for additional cooling of a jazz club in Munich, see Figure 1. Return air of the building is dehumidified in an absorber by a concentrated hygroscopic LiCl-H2O solution, supplied from a tank. Subsequent indirect evaporative coolers, supplied with the dry air, produce cold water for the fan coils and for the cooling of the absorber. The desiccant solution is diluted while dehumidifying the air and is stored in a separate tank. The jazz club needs cooling only at night. During the day the absorber and part of the air handling equipment regenerate the desiccant solution to its original concentration, using hot water at about 75 °C from a district heating system. The cooling capacity is about 20 kW, the regeneration capacity about 40 kW. A storage volume of 1,5 m³ provides solution for 9 hours of full load operation.

The major technical components of the system, the absorber/regenerator and the indirect evaporative coolers are subject of development. New types of these components have been tested in advance. Currently the system is under construction and due to be set into operation in summer 2005.
Figure 76 Open cycle liquid desiccant cooling system for cold water production using a stored concentrated LiCl-H2O-solution

Literature


Contact

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Partners

Muenchner Gesellschaft für Stadterneuerung, Munich, Germany

Stadtwerke Muenchen GmbH, Munich, Germany

Funding

German Ministry of Economics and Labour, BMWA

i:vi Test of Thermochemical Storage of Heat with New Storage Materials

Tests of new X type zeolites (LSX) and modified mesoporous materials for thermochemical storage of heat in lab-scaled storage units of 1.5 and 35 L volume show that application of solar heat for charging of zeolites (desorption of the water) inquires for new microporous
materials which keep a certain energy density and temperature lift but at lower charging temperatures.

![Figure 77 SAPO molecular sieve structure](image.png)

Alumino- and silocaluminophosphate molecular sieves (see Figure 77) are potential candidates for those applications. Therefore, the adsorption properties of water in AlPO₄’s were investigated by thermogravimetry, differential scanning calorimetry and microcalorimetry in respect to utilization of solar heat. The storage density of the aluminophosphates is comparable with that of zeolites. Because of the differential molar heats of adsorption being between the zeolites and the mesoporous materials the temperature lift of AlPO₄’s is significant higher as for silica gels despite the fact that the desorption temperatures of AlPO₄’s and silica gels are about the same. This could be verified by tests in the 1.5 L storage for a SAPO-34 based new microporous storage material.

**Literature**


**Contact**

Dr. Jochen Jähnchen, Fachhochschule für Technik und Wirtschaft Berlin (University of Applied Sciences Berlin) c/o ZeoSys GmbH, Volmerstr. 13, D-12489 Berlin, GERMANY

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**Partners**

Tricat Zeolites GmbH, Bitterfeld, Germany; Chemiewerk Bad Köstritz GmbH (CWK), Bad Köstritz, Germany; ZeoSys GmbH, Berlin-Adlershof, Germany.

**Funding**

German Ministry of Economics and Labour BMWA.

**i:vii Sorption Storage System using Zeolite for Heating and Cooling**

An open sorption storage system was installed in Munich / Germany. It is used for heating by using the heat of adsorption during the discharging process and the heat of condensation during the charging process. Air conditioning is available by the humidification of the dried output air during discharging. Before the humidification the output air is cooled in a indirect evaporative cooler, which imports cold from the humidification of the exhaust air from the building.

The sorption storage system in Munich is connected to the district heating net for load leveling. It is charged during night (or other off peak periods) and has to heat a school building during week days. 7000 kg of Zeolite can provide heating to the school for one day at –16 °C before the storage has to be charged again. In summer time a nearby jazz club has to
be cooled. In this case the Zeolite storage transforms district heat into cool and dry air for air conditioning.

In the heating mode about 92% of the charged heat can be delivered to the school building. Within the zeolite an energy density of 124 kWh/m³ can be achieved. This is about 3 times more compared to a conventional hot water storage, when using the charging temperature of 130 °C. At higher temperatures the storage capacity can be much higher.

For air conditioning about 85 % of the district heat can be converted into cooling energy.

A charging temperature of 80 °C leads to best results concerning this value. The storage capacity for air conditioning at 100 kWh/m³ is still very high. The storage capacity would be higher, if a higher charging temperature would be applied.

If such a system is economically interesting, is depending on the price you have to pay for the delivered thermal energy. This is basically depending on the number of storage cycles, which can be raised significantly by the hybrid application for heating and cooling. In the zeolite storage in Munich 150 heating and 100 air conditioning cycles were assumed, which leads to a payback time of about 7 years. Therefore this new technology will be able to compete with conventional systems in the near future.

**Literature**


**Contact**

Dr. Andreas Hauer, Bavarian Center for Applied Energy Research, ZAE Bayern, Walther-Meissner-Str. 6, D-85748 Garching, Germany, email: hauer@muc.zae-bayern.de
Partners
Howatherm Klimatechnik GmbH, Brücken; Stadtwerke München, SWM; Münchner Gesellschaft für Stadterneuerung, MGS.

Funding
German Ministry of Economics and Labour BMWA.

Seasonal Storage using Silicagel

In the period from 01.07.1998 to 30.06.2001 the European Union funded the Project ‘High Energy Density Sorption Heat Storage for Solar Space Heating’ (HYDES). The major objectives of the project HYDES were:

1. Development of a high energy density heat storage system based on closed cycle adsorption processes suitable for the long-term storage of low-temperature heat.
2. Optimization of sorption materials for low-temperature heat storage applications by specific modifications of the material properties.
3. Testing of this system in the application of seasonal storage of solar thermal energy for space heating purposes under different climatic and system conditions.

The work programme of HYDES consisted of the following technical tasks:

1. Material research for an optimization of the sorption materials
2. Development of prototype modules
3. System integration and monitoring of the prototype modules in Austria and Finland.
4. Study on further applications of the storage modules in industrial processes and solar cooling.
5. Assessment of the results from the system monitoring and feedback on the design of the storage modules.

Five partners from Germany, Austria and Finland participated in the project.

The objective of the material research was to select the sorption material for the prototype system and to find methods for improving material properties. In a first instance, a large number of commercial silica gels were studied and sorption equilibria were determined. Two products were identified as most promising for an application in the storage system. Different measures for the enhancement of heat and mass transfer in the sorption bed were tested experimentally. Finally they led to the conclusion that the simplest method is the introduction of metal filaments into the sorption bed.

In order to study the performance of the sorption heat storage in different climatic conditions two prototype systems were planned and constructed. One test plant was installed in Austria. This system is operated by solar collectors and provides heating and domestic hot water production for a new low energy house next to the office of the Austrian partner AEE. A thermal solar plant with an aperture area of 20.4 m² is available for the test plant as the primary source of energy. The experimental results up to now show that the achieved energy density is about 20 % below the value expected from simulation (150 kWh per m³ of silica gel).
The second test plant was installed in Finland. The chosen test site was Kaskö town on the northwest coast of Finland. The storage is connected to a district heating network (DH) to serve as a back-up heating unit for the peak-power oil burner in order to reduce the operation time of this burner. The storage is charged with forward heat and discharged to the return side. The average power of about 5 kW of the storage is adequate to provide the stand-by heat. The storage capacity of 150 kWh is suitable for a few days operation.

Based on the system design, simulations, optimization and practical experience with the pilot storage unit, the Finish project partner SOLPROS has drawn the following conclusions and recommendations: The Heat storage for district heating and waste heat utilization is still very relevant and topical. The potential is good and large. Increasing the number of cycles per year improves the economics of the storage. Grace 127 B sorption material seems not to be very effective in terms of thermal performance. The average ΔT found for discharge is small and enables not much heat pumping. The maximum storage capacity for a DH system seems to be around 130 kWh/m³.

Recently a follow-up project entitled 'Modular High Energy Density Sorption Heat Storage' (MODESTORE) was approved by the European Commission. The work in this project will start in April 2003 and will continue for three years. The main objective of the present project is to develop a second generation prototype of high energy density heat storage which is adapted to market demands in different European applications.

Future work will put emphasis in the following fields:
1. Continuation of the system monitoring over the coming heating period in order to implement and test the developed control algorithms in connection with a real heating system.

2. Development of stable modified sorption materials based on the practical experience and methods developed in this project.

3. Technical re-design of the storage modules based on the findings of the technical feedback and production of a second series of prototypes.

4. Parallel development and production of smaller units for thermal heat pumping and cooling with smaller storage capacities as spin-off products.

Literature


Contact
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Partners
UFE SOLAR GmbH, Berlin, Germany; Arbeitsgemeinschaft; ERNEUERBARE ENERGIEN (AEE) Gleisdorf, Austria; SOLPROS AY. Helsinki, Finland; AUSTRIA EMAIL AG, Knittelfeld, Austria

Funding
THE EUROPEAN COMMISSION in the framework of the Non Nuclear Energy Programme JOULE III

i:ix Absorption Storage System using LiCl for Solar Dehumidification

An office building of 5700 m² floors space has been built in Amberg, Germany, by architects Hart & Flierl for Prochek Immobilien GmbH. The innovative air conditioning concept using solar energy has been worked out by M. Gammel engineering consultants. The comparatively low heating (35 kWh/m²/a) and cooling demand (30 kWh/m²/a) of the building is covered by thermally activated ceilings, assisted by appropriately conditioned ventilation air.

Well water of 12-14 °C with a cooling capacity of 250 kW is used for cooling the ceilings in summer. In Summer the ventilation air has to be dehumidified to keep the required comfort and to prevent from condensation at cold ceilings. The air dehumidification is done by a liquid desiccant dehumidification and cooling system, sketched in Figure 4. Warm and humid outside air is cooled and dried in a special dehumidifier by a concentrated Lithium Chloride salt solution (LiCl-H₂O) before it is blown into the atrium of the building. From there several air handling units draw the air into the offices and provide additional cooling on demand.
Figure 80: Sketch of the liquid desiccant cooling and dehumidification system.

The exhaust air of the building is collected in three exhaust air handling units. Indirect evaporative coolers exploit the remaining cooling capacity of the exhaust air and cool the supply air in the dehumidifier via a water loop. This cold recovery makes the system more efficient. Depending on ambient conditions the predicted thermal coefficient of performance of the system is 1.2 to 2. The thermal coefficient of performance, COP, is defined as the enthalpy difference between outside and supply air related to the thermal energy used to drive the system.

A special low flow technique enables the dehumidifier to dilute the desiccant significantly when drying the air. The salt concentration changes from 40% to about 28 % wt. Concentrated and diluted solution are stored separately. The dehumidification process can be operated as long as concentrated solution is available. The system of concentrated and diluted solution stores energy very efficiently. The energy storage density reaches up to about 300 kWh/m³ related to the volume of the diluted solution. Since a chemical potential is stored, the storage is non degrading. No insulation of the storage tanks is required.

When solar energy is available the diluted solution is regenerated to it’s original concentration in a regenerator, at temperatures of 70 to 80°C. At this temperature water evaporates from the desiccant solution and is taken to the ambient by an air flow through the regenerator. The Lithium Chloride does not evaporate. It remains in the solution and in the cycle. Heat recovery for the air flow is used to keep up the thermal coefficient of performance.

The desiccant cooling system is designed for a maximum air flow of 30.000 m³/h. The design point for cooling is defined as 32°C and 12 g/kg outside air state and 24.5 °C and 8.5 g/kg supply air state. Under this conditions the air cooling demand is about 80 kW the air dehumidification demand is 70 kW. A total air conditioning capacity of 150 kW is required. The system concept demanded for a system driven solely by solar, no additional fossil fuel should be used, except from electricity for pumps and fans. Solar energy for air conditioning is stored efficiently in about 10 m³ of desiccant solution. The liquid desiccant is regenerated by solar thermal energy from a 70 m² flat plate collector array at 70 to 80°C with a maximum capacity of 40 kW. Summer air conditioning uses only solar energy.

1 In hot and humid climates the COP will be close to 1
The building is in use since June 2000. The prototype desiccant system has been installed and tests of the regenerator and the absorber have been performed within a demonstration project funded by the Bavarian Ministry of Economics, Traffic, and Technology. Unfortunately the owner of the building was not willing to continue the project and neither the operation nor the monitoring of the system was possible.

**Literature**


**Contact**

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**Partners**

Prochek Immobilien GmbH & Co KG, Amberg; M. Gammel Ingenieure für Energie- und Umwelttechnik, Abensberg.

**Funding**

Bavarian Ministry of Economics, Traffic and Technology.

**i:x Development of Supply Air Conditioning System Utilized Granulated Phase Change Materials**

Figure 82 shows conceptual diagrams of the developed system. In this system, latent heat is stored in PCM that is embedded directly below OA floor boards in the form of granules with several millimeters in diameter. The feature of the system is that heat exchange occurs through direct contact between the granular PCM and air serving as the heat medium. This
allows outstanding heat exchange efficiency and then increase of the TES capacity in the entire system. The main objectives of the study are as follows.

* To cover the whole diurnal cooling load by stored cold energy during night
* To improve the thermal environment in the room compared with the one in the conventional floor supply air conditioning system applied building mass storage

Figure 83 shows a flowchart of the development. As a result of some trials, PCM granules named FMC-PCM have been applied which consists of microcapsules with a diameter of a several micrometers containing paraffin wax PCM.

Operating conditions were discussed by using a computer simulation program. It consists of heat transfer equations for each component and includes the radiative heat transfer in the target room. The values of heat transfer coefficient were determined as compared with measurements. The use of a FMC-PCM, which shows phase change between 20.0°C and 22.9°C, led to a load shifting ratio \( \eta_s \) of 100% in the case of the packed bed with a thickness of 25 mm and a weight of 12.5 kg/m². Additionally the effect of the heat radiation from the floor face resulted in the comfortable thermal environment even at a room temperature of 28°C in the office hours.

On the basis of these results, full scale experiments were conducted in a test room with a floor area of 9.2 m². In the system, packed beds of FMC-PCM, which shows phase change between 18.2°C and 21.4°C, were installed in 12.5 kg/m². The proposed system could achieve a load shifting ratio \( \eta_s \) of 92% under the condition with an air temperature of 12°C in the under floor space during the TES period and a set temperature in the room of 28°C in the daytime whereas a condition with a conventional thermal mass storage shows the \( \eta_s \) of 50%. The use of the FMC-PCM can also keep room temperature above 24°C even in the morning just after the TES period. Thermal sensations answered by some people show neither “cool” nor “uncomfortable” throughout the daytime. These results seem to indicate that this system can provide the comfortable thermal environment as well as the high rate of the load shifting.

Cost saving will be a problem to be solved in the proposed system. At this moment, the initial installation cost of the granular PCM exceeds 14 EURO/kg though a calculation shows the cost payback time of 5.5 years even when the cost can be reduced to 2 EURO/kg. Additionally the granular PCM used here is made by paraffin wax, which can be flammable. A process for flame proof finish leads to increase of the cost and reduction of PCM content relatively. Therefore development of noninflammable PCM granules, for example micro encapsulation of inorganic PCMs, is expected in the near future.
Figure 82 Conceptual diagrams of the developed system

Figure 83 A flowchart of the development
Air-conditioning systems in summer consume a huge electrical load during day time and less load during night time i.e. these loads are variable and creates a gap between demand and supply of electrical energy. Annual plant load factor drops due to the use of air-conditioning system. Thermal energy storage makes possible to utilize power during off peak periods. The off peak power utilization benefits both the parties i.e. power generating industries and consumers. In addition, energy storage technologies are able to contribute significantly to energy efficiency, reliability and global environment. The conventional chillers are operating between 7 – 9 °C, therefore, there is a need to develop such material which can store the coolness at above temperatures with its possible retrofit applications in the existing conventional network of chilling machine. The importance of energy storage in A/C Systems can be adjudged from the following advantages (i) Reduction in chiller size up to 35 to 40% (ii) Reduction in installed cooling capacity (iii) Less electric power demand and supply too (iv) Reduction in peak power demand (the benefit of this get transmitted to power generating company) (v) Better plant utilization with saving of prime plant room space (vi) It eases the transition to non refrigerants and (vii) Helps in conserving the energy.

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Takasaki City hall

Takasaki city is located approximately 100 km north of Tokyo. A new city hall had been completed in February 1998. The building was equipped with heating apparatuses using PCM, which was called Thermal Storage Counter (TSC). Figure 84 shows a structure of TSC and Table 3 shows specifications. One TSC unit had 396 capsules containing PCM whose melting temperature was 55 ºC. The capsules were heated up during night using discounted nighttime electric tariff. The stored heat was discharged during daytime by both convection and radiation. Since the climate of Takasaki city is chilly and colder than Tokyo, TSC was used to prevent cold draft or cold radiation from windows.

Figure 84 Structure of Thermal Storage Counter (TSC) with PCM balls
Table 4: The specification of TSC

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total input heat capacity</td>
<td>31,000 kJ/10h</td>
</tr>
<tr>
<td>Heat discharge capacity</td>
<td>581 W</td>
</tr>
<tr>
<td>Dimension</td>
<td>2,793 x 571 x 238</td>
</tr>
<tr>
<td>Electric heater</td>
<td>190 W ·2, 150 W ·4</td>
</tr>
<tr>
<td>PCM</td>
<td>Melting temp. 55 ºC 396 peaces</td>
</tr>
</tbody>
</table>

Prior to construction, thermal performance of TSC was tested in a test chamber. Figure 85 shows the temperature change versus time for charging and discharging. After temperature rise for few hours, temperature stayed around 55 ºC which was melting temperature of PCM. For discharging, due to natural convection

![Figure 85](image1.png)

Figure 85 Inside temperatures of capsules during storage (left) and discharge (right)

![Figure 86](image2.png)

Figure 86 The amount of heat released during heat discharge
Figure 86 shows the amount of heat released during discharge. The heating capacity was maintained at 2100 kJ/hour (583 W) for eight hours from the beginning of heat discharge. As shown in Figure 86, three-fourths of the heat was discharged by convection and remaining one-fourths was by radiation.

To evaluate improvement of indoor thermal environment by TSC, the surface temperature of window glass, which had effect on radiation, was measured as shown in Figure 87. Temperature difference of nearly 4 °C was observed between opened and closed outlet dumper of TSC. From 9 to 10 in the morning, temperature difference was smaller because insolation warmed window surface. Consequently, TSC could prevent cold draft and radiation, and improve indoor comfort in winter season.

![Figure 87 Comparison of surface temperature of window glazing (the east zone of building)](image)

**Literature**

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**i:xiii Narita airport**
Micro encapsulated PCM was used for thermal energy storage system in Narita international airport. The refrigerants in heating and cooling plant should be changed from CFC 11 to HCFC 123 due to abandon of HFC. The encapsulated PCM was adopted to compensate deterioration of cooling capacity by replacing refrigerants. Furthermore, TES system could level the cooling load and utilize electricity in nighttime. The encapsulated PCM was developed under the cooperation with New Tokyo International Airport Authority and Mitsubishi Heavy Industries, LTD with advice by Tokyo Electric Power Company.

Since the existing refrigeration machines continued to use, storage material that could be used in conventional cooling temperature range was needed. Material was chosen to be n-Paraffin waxes because they were non-toxic and controllable phase change temperature. The paraffin waxes were encapsulated in tiny sphere, whose diameter was around 2 micrometers, that formed slurry. PCM slurry had melting temperature of 8 °C and latent heat of 75.9kJ/kg from experiments as shown in Figure 88.
The storage tank was integrated into the existing system through a heat exchanger as shown in Figure 89. PCM slurry was pumped to the heat exchanger and cooled by chilled water of 3.5 °C from refrigeration machine during night time. The stored heat was discharged during daytime together with refrigeration machines.

The system had been in use for nearly 4 years. The effectiveness of PCM slurry storage system was illustrated in Figure 90. Since the phase change temperature was higher than ice storage system, the Coefficient of Performance (COP) was higher than ice storage. Therefore operation cost of system was 32 % lower than ice storage systems.
**Literature**


**Contact**

S. Shibutani, Mitsubishi Heavy Industries.

**Funding**

New Energy Development Organization (NEDO)

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**i:xiv Clathrate Hydrate Slurry**

A new material was developed by JFE Engineering Corp. The material was Tetra n-butyle ammonium salt, which composed hydrate at atmospheric pressure and had latent heat in 5 to 12 °C. It was soluble in water and slurry, shown in Figure 91, was formed by being cooled in flow. The slurry was fluid and could be pumped as heat transfer medium. Therefore, the material was expected to reduce pumping power consumption, which was relatively large in HVAC system. Figure 91 shows the configuration of system.
The performance of system was demonstrated in a real scale experimental facility, which had area of 1,700 m² for air conditioning. The HVAC equipments were ordinal types. The heat transfer coefficient was compared between the clathrate hydrate slurry (CHS) and water. Although flow rate of CHS was lower than that of water, heat transfer coefficient was not deteriorated. Furthermore, no clogging or choking in piping system was observed. Due to latent heat and good heat transfer performance, pumping power consumption was reduced to nearly half of ordinal chilled water system.

The additional experiments in an existing building were conducted. Practical problems were solved in these experiments. The system will be installed in a new building constructed in Tokyo in autumn 2004.

Literature

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Funding
New Energy Development Organization (NEDO), Eco-Ene Urban Project.
Floor heating at an Elementary school

One example of PCM floor heating is Shinanodai elementary school in suburb of Nagoya city. The school was designed as “eco-school” equipped with solar PV cells, biotope and PCM floor heating. As shown in Figure 92, class rooms and common space were paved with electrical heated PCM floor. Figure 93 shows that room temperature was maintained during school hours from a result of measurement. The estimated operation cost was nearly one-thirds of sensible heat storage.

Figure 92 The layout of floor heating in Shinanodai elementary school

Figure 93 Indoor thermal condition with floor heating
i:xvi Microencapsulated PCM in concrete

First experiences with microencapsulation of PCM were performed during the first part of the project. For the demonstration project part, BASF Micronal was used. Two cubicles were constructed and instrumented, one with 5% PCM in the concrete and the other without PCM. Comparison between both cubicles is underway, but preliminary results give a difference of 3°C in temperature. The concrete produced was tested for mechanical and thermal properties. The project included simulation of the behavior of this new concrete with TRNSYS. A new TRNSYS Type was developed for this simulation. Finally, the project will also provide an expert system to help architects and engineers to decide if this new concrete is suitable for their application.

Figure 94 Test cubicle for microencapsulated PCM in concrete

Literature:


L.F. Cabeza, M. Nogués, J. Roca, M. Ibáñez PCM research at the University of Lleida (Spain) IEA IA ECES Annex 17 6th Workshop Arvika 2004 06 07 - 10

Contact: Dr. Luisa F. Cabeza, University of Lleida (Spain), lcabeza@diei.udl.es

Partners: Aspica Constructora (coordinator-Spain), University of Lleida (Spain), Inasmet (Spain), BSA (Spain), Medysys (France), Prokel (Greece), Intron (The Netherlands)

Funding: about 650,000 euros from the EU

i:xvii PCM in stratified water tanks

The idea was to include a PCM module at the top of the water tank to increase its energy density and to improve its performance. Initial simulation showed that short modules were the best solution, so it was implemented in a full solar system. Various PCMs with melting temperatures around 55°C were tested (RT54, fatty acids, and sodium acetate). Since thermal conductivity is essential to get the right power, sodium acetate mixed with graphite was chosen. Experiments showed that the addition of only about 6% of volume of PCM increase
the density energy of the tank by about 40%, and that water was kept at usage temperature a
longer period of time. Simulations with TRNSYS are being developed at the end of this
project.

Figure 95 PCM in stratified water tanks

Literature:

L.F. Cabeza, M. Nogués, J. Roca, M. Ibáñez PCM research at the University of Lleida
(Spain) IEA IA ECES Annex 17 6th Workshop Arvika 2004 06 07 - 10

L.F. Cabeza, C. Solé, J. Roca, M. Nogués Efecto de la inclusión de materiales de cambio
de fase (pcms) en un depósito de ACS conectado a una instalación solar térmica XII Congreso
Ibérico y VII Congreso Iberoamericano de Energía Solar Vigo 2004 09

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Partners: University of Lleida

Funding: about 40.000 euros from the Spanish Government

i:xviii Thermal energy storage with phase change. Experimental procedure

The experimental setup used is a closed air circuit, with fans to move the air, a heating and
cooling device to set the air at the right temperature and a thermal energy storage. Several
PCMs have been tested during the presented work, but finally only two were selected. One
was a molecular alloy with 34% C16 and 66% C18, with a melting temperature of 19.5-
22.2°C, and the other one was RT25 from Rubitherm, with a melting temperature of 20-24°C.
The thermophysical properties of the materials were studied with different methods: adiabatic
calorimeter, energy balance, DSC, and T-history method.
Using the technique of design of experiments, three different responses where analyzed: ratio energy/volume, load/unload rate, and cost of the installation. Of the three responses two were fixed, ratio energy/volume and cost of the installation, and the load/unload rate was measured. The factors considered in the design of experiments were: PCM, thickness of the encapsulates, temperature of the air, and air flow. The experiments to be done were, following a DOE 23, 8 of the process of solidification and 8 of the process of melting.

From the results the following conclusions can be considered:

- The tendency of the curves was as expected: the process was faster when the thickness of the encapsulates was lower, the temperature difference between air and melting temperature of the PCM was higher, and the air flow was higher.

- The heat transfer curves showed two steps in the process: a first step with low conductivity resistance (and therefore the air convection being the dominating heat transfer phenomena), and a second step with a higher thermal resistance.

- Although the encapsulates with smaller thickness gave a faster melting and solidification process, it can be seen that thickness optimization is possible.

A statistical analysis was conducted to determine effects and significant interactions of the variables studied. Once the significant factors and interactions were known, an empirical model with multiple regression analysis was elaborated. Taking into consideration the effects and interactions with influence in the results, and the data of the experiments, an empirical model was developed.

With the results from the results, a real installation was designed. The storage device was designed with a capacity of 3 kW, with an inlet temperature during night of 16°C for 4 hours, and an inlet temperature during day of 30°C.

![Test rig for thermal storage with phase change](image)

Figure 96 Test rig for thermal storage with phase change

**Literature:**

Phase change material slurries and their commercial applications

The energy efficiency of many heating and cooling applications can be significantly improved by the replacement of the existing working fluids with phase change material slurries (PCMS). They require smaller storage capacity and reduce pumping costs. Slurries have similar general fluid properties and they offer the advantage of high latent heat storage capacity at a narrow temperature band corresponding to the phase change temperature. Selection of the correct phase change material and carrier fluid in conjunction with a selection of suitable systems will enable space and water heating, space cooling, systems cooling, industrial processes and refrigeration systems within buildings to be improved.

A review of existing phase change materials that are readily available has been undertaken. Suitable phase change materials (PCMs) have been selected for use in the slurries, which possess the correct phase change transition temperatures between 0 and 20°C for cooling slurries and about 30 to 50 °C for heating purposes. The issues with regard to micro encapsulation of the phase change material, and the formation of a suspension in suitable carrier fluids appropriate for pumping, or of a multi-phase material have been investigated which best fit the scope of applications envisaged by the end users. Materials that were considered include micro-encapsulated paraffins, as well as emulsions and clathrates. Studies to determine fluid flow, heat transfer and transport characteristics have been undertaken at a range of temperatures. Produced samples were characterized in laboratory based experiments. This will involve small-scale experimental apparatus and modeling on the microscopic level. Those that showed to be the most potential at the moment, the microencapsulated paraffins, have been investigated in large-scale macroscopic experiments. These PCMS have been evaluated for use in various energy systems including industrial process heat, solar thermal systems, cooling and refrigeration and energy storage. Heating systems and building/air conditioning system uses of PCMS were also evaluated through system modeling and experimentation using laboratory sized evaluation of components and full systems.

One major success of the mentioned European project was the improvement of the capsule shear stability during the research. The latest pumping test is still running since July 2004. Due to the low fluid volume in the test-facility that allows approximately 30 cycles every day, this period is equivalent to years of conveying in real application. The good stability of the capsules, which has now been achieved, is the result of a diameter which is in the range of 1 to 10 µm associated with a thicker shell.

Compared with water the heat capacity of the tested slurries is up to 4 times higher within the range of melting. The pressure drops of the test system were 30% higher for slurry with a capsule fraction of about 30% and 10% higher for a 20% capsule fraction, respectively. The temperature of the slurry has a much greater influence onto the pressure drop than the carrier fluid alone.
The sub-cooling phenomenon is the major drawback that has to be solved, especially for tetradecane and hexadecane slurries. To solve this problem would be a great step forward to go into market with the micro capsule slurries.

Simulations show the potential in saving energy for pumping the heat transfer fluid. A well dimensioned application could save up to 50% of electricity that is necessary for conveying the same amount of heat of a water system.

![Image of the slurry](Figure 97 The slurry)


**Duration** 12/2001 – 11/2004

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**Partners:** University of Ulster, BASF, Fraunhofer ISE, Graz University of Technology, University of Applied Sciences of Yverdon, Bulgarian Acad. Sciences, Thyforop Chemie, Cristopia

**Funding:** approx. 3.500.000 Euro, duration 3 years, funded by European Commission, grant number ENK6-CT-2001-00507

**i:xx Water cooled PCM-Wall Systems**

Free cooling applications with integrated PCMs suffer from two drawbacks: the wall to heat transfer coefficient limits the useable storage capacity in a 24h cycle and the only available cold source is the night air at dry bulb temperature. In certain climates and applications these two restrictions limit the market for PCM products. If it is possible to integrate water pipings (e.g. capillary tubes) in the PCM-products, the heat transfer to the storage can be increased and the pipings can be connected to any cold source, thus making the system independent from outside temperatures.

The step from passive cooled PCM walls to active cooled PCM-wall systems will increase the possible market for PCM products and offers more system possibilities.
i:xxi Microencapsulated PCMs integrated into construction materials

Light weight buildings often suffer from overheating in summer due to the lack of thermal mass as storage for the cold from the night. This may lead to huge energy consumptions for cooling in daytime or decrease thermal comfort. One solution to this problem is to increase the thermal mass to make use of the cold night air to cool down the building for the day. PCMs are a possibility to increase the thermal mass in a certain temperature range with a very small volume and with low weight. There have been lots of research projects in past trying to integrate PCMs in building materials using macrocapsules or direct immersion processes. None of these products had a great success on the market so far due to various reasons. Direct immersion processes have the problem of possible leakage of the PCM in the liquid phase, macrocapsules often expensive to integrate in the building and may be damaged while the building is in use. Another disadvantage of macroencapsulated PCMs is the poor heat conductivity of most of the PCMs which leads to problems while discharging the storage at night. Therefore the basic idea of these projects was to develop microencapsulated PCMs which are easy to integrate in building materials and may offer a good heat transfer from the construction material to the PCM thus enhancing the discharging process during the night. The project started with material screening and the numerical modeling of PCM walls in a building simulation program to identify the needed material parameters and useful applications. The next step was testing the encapsulated materials and then first wall test samples with integrated PCMs in a test apparatus. When these samples performed satisfying, real size testrooms have been equipped with PCM-products and have been monitored to quantify the effect of the PCM to energy consumption and comfort of a building. In a last step, demonstration projects have been done. As a result of this project, microencapsulated Paraffins are available from BASF as base product, several building products with integrated PCMs are on the market and first buildings are being set up.

Literature: P. Schossig, T. Haussmann, H.-M. Henning: Actively driven construction materials with latent heat storage, second Phase change material and slurry conference, Yverdon 2005


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Partners: Fraunhofer ISE, BASF, Maxit, Caparol

Funding: approx. 2.500.000 Euro, duration 3 years, funded by German Ministry of Economics and Labor BMWA, grant number 0327370 F-J
ii Temperature Control

ii:i Thermal Protection of Crystals using Molecular Alloys

The purpose of this project was the design, construction and test of a prototype using molecular alloys as phase change materials. These materials will act as a thermal protection from the environment. The protein crystals obtained in space laboratory need to be distributed to the characterization installations in several countries. The protein crystals will remain under a fixed range of temperature during a certain time depending on the alloy used and its quantity. We will use molecular alloys with a high latent heat of melting in a double wall of the transportation box. The melted alloy will store all the supply of frigories from the environment during its crystallization. During this process, the temperature inside of the box remains practically constant. The crystallization can be cyclic if we melt the alloy again. We will formulate and characterize the alloy to be used, and search materials of low cost. We will also design and construct the prototype, and determine its mechanical behavior. Finally, we will test the prototype in real conditions of use.
Temperature-controlled packagings for the transportation of sensitive products

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Partners

Universitat de Barcelona; Université Bordeaux; Utrecht University; Laboratorio de Estudios Cristalográficos de Granada

Thermal protection in Catering using Molecular Alloys

We propose the design, construction and test of a prototype using molecular alloys as phase change materials. These materials will act as a thermal protection from the environment. Foods will remain under a fixed range of temperature during a certain time depending on the alloy used and its quantity. We will use molecular alloys with a high latent heat of melting in a double wall of the transportation box. The melted alloy will store all the supply of frigories from the environment during its crystallization. During this process, the temperature inside of the box remains practically constant. The crystallization can be cyclic if we melt the alloy again. This project represents a continuity of the study of molecular alloy as phase change materials. Several applications has been already developed and commercialized. The consortium of the project is formed by a University laboratory, a technological center and two industries from the catering sector. Together, we will formulate and characterize the alloy to be used, and search materials of low cost. We will also design and construct the prototype, and determine its mechanical behavior. Finally, we will test the prototype in real conditions of use.

Literature:


Contact:

Dr. Miquel Àngel Cuevas-Diarte, University of Barcelona, c/ Martí i Franqués s/n; 08028 Barcelona, Spain, e-mail: mangel@geo.ub.es

Partners
Molecular Alloy Phase Change Material for Protection of Temperature Sensitive Biomedical Products

Sensitive biomedical products (blood derivative, organs and biological tissues, vaccines, ...) need to be maintained within a precise range of temperature during their transport or storage. Molecular Alloy Phase Change Materials (MAPCM) based on n-alkane alloys (CNRS patent and Trademark ALCAL) have been elaborated for blood derivatives protection at different temperature levels: –30°C, +4°C and +22°C. The study of solid state miscibility in the n-alkane family and the study of the thermodynamic properties of the binary, ternary and multi-component systems allow us to propose various formulations for one precise application. Special boxes assigned to receive blood bags protected with surrounding pouches containing ALCAL have been designed. Prototypes will be constructed. Diverse tests simulating real conditions of use will be achieved with the prototypes. Thermal modeling of the evolution of the temperature within special conditions will be done in order to improve the design of the prototypes. Other applications in this paramedical field and corresponding to other range of temperature could be undertaken in the same way.

Literature:


Contact

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Partners

Université Bordeaux; ISOS-Laprie Eysines; Universitat de Barcelona; Utrecht University.

Natural and Waste Energy Utilization

High Temperature Waste Heat recovery

Copper is suggested as a phase change material for storage of high temperature waste energy. The copper is encapsulated by a film of nickel (pure or an alloy with ruthenium and/or carbon). The melting temperature of copper is around 1100 °C. Therefore copper is suitable for storage of waste heat from for instance the steel industry where energy is intermittently emitted at a temperature above 1600 °C from the LD converter. Because of the intermittent nature of the emission this energy is rarely used. The stored energy is suggested to be used for production of hydrogen and carbonmonoxide, further processed to methanol.
iii:ii MgO/Water Chemical Heat Pump

The possibility of chemical energy storage systems that used reversible metal oxide reactions were reviewed to promote utilization of thermal energy at temperatures more than 200 °C from experimental discussions. A chemical heat pump that used a reversible magnesium oxide/water (MgO/H₂O) reaction system was discussed mainly. The development steps of MgO/H₂O heat pump were reviewed firstly. Magnesium hydroxide prepared from ultra fine particle magnesium oxide and purified water showed enough reactivity, and also high durability to repetitive reaction cycle.

The chemical heat pump has been examined experimentally using a bench-scale heat pump packed with 7.0 kg and having 500 W class output. A basket type reactor was used in the heat pump. A developed reactant of Mg(OH)₂ was packed in the reactor as a precursor. Thermal energy storage density over 700 kJ/kg was measured from the experiment.

Because a reactant for the heat pump use was required to fit multi-production process, a molding method for reactant preparation was discussed for the heat pump development. Some molding samples under different preparation conditions were evaluated kinetically by a thermo-balance analysis. A candidate in the molding samples was examined experimentally using packed bed reactors in an experimental heat pump apparatus.

From experimental results, the heat pump was expected to be applicable in decentralized cogeneration systems using gas and diesel engines, fuel cells and micro gas turbines, by chemically storing the exhaust heat from those engines, also for peak shaving of electricity supply. The chemical heat pump would have a possibility to develop new heat utilization market.

Literature


Contact

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email: yukitaka@nr.titech.ac.jp
iii:iii Environmentally Sound Cooling through Absorption Chillers with Integrated PCM Storage

With a worldwide increasing cooling demand, conventional electrically driven chillers put high demand on available electrical power during peak hours. Heat driven absorption cooling technology can potentially replace such electrically driven chillers and thereby decrease peak hour electricity demand. The economic feasibility of absorption cooling systems can be improved if cool thermal storage (CTS) is used for peak shaving the cooling demand.

In the project, various systems have been compared with regards to energy efficiency and economics for satisfying a particular cooling demand (1 MW peak cooling demand). These systems are: 1) absorption cooling only; 2) absorption cooling and CTS; 3) a combination of absorption cooling and conventional cooling; and 4) a combination of absorption and conventional cooling, along with a CTS (see Figure 99).

Results show that for the two systems employing CTS, the chillers operated at design load a larger part of the time thereby enhancing the energy efficiency (Figure 100). Also, the storage systems were found to give lower capital and operating cost. However, employing some conventional electrically driven cooling in the system (alternatives 3 and 4) is the most cost effective (Figure 101).
Figure 101 Annual operating cost versus electricity price

**Literature**


**Contact**
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e-mail: vmartin@kth.se

**Partners**
Fredrik Setterwall Konsult AB, Berglunds Rostfria AB, Climator AB

**Funding**
Swedish District Heating Association, the Swedish Energy Agency, Fredrik Setterwall Konsult AB, Berglunds Rostfria AB, Climator AB.

**iii:iv PCM Applications in Industry**

**Classification:**
Waste Heat Utilization, Case Study

**Country:**
Germany

**Description:**
Diploma Thesis at the ZAE Bayern, Section 1 Garching; Titel “Investigation of possibilities to use latent heat stores in industrial applications” done by Jörg Müller-Ali

The goal of the thesis was to investigate different fields in industry for their potential to use latent heat stores. Main points of the investigation were applications with varying heat demand and batch processes which make heat storage necessary.
Time table:
Start: June 2001
End: September 2001

Finance:
No costs

Results:

1. PCM at the market
Currently the following companies produce PCM and sell them:
   - Merck
   - Rubitherm
   - TEAP
   - Climator
   - Mitsubishi Chemicals
   - Christopia
The temperature range of melting points is -33°C to 120°C, covered by salt solutions, salt hydrates, paraffins and sugar alcohols. Ice and cold storage below 0°C is already state of the art and therefore not considered any further in this investigation.

2. Current and past R&D
Current and past R&D has focused on applications for heating (30°C to 60°C) and cooling (20°C to 25°C) of buildings and on storages for solar power plant (300°C to 500°C).

3. Existing PCM applications in the industry
Two applications have been found in the industry:
   - Ice storages and other cold storages based on salt solutions are state of the art and therefore not discussed here any further.
   - The development of a paint drying system in Japan in the 1990s has been reported. Two LHS with melting points of 48°C and 117°C are heated in daytime. At night the heat stored is used to produce hot air for drying paint. There is no saving in energy, but security personal that is necessary to observe an optional gas burner to produce hot air during night is not necessary using the LHS. Therefore the application becomes economic by saving cost on labour. A payback time of 3 years was reported.

4. General criteria for the search for new applications
Two general criteria have been used in the search for new applications:
- The cycling time of the storage should be less than 1 week to have a chance for becoming economic.

- The temperature range from 0°C to 100°C should be avoided for the strong competition with hot water heat storages unless the main advantages of LHS, that is high storage density at small temperature differences and its temperature stabilizing effect do not become an important issue.

5. **Statistic data**

Energy balance of processing industry in 1998 (Bavarian ministry of economics, traffic and technology 2000)

<table>
<thead>
<tr>
<th>Energy balance, Bavaria 1998</th>
<th>Energy total [terrajoule]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing of stone and earth</td>
<td>36728</td>
</tr>
<tr>
<td>Chemical industry</td>
<td>31434</td>
</tr>
<tr>
<td>Paper-, publishing-, printing industry,</td>
<td>31427</td>
</tr>
<tr>
<td>Food and tobacco industry</td>
<td>30003</td>
</tr>
<tr>
<td>Metal production and processing</td>
<td>20060</td>
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<tr>
<td>Car production</td>
<td>19371</td>
</tr>
<tr>
<td>Glass and ceramics</td>
<td>19302</td>
</tr>
<tr>
<td>others</td>
<td>14443</td>
</tr>
<tr>
<td>Machine production</td>
<td>13100</td>
</tr>
<tr>
<td>Production of rubber and plastics</td>
<td>10981</td>
</tr>
<tr>
<td>Production of machines for electricity production, distribution, etc</td>
<td>7344</td>
</tr>
<tr>
<td>Textile and clothes industry</td>
<td>7406</td>
</tr>
<tr>
<td>Production of metal based products</td>
<td>5729</td>
</tr>
</tbody>
</table>

If energy use relative to production value is accounted for, data from the Bavarian Ministry of Economics, Traffic and Technology from 1998 show the following order:

- Paper industry
- Glass, ceramics and stone
- Metal production and processing
- Chemical industry
Data for the suitability of processes with regard to changing heat demand and waste heat were only found in a NATO report from 1977. With respect to these criteria, the most interesting industry fields are

- Metal production and processing
- Glass and ceramics
- Paper and printing
- Textiles and clothes production of rubber and plastics
- Food industry

For the following reasons three fields were investigated in more detail as examples.

Metal production and metal working:

- Top field in most studies, high temperature heat in large amounts

Food industry

- Top in most studies, often discontinuous processes eg. milk processing

Textiles and clothes

- Not top with regard to energy use, but many products with many production steps and different processes. Often steam is used in processes

For these three fields, companies were contacted to get more detailed information and this information was summarized and evaluated. The result is:

6. Metal production and metal working

Heat storage is already used for a long time as sensible heat storage with ceramics to preheat air for batch processes. These processes make 10 to 20 cycles a day with storage temperatures up to 1500°C. This is state of the art.

There is also waste heat from fumes that have to be cooled for technical or legal reasons, for example fumes from melting ovens have to be cooled down from 960°C to 200°C to prevent forming of dioxins or furans. These ovens run continuous. The heat is currently discarded!

Generally, for application of PCM there are two problems in this field

- there is lots of waste heat but few demand
- the powers for heating and cooling are usually high
Positive is, that salt baths are often used for heat treatment and some of these salts are potential PCM; they have reasonable enthalpies, suitable melting points and low price because they are produced in large quantities.

7. Food industry

Constant temperatures are important for any fermentation process (joghurt, cheese, beer...). In contrast to pharmaceutical processes, where sometimes a temperature stability within 0.1°C is required, here 1 to 2°C are often sufficient.

Application of PCM seems technically feasible, but is not economic considering only energy savings. Electric equipment for process control is standard. Safety considerations for electrical power failure might be a reason for applying PCM. Generally, there is little interest in trying out new technologies in this field if the technology touches sensitive and important parts of process technology.

However, many heating and cooking processes require temperatures in the 100°C range or above. If heat from cogeneration is used for this processes, LHS might be a good option to replace hot water heat storages.

8. Textiles and clothes

Production and processing for quality improvement needs large amounts of heat, often in the 80°C to 190°C range. This heat is in most cases supplied using steam. The demand is zero at night and has peaks during the day with a duration of less than 1 h. Compared to producing the steam electrically, PCM storage of waste heat still needs a much larger volume than the evaporated water, 10 L PCM are needed to evaporate 1 L of water, however if water is used as storage medium (Ruths storage) PCM is advantageous. At the moment, the industry is constantly improving existing electrical heaters and heat recovery systems.

9. Conclusion

Most people contacted within the survey know at least the physical effect of LHS, and many know the application in ic storages. Almost nobody knows the current state of the technology. Some people know the technology, but only remember the problems of the past and therefore think of PCM as an exotic and not useful technology.

Many people were interested hearing that the problem of low power density has been solved by the combination of PCM and graphite and that this will become a product soon. In many cases, this led to a new evaluation of PCM-technology.

To convince people, what are still missing are industrial pilot and demonstration projects! They would make F&E results much more convincing.

The most important argument for industrial applications is of course economics. With respect to return of investment times, at the current stage with very few installations there is no data basis for arguing. The financial advantages of a PCM storage need to be obvious. In some cases, PCM can contribute to improvement of quality. In contrast to energy savings, this currently seems to be the more promising argument.

iv Other Activities in the Field of Phase Change Materials and Chemical Reactions for Thermal Energy Storage
iv:i Optimal Design of PCM Suit Based on Human Thermal Response Experiment

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PCM (phase change material) can keep invariable temperature range, absorbing, storing and releasing large quantity of latent heat while changing its phase state (for example from solid state to liquid state or from liquid state to solid state). Therefore it is used in the clothing to approach the heat regulation function. The PCM with transformation temperature close to human skin temperature is chosen.

There are mainly two methods to use PCM in the clothing: using MPCM (Microcapsule Phase change material) fabrics or using PCM bags. The MPCM is the PCM sealed in microcapsules which has a diameter of several microns. Compared with using MPCM fabrics, directly using PCM bags in the clothes is a simple and economical method. This suit is sometimes designed as bullet-proof vest, on which arranges many small pockets to put in PCM bags. Alternatively, the PCM is directly sealed on the suit like a life jacket.

In 2003, SARS (Severe acute respiratory syndrome) prevailed widely in the Asia. When the staffs of hospital entered the isolation sickroom, they should wear exposure suits. This kind of suits are high thermoresistance (>2.0clo) and low moisture-penetrability, preventing heat and moisture from extracting. In this situation, the body temperature will continuously keep rising. Once the body temperature rise to 40.0°C, human would catch heat-stroke and be exhausted. In order to protect the staffs’ health and keep worked efficiency, a heat-sink method inside exposure suit is in need. Thus, using the suit with PCM bags as a cold source was presented (shown in Fig.1). The PCM bags can absorb human body heat during working hours. And after melted it could be recycled by putting it into refrigerator or cool water and curdled again.

Thus this article mainly considers the following principle while optimizing the suit designs:
1. Thermal flux on the skin. The thermal flux is supposed to maintain the appropriate value between human body surface and PCM bag surface. If the value keeps too high, the skin is in excessively cold exposition. And a series of negative physiological reactions will be caused such as vasoconstriction, tissue soreness and so on. In contrast if the value is too low, heat absorption is not enough to counteract heat produced by human body, the cooling effect is not obvious. Therefore the designer needs to choose appropriate transformation temperature of PCM, controlling heat flux of the skin. At the same time the highest temperature parts of human body are head, neck and chest and back, these parts have larger thermal flux and are supposed to place more amount of PCM.

2. Local thermal sensation weight of different parts. The research pointed out that local thermal sensation of head, neck, chest, back has large weight and control whole-body thermal sensation. Cooling these regions may obtain ideal cooling effect.

3. Comfortable and health. In traditional Chinese medicine research, calvarias, stomach and kidney and other organs cannot keep low temperature for a long time, though heat production of these parts is large. Otherwise the cold factors will cause visceral symptoms and damage human health. As a result, the PCM should be keep away from these places in the design.

4. Agile Movement. The distribution of PCM bags should keep away from joints and waist, in consideration of normal activity and operation of the users.

In the experiments presented, every 10 minutes during the experiment, the subject was asked about TSV (thermal sensation vote), and TCV (thermal comfort vote), hottest and most uncomfortable regions of the body. At the end of the experiment, the subject was asked to list the positions he or she like or dislike placing PCM. The melting rate of each bag also was recorded. TSV and TCV scales are shown in Table.4.

Table 4

Table 5 ASHRAE thermal sensation scale (7 points) and thermal comfort scale (4 points)
First TSV and TCV values of Group A (not wearing PCM suit) were compared with Group B (wearing uniform distribution vest). When subject didn’t wear PCM suit, the heat and moisture produced by human body was accumulating inside the exposure suit. The hot sensation and discomfort increased gradually, approaching the predictions arising from PMV (total thermal resistance is about 2clo, metabolism rate 2met, air temperature 30°C, RH 50%). The subject in Group B felt cooler and more comfortable while wearing PCM suit. Furthermore T-test demonstrated that there was significant difference between the two groups (p<0.01), both in TSV and TCV values. The experimental results were shown in Fig.4. It justified that PCM suit is an effective strategy to sustain comfortable environment in the exposure suit.

iv:ii Cooling of newborns with PCMs

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Most hospital workers know that neonatal children get fever cramps or even sometimes die due to fever. Also, young children are getting brain injuries due to hypoxia.

Young children can be treated in many ways, for example with cold towels, medicine, chilled rooms e.g. to keep the temperature down in hospitals. Hypoxia has been treated in different ways due to the knowledge of doctor, to minimize brain damage.

In most hospitals in the industrial world treatment to chill children are done by one or more of the following options: the towel method, the air conditioning method, cooling the whole body
or only the head by water mattress, or no cooling/heating as the rest of the children (with no problem).

Between hospitals in the third world, the options used are: the towel method, by ice/coolpacs, or without any cooling.

When the whole body is cooled with a water-mattress, the exact temperature control of the patient and the water moving around can be achieved at all times. There have been companies that have supported trials, and they are continuing to develop equipment for this. In England a multi-centre study called TOBY is done.

In both the TOBY clinical trials and our clinical trial the set up shown in Figure 104 has and will be used.

![Figure 104 Set-up used in the clinical trials.](image)

The authors intend to measure the following parameters: temperature from 3 points, rectal, lung, and scull, and also will have a few extra check points, like environment heat, air humidity, and our equipments temperature.

Other parameters considered in the protocol of the study: stress we will use the NIDCAP protocol, to control that we don’t stress the children more than absolutely necessary; NIRS, a way to measure different part of the brain function; environment stress; and, all other treatment and medicine each patient are prescribed by doctors, and other staff.

In June 2004, the authors had already started to collect the equipments needed, had also applied for ethical control and ok from the Swedish government, had started to make the
different head caps and mattresses but we need to find the right PCM-solutions and fill the above. The first patient was done that summer.

In June 2005, the authors reported that more work has been performed since then:

- A preliminary set up has been developed - ”Water bottle test”: The set up was done to mimic a newborn child. In the first setups they used a container that was heated with a coil. They then placed PCM on the outside and checked that the temperature cooling was efficient and stable. In further setups they modified both PCM and set up until they found a set up that mimics a newborn child.

- A animal test have been done to verify that the results found in ” test” could be applied to treatment of hypoxia-ischaemia. The aim of the study was to verify that PCM could be used instead of traditional cooling methods, treat a transient moderate hypoxia-ischaemia piglet, verify that whole body cooling gave the correct cooling of the brain, verify that the calculated and tested ”water bottle model” was correct, and test that the PCM wasn’t effected when in contact with the skin or by magnetic resolution imaging MRI

![Figure 105 Piglet cooling](image)

Future aims and proposed studies of the authors are a mimic of clinical situation. In this set-up we aim to assess the efficacy of cooling to 33-34ºC, the duration of cooling, and the stability of cooling with a PCM set temperature of 28ºC. In addition they aim to assesse whether more than one PCM set temperature is required to maintain a stable rectal temperature of 33-34ºC for 72 hours.

iv:iii Will PCM help Athletes in the Olympic Games in Athens 2004?

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Heat can be a problem for professional athletes both in training and at competition. Heat can also be a problem for other people like elderly, people with some diseases and children. If the body-temperature can be reduced most people would feel more comfortable, perform better, be able to keep concentration better and for a longer time and the risks with dehydration and fatigue is reduced.
The Swedish Olympic Committee wanted to cool the forehead, neck, wrists and the vital parts of the body (upper body). We developed vests together with TST AB in Kinna, Sweden.

The wristcooler: At the wrists the blood is flowing near the skin, so it is a good place to have equipment that can cool the body.

The neck-cooler: The purpose for the neck-cooler is to protect, and keep the neck cool.

The Vest: To keep the upper body, and the spine cool, is important.

The Cap: It is really important to keep the head cool.

More and more people are discovering the good things with the COOLING VEST. People with MS-disease has tried the COOLING VEST and they feel an improvement when it is warm outside. The tests show that athletes can feel more comfortable with the COOLING VEST. If it will improve the athletes performance in the Olympic Games in Athens, will be shown in August!
The study of PCM thermal management solution for portable computer

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High powered laptop computers present great thermal challenges since the power dissipated within the sealed confines of the main housing has to be transferred to the environment as soon as possible without increase the weight and size of the portable computer. In most current laptop computers, the heat generated by the CPU and other components is over 25W and even 30W.

The laptop is cooled with both passive and active thermal management solution. Although active solutions can dissipate more power than passive, the active solution requires a fan and thus result in a noise problem. A survey has been done by the authors. In the survey with 20 participants who work with laptop computers, the result shows that 90% of the people are affected by the noise whereas 10% say that it doesn’t bother them. From a view point of end user discomfort, creating a quiet environment for the people who work with the laptop is relevant.

Designing a new thermal management solution to replace the fan’s function is one method to eliminate the noise from the fan. Here, the challenge is to provide the solution without
increasing the size and weight of a portable computer. Currently, the weight of portable computers is under 3.5 kg and it will become lighter as technology improves. The fan cooling solution is a reliable strategy, in other words, the fan system cannot be replaced in current cooling solutions.

One of the possible alternative methods is to add a PCM pad under the computer chassis. When the temperature of the computer chassis rises to the melting point of the PCM, the temperature of the computer will be kept close to this temperature. To prevent the fan from turning on, the PCM must be selected such that its phase change temperature is below the set point temperature of the fan. Then, an external supplemental cooling system is provided.

The purpose of the present investigation has been to examine the fan’s running characteristics, for example if it is controlled mainly by temperature. Next, a suitable PCM pad was chosen among several candidates, and its ability to eliminate the fan’s noise has been investigated. The ultimate goal is to eliminate the noise from the internal cooling fan for as long as possible so that the people who are working with the computer will have a quiet working environment. However, the PCM pad is only able to replace the fan’s cooling for a certain time. When the PCM pad is melted and the temperature of the portable computer reach the fan’s running temperature the fan cooling system will work normally again.

Conclusions

- In an environment with the temperature 21°C ±1°C, Climsel C24 is the best choice for laptop computer cooling through an external PCM pad. When the temperature of the environment is higher, say over 24°C but below than 28°C, the Climsel C28 will be a good solution.

- According to one investigation, the noise by the fan of laptop computers is the drawback of active cooling for it is loud enough to affect the people who work with the computer. For an existing computer using an external PCM pad for cooling will eliminate the noise from the fan for a certain time, and hence is a good solution.

- In laptop computers, passive cooling solutions work as soon as the portable start whereas the active solution is controlled mainly by temperature and partly by special operations such as when the portable is started or restarted, when the CD is inserted etc.

- The price of the PCM pad is 15USD including shipping. It is not very expensive and would probably be accepted by the end user.

- One deviating result was observed. Out of a total of 20 tests, two where the PCM C28 and PCM C32 are tested it was found that the fan’s running was not dependant on temperature totally. Instead, it came on in an irregular way. In those two cases, the PCM pad was no help for reducing the noise from the fan.

- A powerful, without noise and no weight gain’s thermal management solution for portable computer should be developed. In other words, this is an important task for the people who work in the cooling field of the portable computer.

iv:v Solar cooker
Concentrator and box type solar cookers are commonly used for the cooking of food in the noon. Among these, box type solar cookers are more popular due to their simplicity of handling and operation. The detailed design, test procedures, theory and utility of box type solar cookers are well developed. The use of a box type solar cooker is limited because cooking of food is not possible due to frequent clouds in the day and in the evening. A solar cooker with storage unit has to be designed & developed.

A PCM storage unit for a solar cooker was designed and developed to store energy during sunshine hours. The stored energy was utilised to cook the food in the late evening. In the literature, it is recommended that for evening cooking, the melting temperature of a PCM should be between 110 – 120 °C. Commercial grade acetanilide (Melting Point 118.9 °C, Latent Heat of Fusion 222 kJ/kg) was identified and used as a latent heat storage material. The storage unit has two hollow concentric aluminum cylinders and the space between the cylinders first was filled with 2.25 kg acetanilide to store the solar energy for the evening cooking. With single existing reflector and this storage capacity, the evening food was cooked, if loaded on or before 5.00 p.m. To cook the food in the late evening, additional 1.75 kg PCM was filled in the PCM storage unit. It was not possible to melt this quantity (4.0 kg) of PCM with a single reflector. Therefore, two more reflectors were fitted into the solar cooker and these reflectors were used to enhance the incident solar radiation on the glass cover. Late evening cooking experiments were conducted with different loads and loading time during the winter season and the experimental results has been presented.

Figure 108 Schematic diagram of solar cooker based on evacuated tube solar collector

Literature:
iv:vi Investigation of the Potential to use Latent Heat Stores in SOFC-fuel cell Systems

Classification:

Waste Heat Utilization, Case Study

Country:

Germany

Description:

Diploma Thesis at the ZAE Bayern, Section 1 Garching; Titel “Investigation of the Potential to use Latent heat stores in SOFC-fuel cell systems ”

Within the diploma thesis different SOFCs systems are investigated with respect to the use of latent heat stores using simulation programs:

Basically, two main fields of application exist:

- thermal management in the SOFC system upon load change, start and shut down

- waste heat utilization (currently Sulzer Hexis plans to go on the market wit a 3kW SOFC system for heating of buildings and supplying electricity to the grid; a hot water heat store is integrated in that system)

Within the experimental part of the thesis, a lab model of a latent heat store for such a system will be build. Knowledge on latent heat stores with high melting temperatures from earlier projects on latent heat stores for solar power plants will be used.

Time table:

Start: August 2001

End: August 2002

Finance:

No costs

Results
The elevated operating temperature of SOFC fuel cells offers possibilities to use waste heat. The difficult thermal management of such systems seems to offer good perspectives to integrate a PCM-storage. The search for possibilities to apply PCM in SOFC-systems using simulation models and estimations was directed towards three different areas:

- use of waste heat for external processes
- thermal management within the SOFC system
- improvement of system performance on stand still

The use of waste heat for external processes was not investigated in detail as this application is already known and solutions are independent of the actual source of the waste heat.

Investigations of the thermal management within the SOFC system were based on the predominant advantages of PCM, which are their high heat storage density and their capability to stabilize temperatures. Surprisingly, the investigation showed no significant potential to apply PCM for this purpose. Applications to stabilize the operating temperature of the stack reduce necessary cooling power and weight, but also reduce flexibility in operating the system. The balance of internal heat recovery at load changes can be retained by the thermal mass of system components and therefore no LHS is necessary for that purpose.

With regard to the improvement of system performance on stand still, it is important that during stand still the temperature does not decrease below the minimum operating temperature. The time for cool down by heat loss can here be significantly extended using PCM. In the diploma thesis a new strategy for this purpose has been developed, the integration of the PCM-storage into the insulation. Because the standard operating temperature is much higher than the minimum operating temperature, this strategy leads to longer cool down times than if the PCM is integrated into the inner compartment of the system. Furtheron, heating up the system is also faster.

iv:vii ACME Tele Power (P) Ltd. Synchronized Power

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E-mail: anil@acme.in / anilchutani@yahoo.co.in

The authors reported that they are commercializing a telecom shelter which includes PCM as thermal back-up up to 35ºC. The features for this passive cooling are:

- Quiet: This system is non mechanical in nature and thus has a added bonus of being quiet (both acoustically and electrically).
- Safe: This system is totally safe and can be used in any indoor and outdoor environment.
Cost Saving: The Heat Absorbent Thermal Management system will save the operational cost due to its design. Its use results in lower running requirements of Air-conditioner units, Fan trays or coolers, saving the electricity consumption and cost.

In case of mains failure, the system maintains the temperature within operating limits for longer time and thus reducing or totally avoiding the DG running requirement which results high savings in the site operational costs.

The author reported that they have already installed over 2000 shelters with PCM, each one having over 300 kg of PCM.

Figure 109 Telecom shelter with PCM
### III Physical properties of Commercially Available Phase Change Materials

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<th>type</th>
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<th>H kJ/kg</th>
<th>°C</th>
<th>H kg/l</th>
<th>densit oC kg/l</th>
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