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A compact guide to energy research

BINE Informationsdienst

Latent heat storage in buildings

Storing heat and cold in a compact and demand-oriented manner

A service from FIZ Karlsruhe

Straight to the point

Can heat – or cold – be stored directly in walls and ceilings? Can heat be stored at precisely the temperature level at which it is to be used later on? And can the heat storage effect be used in a controlled manner as regards time and intensity?
The answer is a clear "yes" – using materials that store heat "latently", using a process that occurs at a defined temperature level and delivers high "concentrations". The term "phase change materials" – or "PCMs" for short – refers to the large number of materials for various temperature ranges that can be used in buildings to achieve heat management that is tailored to meet the specific requirements.

The topic of latent heat storage is in itself nothing new. Water at 0 °C is a standard latent heat storage medium that has been in use for many years in refrigeration technology. As an alternative to traditional hot water storage, latent heat storage devices were introduced into heating technology many years ago in order to significantly increase heat storage capacities. However, the idea of integrating phase change materials into the surfaces of walls and ceilings is new. Heat management and the desired stabilisation of room temperatures operate in a largely passive manner if night ventilation removes heat during the night. PCMs can also be integrated very easily into thermo-active building systems. This results in active systems that can be used to control heat management as desired. Because of the low temperature differences between heating and cooling, low-exergy systems can be implemented that stand out for their particularly efficient use of energy resources.

Low-exergy systems and technologies are subject of LowEx, a focal point of the German Federal Ministry of Economics and Technology's EnOB research initiative. As part of this work, systems for buildings, building services technology and energy supply are being developed that work with lowest possible temperature differences for heat generation and refrigeration and for the distribution of heating and cooling in rooms. Renewable energy sources can also be used in this manner, e.g. the natural low temperatures of the ground, or of ground water, can be used for cooling, and solar thermal energy for heating. Latent heat storage media or phase change materials are a key component in LowEx systems.

This Themeninfo will present the current state of the art in PCM technology, alongside current PCM products and their possible applications. Initial pilot projects are also scientifically investigated.

Your BINE editorial team
redaktion@bine.info

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FIZ Karlsruhe GmbH
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Authors
Dr. Harald Mehling, ZAE Bayern
Dr. Peter Schossig, Fraunhofer ISE
Doreen Kalz, Fraunhofer ISE

Technical consultation
Prof. Dr. Dirk Müller, RWTH Aachen

Editor
Uwe Friedrich

Cover image
GLASSX, Gaston Wicky

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BINE
Informationsdienst

FIZ Karlsruhe, Büro Bonn
Kaiserstrasse 185-197
53113 Bonn, Germany
Tel. +49 228 92379-0
Fax +49 228 92379-29
bine@fiz-karlsruhe.de
www.bine.info

Fig. 1 *PCMs are used to avoid peak temperatures indoors and thus to save on cooling energy. Conventional night ventilation involves the replacement of warm air in the building with cold night-time air. Source: GLASSX, Gaston Wicky*

Storing heat using phase changes

Heat storage is often necessary in order to use energy efficiently. Materials that store latent heat can deliver tailored solutions for many application areas.
Optimal processing of the phase change materials in order to provide for effective heat exchange is a critical factor in this type of application.
Particularly flexible are the micro-encapsulated PCMs that can be integrated into many building materials and building systems.

Heat storage plays an important role in all cases where the supply of and demand for heating/cooling have to be matched in terms of times and amounts; heat storage is also important when security of supply and stand-alone (off-grid) supply must be ensured. Many “heat sources” such as solar energy or waste heat from industrial processes or power plants can be used in a viable manner by employing heat storage, which makes these sources available when they are needed. This means that heat provision from a heating or solar energy system need not be designed for the maximum demand, but can instead be sized for a given intermediate demand level. Alternatively, the low temperatures available at night can be used for cooling during the day.
Nowadays, demand-oriented heat storage is generally implemented using hot water storage, where the temperature of the stored water is raised to the demand temperature or above it. The heat stored in this manner is referred to as sensible heat, as this is “tangible” storage. The advantage of using water in this process is that water is most often the medium that is required later on – for example, shower water can be taken directly from the storage tank. In addition, water is generally inexpensive. Sensible heat storage also takes place when the tiles on a tiled stove are heated up. These tiles then release their heat over the course of number of hours, even long after the fire itself has already gone out.

Latent storage materials, also called PCMs (phase change materials), store large quantities of heat by means of a phase change – for instance from solid to liquid. Compared to conventional sensible heat storage equipment, PCM storage devices allow for a high energy density with a largely constant operating temperature. The amount of energy required to melt one kilogram of water would result in a temperature increase of around 80 °C in the case of sensible storage. For many materials, temperature changes of just a few degrees (10 K) that involve a melting process can achieve heat storage densities which are up to 10 times higher than those achieved with sensible storage. Figure 2 shows:
Heat storage is usually associated with an increase in the temperature of the storage material that is proportional to the amount of heat stored (blue curve). Once the phase change temperature has been reached in the case of “latent” (hidden) heat storage, no temperature increase occurs for a period until the storage material has fully melted (red curve). The heat stored is released again during solidification.

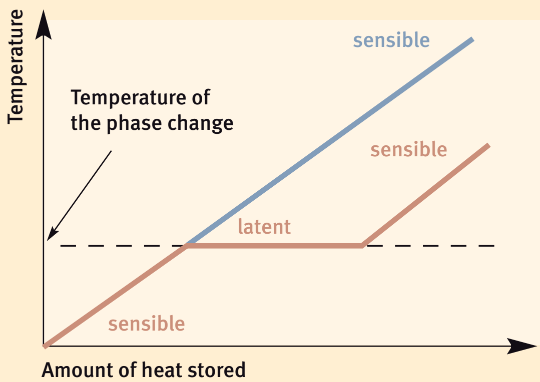


Fig. 2 *Temperature profile as a function of the amount of stored heat in the case of storage of sensible heat and latent heat. Source: ZAE Bayern*

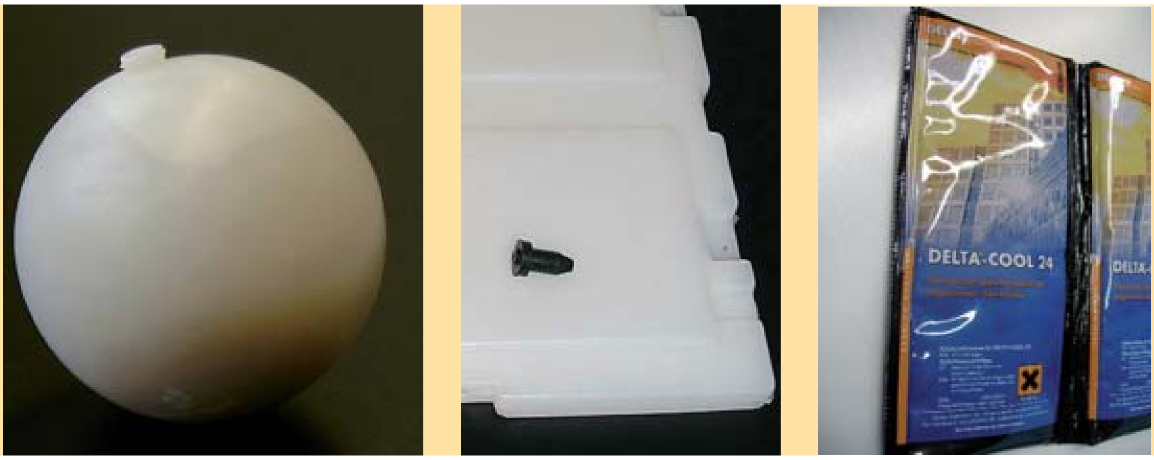


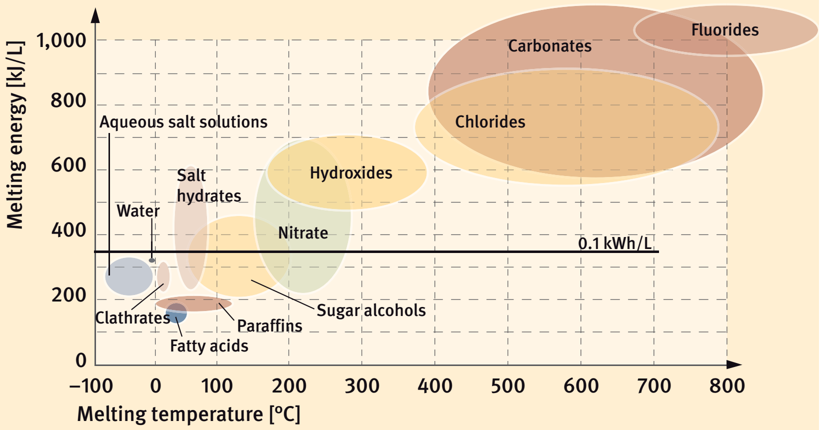
Fig. 4 *Examples of macrocapsules.*
Source: ZAE Bayern

Which storage materials are used?

Intensive research work over the last two decades has identified many phase change materials that are suitable for use in latent heat storage and cover a wide temperature range with their melting points (Fig. 3). Various mixtures of water and salts yield eutectic salt solutions with melting points significantly below 0 °C, for example, or salt hydrates with melting points in a temperature range between 5 °C and 130 °C. This results in numerous applications in the areas of heating, cooling and air-conditioning. These materials can boast high storage densities and are relatively inexpensive. Paraffins and fatty acids are the main organic materials that are suitable. They generally have lower storage densities and have higher costs relative to salt hydrates. However, they are easier to work with than salt hydrates.

Although the combination of building materials with PCMs appears rather unspectacular at first glance, there are still a number of requirements that have to be fulfilled. The mechanical stability of the PCM materials must be ensured, and sufficient fire protection must be in place for paraffins, for example, which are flammable. It is often a good idea to modify the PCMs in order to change their properties. Examples are granulates that can be poured or trickled, or PCM graphite composite materials for heating or cooling applications.

Fig. 3 *Material classes that are being investigated and used as PCMs.*
Source: ZAE Bayern



PCMs – encapsulated for controlled amounts

PCMs are suitable for the construction of storage devices with a high storage density and for passive temperature stabilisation based on melting at a constant temperature. As PCMs become liquid during their use, it is generally necessary to encapsulate them in some type of container. For conventional storage devices, this function is fulfilled by the storage tank, whereas in many applications PCMs are employed as independent storage elements in an existing system.

In such cases, the storage containers used for the phase change materials are termed “capsules”. Depending on their size, they are classified as macrocapsules with a diameter of greater than 1 cm, microcapsules with less than 100 mm, or mesocapsules which cover the intermediate range. Figure 4 shows examples of conventional macrocapsules: plastic containers with a flat shape or else as spheres or bags, etc. Any type of material class can be “packaged” using this technology. However, these capsules cannot be used everywhere because of their size.

Microcapsules have to be used in order to add PCMs to other materials such as building materials. The small size of these capsules means that they can be mixed into these building materials during manufacture, and thus these materials can be processed on the building site in the same way as conventional building materials. Further processing during the usage phase is also permitted, as damage to the capsules is unlikely due to their small size. If a few capsules should be damaged, the amount of material released will be negligibly small. Paraffins in microcapsules have been commercially available for around ten years. Micro-encapsulation of salt hydrates and new methods of meso-encapsulation are the subject of intensive research.

When constructing heat storage devices using PCMs, the usually low thermal conductivity of these materials generally makes sophisticated charging and discharging systems necessary. These systems and the surface of the storage device must be designed to cope with changes in the PCM volume which are often substantial. Energy density and capacity density are key criteria here

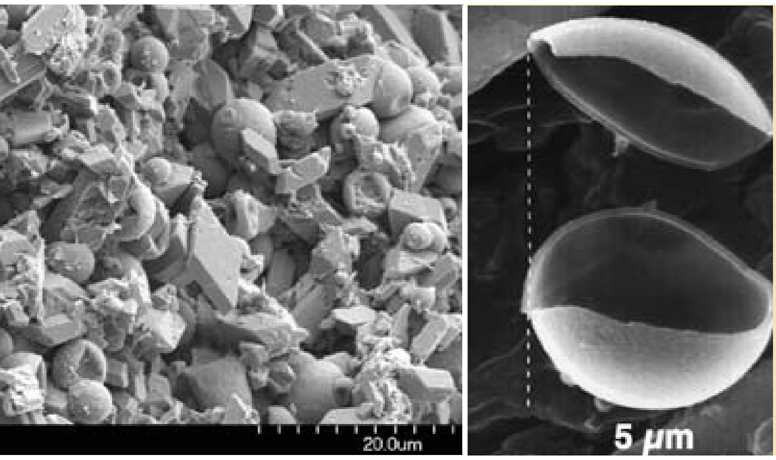


Fig. 5 *Microcapsules.*
Source: Fraunhofer ISE, BASF

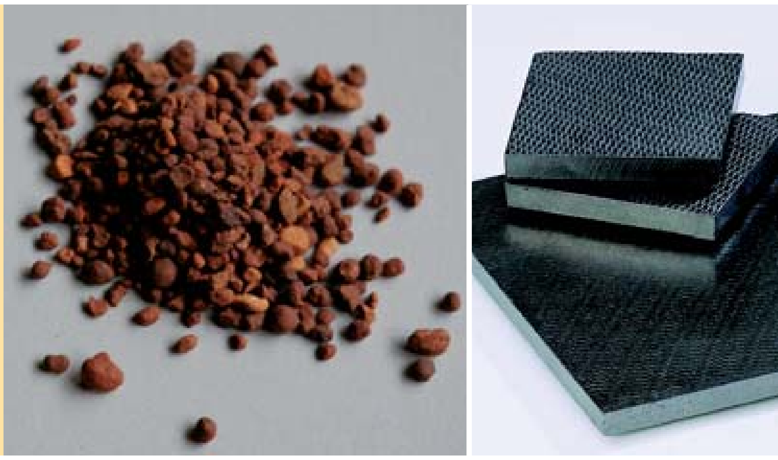


Fig. 6 *Examples of PCM composite materials: mechanically stable, pourable granulate from Rubitherm GmbH; PCM graphite composite with high thermal conductivity.*
Source: ZAE Bayern

in the selection of suitable materials, but storage losses, costs and safety also play important roles.

Potential applications for PCMs

Most applications of PCMs under the heading of “energy saving” involve the buffering of temperature cycles in buildings. The focus here is avoiding peak temperatures and thus saving on cooling energy. In the case of conventional night ventilation, warm air in the building is replaced by cold night-time air; PCMs can increase the heat capacity of a building and thus store the night-time coolness in the building mass. Storage devices that play a supporting role in building heating represent another important application.

In general, applications for phase change materials in buildings can be classified as follows:

- PCM integrated into the building structure (wall, ceiling)
- PCM in other building components (e.g. facade element)
- PCM in separate heat and cold storage devices

The first two applications are passive systems that automatically release the heat or cold stored. The third system requires active components such as fans and pumps, as well as a control system. However, it has the advantage that the stored heat or cold can be accessed in a targeted manner when it is required. PCMs with various phase change temperatures are used depending on the area of application. Storage temperatures of between 0 °C and 40 °C are favoured in buildings, with the exception of hot water and heating water provision where temperatures of between 50 °C and 60 °C are needed. The integration of PCMs into the building structure is focused on the temperature range of 21 °C to 26 °C.

Ice storage devices have a much higher storage density than cold water storage equipment. They currently represent the state-of-the-art technology in air-conditioning for buildings and the use of industrial process cold. They are integrated into the cooling system by means of a brine circuit with a pump. The storage devices can be actively controlled in order to charge and unload them and regulate their performance in a targeted manner. Air-carrying heating and cooling systems represent another possible method for active integration.

By contrast, PCMs with no external control are used for passive temperature stabilisation. An example of this is the use of macro-encapsulated PCMs in transport boxes for temperature-sensitive goods such as pharmaceuticals and blood plasma. In recent years, PCMs have increasingly found applications in clothing; here, PCMs buffer short-term excess peaks of heat and reduce perspiration or else use stored heat to stop the body getting cold. Micro-encapsulated PCMs are generally combined with the clothing fabric in these applications.

This approach has also been used for a number of years now in passive temperature stabilisation in buildings. The heat stored by PCMs when they melt is a multiple of the heat capacity of building materials such as plaster, wood, cement or stone, which is generally between 0.8 and 1.5 kJ/kg per 1 °C interval. Micro-encapsulated PCMs are generally integrated into the building materials.

Another area of application has resulted from a building technology that is already established: These systems cool buildings using tube heat exchangers which are integrated into the building elements are used to condition the indoor environment – either completely or else as a support measure. These thermo-active building systems (TABSs) can be used in combination with conventional heating systems (radiators) or with natural or mechanical ventilation. They take the place of conventional building cooling in these applications. In the case of purely passive systems or TABSs, a large heat transfer area should be available because of poor heat transfer to the air. This is not necessary for active systems, as even a small amount of air movement considerably improves the heat transfer and thus the performance of the system.

Fig. 7 *Modern architecture is increasingly characterised by lighter constructions and energy-optimised planning, without compromising on comfort. PCMs integrated into building materials – e.g. in the form of plasterboards – deliver a pleasant indoor atmosphere by balancing temperatures. Source: BASF*

Building materials and indoor environment

The heat capacity of lightweight-construction buildings can be significantly increased by including latent heat storage materials in the surfaces of the building fabric. The effect is improved "passive" building cooling and indoor temperature regulation, thus resulting in energy savings and increased comfort. Building materials with PCMs for passive building cooling are already commercially available.

It is often pleasantly cool in the summer in buildings with exposed solid concrete walls or masonry. This cooling effect is made possible by the high heat capacity of the building fabric itself. Solid, exposed building components function as heat buffers – they can absorb heat during the day and then release it again at night. In contrast, the room temperature quickly rises in buildings with low heat capacities, such as lightweight constructions with components made of wood or plasterboard.

Protection against heat and cold in buildings is generally the result of a combination of heat storage in the building mass and appropriate insulation measures. Heat is absorbed and released by the building mass without special technical equipment being necessary, hence the term "passive temperature stabilisation". Because of their high storage capacity in a narrow temperature range, PCMs are ideally suited for improving the ability of various materials to provide passive temperature stabilisation. This effect has been finding commercial use in building services technology for a number of years now.

The work of the research projects "Innovative PCM technology" and "Micro-encapsulated latent heat storage devices" has provided the foundation for many of the developments and products that will be described here. The research work on the applications of PCM technology have now been bundled as part of the German Federal Ministry of Economics and Technology's EnOB research initiative. Three methods of integrating PCMs into buildings have been investigated: integration into the exterior plasterwork, into the masonry, and into interior plasterwork. For each of these three cases, the melting temperatures were varied in simulation studies as a function of the specific application and the amounts used.

The issues of energy savings, increased comfort and, in the case of exterior applications, component protection were all evaluated. Because of the significantly lower heat flows and the direct influence of surface temperatures on users' perceived comfort, the use of PCMs is the most promising in interior applications. When PCMs are used in our climate zone, the savings in heating energy have been too small so far in standard residential and office buildings. On the other hand, the use of PCMs in building materials significantly increases user comfort in buildings in the summer. If appropriate measures are taken during building planning, it may even not be necessary to employ any other cooling measures.

The use of PCMs in lightweight constructions has great potential, particularly in office buildings because of their strongly fluctuating load profiles between day and night. The melting point should be chosen such that temperatures above 26 °C arise only for very limited periods and temperatures above 28 °C are fully avoided if possible. This means that the majority of melting heat should be absorbed under 25 °C. Night-time unloading of the storage device is essential in order for the system to work properly and should be provided for by suitable measures. The loads occurring should generally be in reasonable proportion to the storage capacity of the system. It should be ensured that sufficient PCM surfaces are provided and that these are not blocked. These materials will only be a replacement for a sunscreen system if there is no or very little irradiation.

In practice

"Living 2015" prototype

Fig. 8 Northeast view of the "Living 2015" prototype.
Source: TU Darmstadt, Kubina

The prototype solar house designed by students from the Technical University of Darmstadt won the "Solar Decathlon" international competition in the USA in 2007 for the most attractive and energy-efficient solar house. This energy-independent building was constructed on the TU Darmstadt campus and then transported to the USA once it was finished. The house is a lightweight wooden construction with a low heat storage mass compared to solid constructions. It has a floor area of 80 square metres. In order to combine the highest possible living comfort with the lowest possible energy consumption, a compact building envelope with excellent insulation was selected. 50 square metres of BASF plasterboard containing PCMs were integrated into the walls. In addition, 50 square metres of active, water-carrying PCM cooling ceiling elements from ILKAZELL were used.

As part of the energy concept of the Darmstadt prototype building, the use of PCMs played a crucial role in maintaining the required constant interior temperature of the house. The students implemented an intelligent system to transport the heat stored in the melted wax out of the house: Cold water at 16 °C is fed from a water tank through the cooling ceiling elements during the day, thus actively cooling the room, while at night the heated water is fed to the photovoltaic modules attached to the roof, where some of it evaporates. The cooling effect achieved by the evaporation process cools the residual water again, which is then returned to the water tank. The inclusion of the PCM plasterboards with a thickness of 15 mm in the Darmstadt lightweight construction means that the structure can store as much heat as a 90-mm concrete wall.

Fig. 9 Internal view: Alongside the cooling ceiling elements, the use of PCM plasterboard also played a crucial role in obtaining the desired constant interior temperature.
Source: TU Darmstadt, Christian Stumpf

En passant

Fig. 10 Frost spraying of apple trees in the Altes Land area near Hamburg

Frost protection for apple trees

Plants do not have body heat of their own, and are thus directly exposed to the surrounding temperature and generally have no means of protecting themselves. However, there are some species in the highlands of the Andes in South America that store water in cavities in their trunks in order to protect themselves against frost damage. On cold nights, this water begins to freeze, thus releasing heat of crystallisation, also known as heat of solidification, which prevents further cooling and stops the plants themselves from freezing.

Humans are now using the same approach: In order to protect fruit trees against frost damage, they are artificially sprayed with water on cold nights. The consequence of this spraying is that blossoms and buds are covered with an ice layer. The frost protection effect occurs thanks to the release of heat when the water solidifies (freezes) on the blossoms. The steady growth of this ice layer leads to a continuous freezing process that ensures a constant temperature of 0.5 °C inside the ice sheet. In this way, the buds and blossoms are protected against freezing.

Source: Obsthof Axel Schuback, www.apfelpatenhof.de

Fig. 12 *PCM plasterboard from Knauf. Source: ZAE Bayern*

Fig. 13 *Interior gypsum plaster with PCM. Source: Maxit Deutschland*

Fig. 14 *PCM board from DuPont Energain. Source: ZAE Bayern*

Building materials with PCMs

As part of development work at the Fraunhofer ISE, various PCM building materials have been developed in cooperation with industrial partners and then monitored in test rooms under real external conditions. Figure 11 shows the potential of a PCM building material for achieving temperature reductions in buildings under ideal conditions. Used here was PCM gypsum plaster that was applied with a coating thickness of 15 mm to walls and ceilings. On day 1 (ideal case), the PCM storage was only slightly overloaded, and a temperature difference of up to 3.5 K was measured between the reference room and the PCM room. The subsequent days show that other heat protection measures – such as shading or the optimisation of indoor loads – should generally be implemented before PCM building materials are used. In addition, mechanical ventilation to regenerate the heat storage facility is essential, particularly on warm nights. If the PCM cannot release its heat, overheating may result the following day.

Some products for passive building cooling are already available on the market and will be briefly introduced here. The products are classified here depending on whether they use micro-encapsulated or macro-encapsulated PCMs:

• Plasterboard: Knauf PCM Smartboard
PCM plasterboard available for drywall construction applications with around 30% mass fraction of PCM with a layer thickness of 15 mm.
Available melting range: 23 °C and 26 °C;
latent heat capacity around 90 Wh/m^2;
manufacture and distribution: Knauf Gips KG.

• Gypsum plaster: Maxit
Gypsum machine-applied plaster with around 20% mass fraction of PCM for a layer thickness of up to 15 mm. In addition, the plaster can also be activated using water-carrying systems. Available melting range: 21 °C, 23 °C

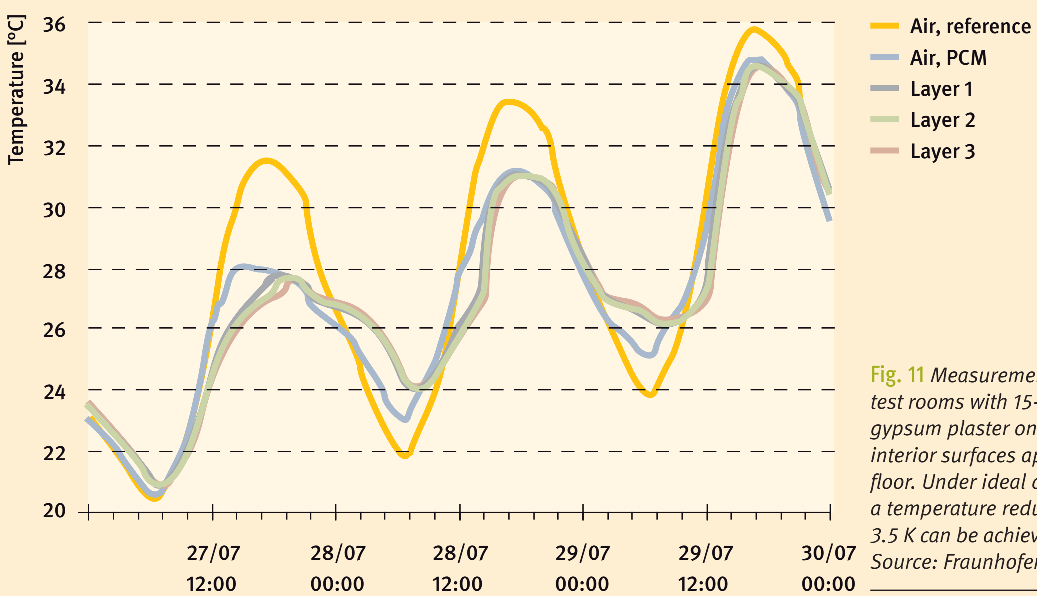


Fig. 11 *Measurements from two test rooms with 15-mm PCM gypsum plaster on all opaque interior surfaces apart from the floor. Under ideal conditions, a temperature reduction of around 3.5 K can be achieved using a PCM. Source: Fraunhofer ISE*

Fig. 15 *Examples of PCM components: PCM cooling ceiling, PCM sun protection, GLASSXcrystal facade building element. Source: Dörken, ZAE Bayern, GLASSX*

and 26 °C; latent storage capacity around 70 Wh/m²; manufacture and distribution: Maxit Deutschland GmbH. In contrast to the building materials described so far where micro-encapsulated PCMs are integrated as additives, DuPont has developed a board where paraffin is integrated into a plastic matrix.

• Integrated storage container:
DuPont Energain® has a thickness of 5 mm and a weight of around 4.5 kg/m². Around 60% of its mass is paraffin, which has a melting range of 18 °C to 22 °C. These boards were tested in two identical rooms in a building at the University of Lyon, where one room was equipped with PCM boards and one was not.

Building integration

The building materials described so far mostly use micro-encapsulated PCMs as additives. It is thus possible to integrate these building materials into buildings in almost unlimited amounts and forms. Handling is no different than for conventional building materials. The approaches identified for the inclusion of PCMs have only been fully developed for paraffins and fatty acids. In contrast with building materials, PCM components can be fully prefabricated, meaning that no processing is necessary during installation. It is thus possible to use macro-encapsulated PCMs, such as salt hydrates, in the manufacture of these components.

Figure 15 shows examples of applications of PCM components: The first example is the integration of a PCM into a ceiling, where the PCM serves mainly to cool the room. Dörken employs encapsulated salt hydrates here. If the air temperature in the room rises, the warm air rises, melts the PCM and is thus cooled again. Maximum cooling rates of 40 W/m² to 45 W/m² can be achieved here. However, active ventilation is recommended to remove heat at night. The power required for fans should be taken into account in the energy balance.

Another attractive method of integrating PCMs into building components is the PCM composite sunscreen system. Just such a system has been developed by Warema in cooperation with ZAE Bayern as part of a project supported by the German Federal Ministry of Economics and Technology. Internally fitted sun protection is generally intended to reduce the amount of sunlight, but the sun protection equipment is actually heated up in the process and then releases its heat into the room. The integration of a PCM into the sun protection leads to reduced or delayed heating of the room. Investigations carried out on laboratory samples have shown that the maximum temperature of the sun protection fittings is delayed by 3 hours and the room stays 2 °C cooler. The radiation asymmetry can be reduced by 6 °C. As with all other applications, however, heat removal by means of night ventilation is necessary. This approach is currently being investigated in real installations as part of the "PCM demo" project.

The transparent facade building element by GLASSX is a passive system that is mainly used for heating, but can also be used for cooling a room. It consists of a number of layers: A PCM layer on the side facing into the room stores the heat of the incoming solar radiation. Multiple glazing on the facade prevents heat losses and prismatic glass that is fitted in the gaps allows the incoming sunlight to pass through only if it is at a shallow irradiation angle (i.e. in winter), thus protecting the interior from overheating in summer. Ceramic screen printing on the interior side gives architects freedom of design as regards colour selection. The system has been installed in around a dozen buildings in Switzerland so far. The cover picture on this Info brochure shows the use of PCM heat storage in the facade of a nursing home.

Fig.16 *PCM ceiling cooling panels in an open-plan office Source: Julia Schmidt/ Deutscher Drucker*

Active heat management

The heat storage effect can be used in a controlled manner as regards time and intensity by employing active, water-carrying PCM systems. Surface building components can be used to decouple demand for cooling and cooling supply in terms of time. PCM cooling ceilings have already been implemented in various demonstration projects.

Passive cooling concepts – in combination with PCMs in particular – are subject to two main restrictions that could limit their applicability. Firstly, heat transfer between the walls and the air limits the amount of heat that can be absorbed and, more importantly, released again over a 24-hour cycle. Doubling the thickness of the plaster layer does not necessarily lead to double the actual heat storage capacity available. Secondly, the only source of coolness available is the night-time air. Particularly on hot summer nights, this can mean that heat cannot be released from latent heat storage, with the result that the system will not work properly the following day. However, the stored heat can be removed efficiently and reliably using cooling water circuits. These systems can be integrated into the walls or ceiling, or can also be installed as suspended ceiling elements. They can also be integrated into walls or floors for heating purposes.

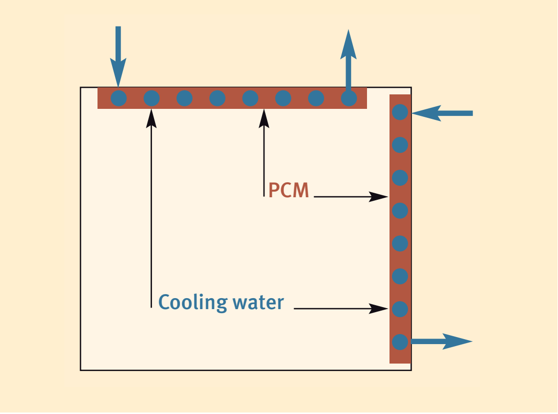


Fig. 17 *Schematic representation of active PCM systems for cooling. Source: ZAE Bayern*

Innovative surface cooling and heating systems

As part of the “PCM active” project, the Fraunhofer ISE, together with project partners, has investigated active flow-through surface cooling systems combined with PCM building materials. The main goal of this work was the development of a water-carrying cooling ceiling, based on available PCM building materials. The PCM in the cooling ceiling means that a large fraction of the heat that would have to be actively removed in conventional systems can be stored passively in an intermediate manner. It is only necessary to actively remove the remaining excess. Outside of the melting range, the ability of a thin-layer cooling ceiling to react quickly remains intact, however. Another advantage of PCMs in cooling ceilings is that cumulative cooling capacity is available. Conventional cooling equipment must be designed in such a way that it can deal with peak loads. However, the ability of PCMs to store cold makes it possible to use smaller cooling systems. On top of this, additional cold sources can be used that only contribute low cooling capacities – these could include environmental heat sinks, such as borehole heat exchangers.

Cooling ceilings can be operated in a demand-oriented manner so that they can absorb cold at times when it is favourable from an energy or economic point of view. One of the central issues addressed by the “PCM active” project was the determination of the optimal melting range for PCMs. This melting range should be at the upper end of the human comfort range for passive applications. It should be selected in such a way that the ceiling can be operated in a highly energy-efficient manner in the case of active systems. So far, various series of tests and simulation studies have shown that a melting range of around

In practice

Refurbishment of a printing house: Cooling using environmental energy in combination with thermo-active building systems and PCMs

Fig. 18 *Engelhardt & Bauer printing house in Karlsruhe after comprehensive refurbishment measures. Source: Patrick Beuchert*

The administration building at the Engelhardt & Bauer printing house in Karlsruhe is a commercial facility from the 1970s that had typical weak points such as high energy consumption, insufficient daylight and poor thermal comfort. This low-rise building has now been fully refurbished and extended by one storey (usable floor area of 900 m^2, building volume of 3,000 m^3), and is a pioneering project: A high-class architectural solution was found for a lightweight construction building with a high percentage of glass, using commercially available products and services.

The use of PCMs is one possibility for adding thermal mass to lightweight structures without adding significant weight. 260 m^2 of ceiling cooling panels from ILKAZELL were first installed in the upper storey. These combine BASF's latent heat storage medium in the form of a conventional smartboard (melting temperature 22 °C) with active cooling using capillary tube mats. The area available for the PCM cooling ceiling was defined by the building geometry, meaning that the heat transfer capacity was limited to around 12 kW.

On the basement level, plastered capillary tube mats were fitted to the existing concrete ceiling as a quick additional system with a capacity of around 10 kW.

The thermal, visual and acoustic comfort was improved relative to the original situation, and the energy requirements for heating, cooling, ventilation and lighting were reduced by 50%. The existing split devices for cooling provision were replaced by energy-efficient cooling using thermo-active building systems. The ground was used as a natural heat sink, which was exploited using 13 borehole heat exchangers at a depth of 44 m. Despite the building's lightweight steel construction, a stable indoor environment is achieved in the summer. The energy transferred using the PCM ceiling cooling panels was 80 kWh/m^2 of ceiling area p.a. for the 2008 operating year. Alongside sizing the equipment correctly and choosing the individual components, the control of the system was the critical factor in delivering energy-efficient operation.

Fig. 19 *Cooling ceiling system with a PCM (Ilkatherm). Source: Sven Meyer*

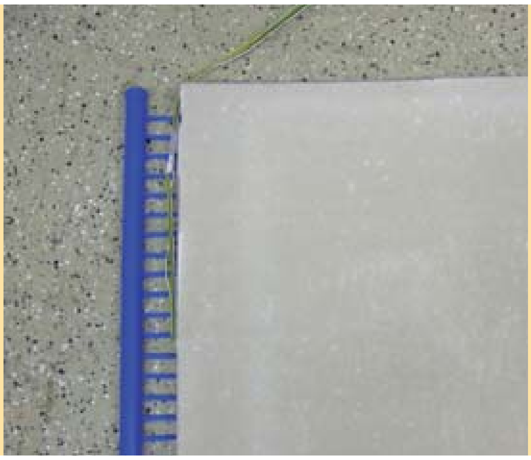


Fig. 20 *PCM screed underfloor heating. Source: Maxit Deutschland*

19 °C to 22 °C is ideal for cooling ceilings. This makes it possible to release heat at night with relatively high supply temperatures in the cooling circuit. Environmental heat sinks can achieve the same temperatures. It also allows for cooling ceilings to be operated at maximum surface temperatures of around 23 °C. Measurements of the cooling performance confirm, as expected, that there are no significant differences as compared to conventional plastered cooling ceilings with capillary tube mats. The second main issue addressed was how to regulate a PCM ceiling with the aim of achieving energy-efficient ceiling control while at the same time adhering to comfort criteria. The operating periods of the ceilings are to be minimised, and the volumetric flow rates and cooling water temperatures, which can vary depending on the heat sink used, should also be taken into account. Operational investigations are currently being conducted on various test cooling ceilings. In addition, cooling ceilings are also being used in real buildings – for example, in five offices with a total ceiling area of 100 m^2 at the Fraunhofer ISE.

The first active cooling system to be distributed commercially is the Ilkatherm® cooling ceiling from ILKAZELL. It is based on PCM plasterboard, which is stuck onto the room-facing side of a polyurethane sandwich composite. Capillary tube mats are fitted between the smartboard and the rear insulation for activation purposes. The system has already been used in combination with borehole heat exchangers as heat sinks in a demonstration building, namely the Engelhardt & Bauer printing house in Karlsruhe. The cooling ceiling has a modular structure, and can be used as a full-surface suspended ceiling or as an individually rear-ventilated ceiling element.

A screed underfloor heating system was developed in cooperation with Maxit Deutschland to provide surface heating.
Micronal® from BASF was the PCM used. The thermal benefit of using additional PCM is minimal, however, because of the already very high storage capacity of the screed system. A further advantage is that the layer thickness for the underfloor heating can be reduced by around 25% as compared to conventional screed underfloor heating.

Testing under conditions close to those in real applications is also necessary alongside product tests in laboratory test rooms. Firstly, manufacturers require concrete data on how efficiently their products actually are under real conditions; secondly, along with technical data, users also like to be able to visit show buildings that demonstrate how PCMs can be integrated into a lightweight construction architecturally and in terms of building services technology.

After the successful development of components and materials, the current task is to increase the acceptance of PCMs in building applications among planners and users, and, among architects in particular, to create an awareness of PCMs as an energy-saving alternative or supplement to active air-conditioning and/or heating technology. For this reason, research is currently under way on “Practically oriented testing of the performance of building components with PCMs in demonstration buildings” (German Federal Ministry of Economics and Technology’s “PCM demo” project).

The “Water-carrying cooling ceilings with PCMs” subproject involves an investigation of a combination of macro-encapsulated PCMs and a water-carrying cooling ceiling. Suspended water-carrying cooling ceilings can achieve high cooling capacities (max. 100 W/m^2) with low response times; however, this often means that they require high peak loads from cooling supply. The integration of PCMs means that a purely passive basic cooling capacity of around 40 W/m^2 can be provided during the day when cooling load peaks occur. At night, the PCM can then be regenerated using cold water. In this way, load peaks can be avoided during the day and the cooling load can be distributed more evenly. There are particular advantages if shallow geothermal energy (borehole heat exchangers) is used as the cold source, as the borehole heat exchangers have to be designed for peak loads. If the PCM system is combined with conventional technology (partial use of PCM modules), the advantages of short “response times” are preserved, and only peak loads in excess of the basic loading have to be dealt with. Up-to-date progress reports on the investigations will be presented to the scientific community from autumn 2009 onwards.

In practice

Demonstration building with PCM cooling ceilings

Fig. 21 *DAW cooling ceiling with a cold water system as a heat sink. Source: Fraunhofer ISE*

As part of the "PCM active" project, two different PCM cooling ceiling systems have been implemented in demonstration buildings. The laboratory building at Deutsche Amphibolin-Werke (DAW) in Ober-Ramstadt, which has around 100 m² of ceiling area, has a cooling ceiling based on a 1-cm layer of PCM filler containing around 40% of PCM, with recooling using a cold water system installed outdoors. The goal here was to demonstrate that conventional cooling technology can also benefit from being combined with a PCM cooling ceiling. The two main gains here are the reduced operating periods for active cooling and the shifting of recooling into the cooler night-time period.

A PCM cooling ceiling with a combined heating, cooling and power (CHCP) cogeneration system as a heat sink has been fitted to five offices at the Fraunhofer ISE in Freiburg (which also has around 100 m² of total ceiling area). This system consists of a CHP plant that is used for generating electricity. The waste heat from this plant is converted into cooling capacity using adsorption chillers and then passed on to the consumer loads. The cooling system (with around 11 kW of thermal capacity) supplies an open-plan office during the day through heating/cooling convectors, as required. The five PCM cooling ceilings are only cooled at night, so that they can passively cool the office areas the following day. The combination of two consumer loads operated in turn results in significantly improved utilisation of the CHP plant without having to provide large heat storage tanks. Thus, the office area that is cooled can be doubled even with a cooling system of unchanged size. Figure 23, with data from summer 2008, demonstrates that this concept works in practice. The graph shows the temperatures of the room, plaster and water in one of the offices. At an outside temperature of up to 30 °C, room comfort is maintained with a maximum temperature of 25 °C. At the same time, the PCM storage capacity is sufficient to provide passive cooling for a whole day. Only around 3 p.m. do the ceiling temperatures leave the PCM's melting range (grey highlighting).

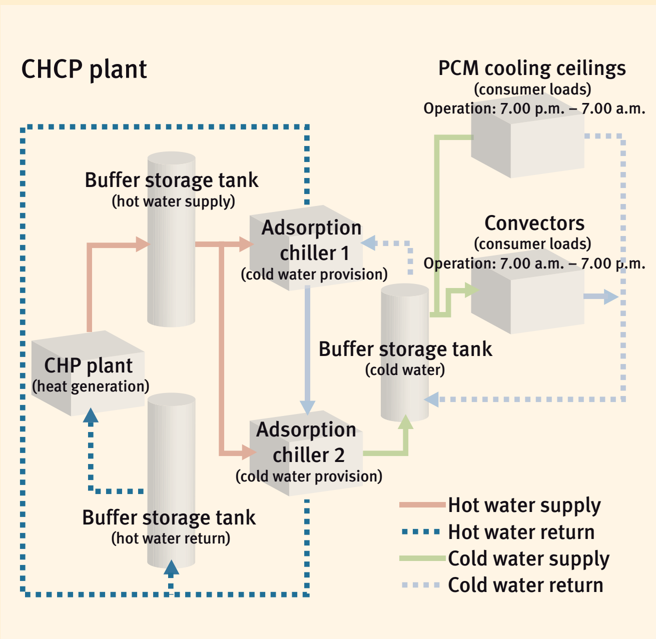


Fig. 22 *CHCP system implemented at the Fraunhofer ISE for cooling an open-plan office using cooling/heating convectors and for five offices using a PCM cooling ceiling. Source: Fraunhofer ISE*

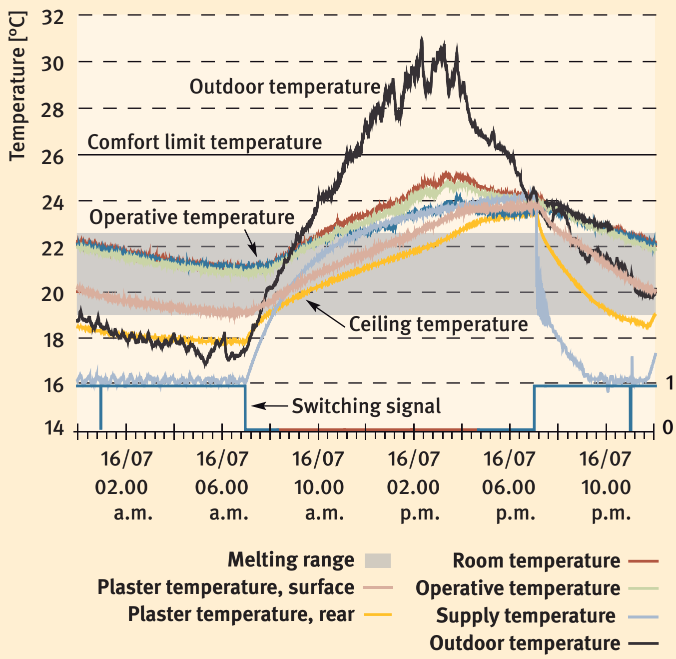


Fig. 23 *Temperature profiles in a PCM-cooled office. Source: Fraunhofer ISE*

Fig. 24 *Innovative concepts for room cooling create a pleasant atmosphere – especially in workshops and other workplaces.*
Source: Lichtblau Architekten

Concepts for building services technology

Storage systems for heating and cooling of rooms with various heat-transfer fluids are very energy-efficient and have already been developed as products in certain cases. Large additional heat storage capacities can be achieved using PCM slurries as fluid storage media that can be pumped.

The heat and cold storage devices that are integrated into innovative building solutions are based mainly on three different concepts. Figure 26 shows the most familiar system on the left, where the storage material is contained in a storage tank and the heat-transfer fluid (HTF) flows through channels into a heat exchanger. With the second concept, the PCM is macro-encapsulated in PCM modules that are located in the storage container, and the heat-transfer fluid flows around the capsules. In the case of the third concept, the PCM is a component of the heat-transfer fluid and increases its capacity to store heat. It can thus be pumped to any given location in the system in order to release or absorb heat directly. The heat-transfer fluid and the PCM form a pumpable storage medium together, also known as a "PCM slurry".

Air, water or other fluids can be used as the heat-transfer fluid in the first two concepts, whereas the third concept is only suitable for fluids.

Systems with heat transfer to the air

Storage in thermo-active building systems (TABS) only uses free convection in the air and radiation exchange as the mechanisms of heat transfer to the rooms. Their performance is thus limited. This is particularly true in connection with PCMs as heat storage devices, as the temperature difference between the storage material and the room air is only a few degrees Celsius here. One solution is the use of forced convection, meaning that the air is actively blown across the surface of the storage material. For simplicity, this approach is used in the same way for both charging and discharging. Possible installation forms include a ceiling construction, integration into the floor, or a separate unit. As air is used as the heat-transfer medium, the provision of cooling using cool night-time air is the aim in the case of most systems. These systems are also called "free cooling" systems as the cooling is freely available. They are very energy-efficient, as no energy is consumed in the provision of cooling. However, the channels should be designed in such a way that cleaning of the air path is possible.

• Systems for room cooling using a ceiling construction
...are currently being tried out in pilot systems. PCM bags filled with salt hydrates are already being used in passive cooling ceiling systems. These are easy to install. However, the cooling capacity is limited because of the low thermal conductivity of the surface boards facing into the room – e.g. gypsum boards. Active rear ventilation improves heat transport and allows for higher cooling capacities during the day along with planned night-time regeneration of the system using cool outside air. The temperature profile calculated for an office room with a rear-ventilated ceiling construction with a PCM shows that the peak temperatures can be reduced by around 2 K using the PCM. This type of "rear-ventilated cooling ceiling with PCM" is being investigated in the "PCM demo" project. Another example here is the CoolDeck developed by the Swedish company Climator. It features specially designed air flow paths where the ceiling of the room forms the upper limit of the air duct. This means that the PCM itself and the ceiling are used for storage. The system has been installed in the offices of Stevenage Borough Council in England as part of a demonstration project. The maximum indoor air temperature was reduced by 3-4 K in summer. As cooling is provided by the night-time air alone, the only energy consumption was that of the ventilator. This results in a coefficient of performance (COP) in the range of 10 to 20, according to Climator. The system has already been installed in a number of buildings.

• Systems for room cooling using a floor construction
...have only been tested on a laboratory scale so far. This

In practice

Testing of a decentralised PCM ventilation device

As part of a demonstration project, 50 modules from the ventilation and cooling system developed by Imtech, with a PCM graphite composite material as storage medium, were installed in an administrative building – one module for every 7 m^2 of office area. This corresponds to a PCM distribution of 5 kg/m^2 and a storage capacity of 0.14 kWh/m^2. Preliminary building simulations showed that the installed modules should be capable of keeping the operative temperature almost permanently under 26 °C during normal summers. The tests started in March 2006 showed that the system is capable of cooling the indoor air by up to 5 K before it is returned to the room again. A maximum cooling capacity of 300 W was achieved. Relative to a conventional system with a compression refrigeration machine, the new system provides 82% of the cooling with only around 5–7% of the electricity consumption. It thus provides energy-efficient room cooling during the day with electricity savings of between 60% and 90%. PCM ventilation devices including control units have been commercially available since 2007. They are currently being adapted for use in patients' room and hotel rooms.

Fig. 25 *The Imtech building in Hamburg: Testing ground for 50 PCM ventilation modules. Source: Imtech*

LowEx research focus

EnOB
Forschung für Energieoptimiertes Bauen

LowEx

LowEx stands for "Low-exergy technologies". Various innovative technologies for buildings, building services technology and energy supply are being developed here that have one thing in common: They work with the lowest possible differences in temperature to the room temperature for heating and cooling, as well as for distribution of heat and cold within rooms. Renewable energy sources can also be used in this manner – for example, the natural low temperatures of the ground or of ground water can be used for cooling, and solar thermal energy for heating. LowEx is one focus of the German Federal Ministry of Economics and Technology's "Energy-Optimised Construction" (EnOB) research initiative.

Further information can be found on the Internet at **www.enob.info**

RAL QUALITY SEAL

RAL GÜTEZEICHEN Phase Change Material

The increasingly widespread availability of PCM technology has made quality assurance more important. For this reason, a number of German companies founded the Quality Association PCM e.V. in 2004 and employed the Bavarian Center for Applied Energy Research (ZAE Bayern) and the Fraunhofer Institute for Solar Energy Systems (ISE) to develop suitable quality assurance procedures. The goal here was to ensure the quality of the storage materials themselves as well as that of buildings and systems that contain these storage materials. The RAL quality seal was awarded in June 2008 after this work was completed. The main criteria for this seal are the amount of heat stored as a function of temperature, the cyclical repeatability of the storage process, and the thermal conductivity of the storage materials, which is important for the charging and discharging times of the storage devices.

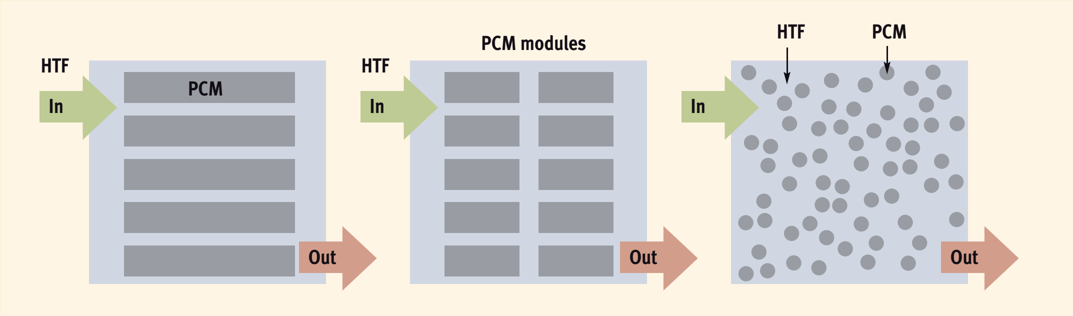


Fig. 26 *Storage concepts for active integration into heating and cooling systems. Source: H. Mehling*

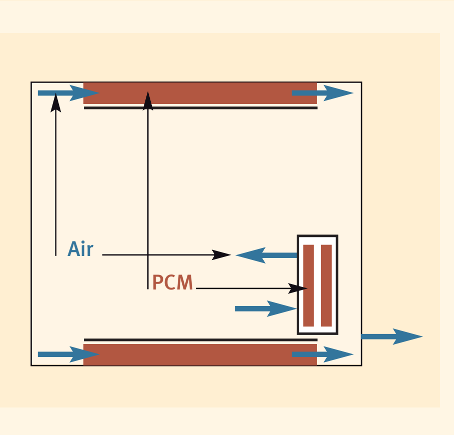


Fig. 27 *Schematic methods for active systems with air as the heat-transfer fluid. Source: ZAE Bayern*

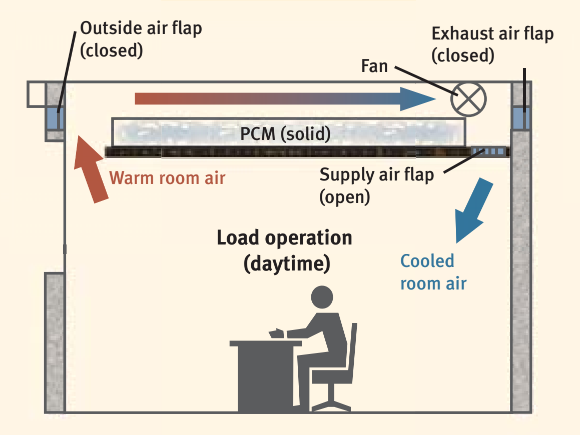


Fig. 28 *Schematic principle of an active PCM cooling ceiling. Source: ZAE Bayern*

type of system, with granulate PCM integrated into a double floor, has been tested at the University of Hokkaido in Japan. To cool the room, air is extracted from the room through a ventilation opening, cooled when it flows through the granulate PCM, and then fed back into the room through openings in the floor covering. A chiller is also connected to the air circuit by means of heat exchanger in order to provide a backup to remove stored heat during the night. The commercial implementation of this concept is planned.

• **Systems for room cooling using a separate unit**

...are already available as products on the market. Imtech has developed just such a system (as part of the German Federal Ministry of Economics and Technology's "Low-Ex" research focus). Figure 30 shows the structure schematically. A PCM graphite composite material that combines a high storage capacity with high performance at low temperature differences is used as a storage medium. It stores around 30 Wh/kg (108 kJ/kg) in the temperature range of 18 °C to 22 °C. The storage material is integrated into the device as a stack of storage plates around which the air has to flow. Each device contains about 35 kg of the storage material – this corresponds to a storage capacity of around 1 kWh. Here too, the night-time air is used as a cold source. Depending on the setting of the outside air flap, the indoor air in the room can then be cooled using the stored cooling capacity. In ventilation mode, it is also possible to draw in fresh air from the outside before it is fed into the room.

• **Systems for room heating**

...are used in solar-air equipment, for example. These have the advantage that they can combine ventilation and heating in one system. Research has been in progress on suitable latent heat storage devices for a number of years now, and they have already been tested in pilot systems. One example is the storage unit developed by Grammer in cooperation with ZAE Bayern as part of the "Innovative PCM technology" project: During charging, the temperature peaks in the air caused by the solar collector are smoothed and, during discharging, the air temperature is increased by 5–8 K over a period of a number of hours. This storage unit was in operation from February 2003 to December 2007, and no detectable changes in its thermal behaviour were recorded over the entire operating period relative to the unit's performance when it was new.

Systems with heat transfer to water

There are numerous examples of systems that use water or other fluids as a heat-transfer fluid: Storage tanks with heat exchangers or with macro-encapsulated PCM modules are familiar. These storage devices are generally used as ice storage tanks in combination with chillers to provide cooling for buildings. The most important energy benefit is the increase in the coefficient of performance due to the use of night-time cooling. Another factor is the optimal operation of the chiller. The use of a smaller

Simulation software

The PCMexpress simulation software was developed and released as part of the "PCM active" joint research project. This software makes it possible to obtain a quick initial estimate of the comfort gains that can be achieved by using a PCM building material. It makes recommendations on the PCMs that could be employed, how they could be used, and also gives initial estimates regarding financial viability. The simulation software contains a comprehensive databank regarding building materials, construction and weather conditions, and this databank can be added to by the user. PCMexpress is available at no charge from Valentin Energiesoftware GmbH's website. It is not a substitute for EnEV certification, however.

Fig. 29 *Screenshot of PCMexpress at www.valentin.de*

chiller, which is sized for an intermediate load, leads to reduced investment costs. The consumption costs can also be reduced thanks to the increased coefficient of performance, and the amount of electricity used at peak tariffs can also be lowered. In the area of building heating, research on latent heat storage devices initially concentrated on use in solar heating systems which aim to increase the solar energy share. The goal right from the beginning was to store heat for a number of days with the same volume or a smaller volume. The first products have been commercially available for a number of years now. A storage tank from Alfred Schneider GmbH uses salt hydrate as its storage medium. It has already been installed in dozens of systems. Solar collectors, CHP plants and wood-burning systems can all be used as heat sources here (Fig. 31).

A storage system integrated into the facade that works with water as its heat-transport medium has been developed by TROX GmbH as part of a further research project. The latent heat storage device's particularly compact design makes it possible to install the system for each room in the facade. This means that the system is also suitable for refurbishment projects. Figure 32 shows the system investigated, which provides room cooling and uses the ambient air as a heat sink: The system consists of the latent heat storage unit (1) with paraffin as the storage material, a cooling ceiling with capillary tube mats (2), and a facade heat exchanger (3). The excess heat present during the day is extracted from the room

In portrait

Manufacturer, developer and user – three expert opinions

Marco Schmidt

Technical Marketing for Micronal® PCM at BASF SE, co-developer of micro-encapsulated PCM systems for the building chemicals industry and manufacturers of building materials.

Microcapsules are a vehicle for integrating the physical effect of PCMs into any given building material. This technology opens up new possibilities for latent heat storage. Little additional work is involved when using this technology in buildings, however. The manufacturers of conventional building materials only need to make minimal changes to their products. The development of the first building materials such as gypsum boards, indoor plaster and aerated concrete will be followed in the near future by further innovations with PCMs. In the future, buildings will have to be able to compensate for the time difference between currently available (environmental) energy and the actual use of same. PCMs can serve as the link between heat supply and demand, particularly in lightweight constructions, in a particularly efficient manner.

Bruno Lüdemann

Imtech Deutschland R&D, Project Manager, Development and Optimisation of Energy-Efficient Systems for Building Services Technology, involved in the development of a PCM ventilation device and PCS storage devices.

Innovative storage technologies are a key technology in the optimisation of the efficiency of energy systems and the major-scale use of the time-delayed potential of environmental energy. Micro-encapsulated materials in the form of water-based slurries (PCSs) represent an alternative technology to already tried-and-tested applications. PCS technology is being used by Imtech in a pilot project for the cooling of machine tools in industry. The viability of PCM systems could be considerably increased by using significantly less expensive salt hydrates, or by developing more stable emulsions that promise a higher PCM concentration in water at lower costs when compared to slurries.

Rolf Disch

Managing Director of Solarsiedlung GmbH and Wirtschaftsverband Erneuerbare Energien Regio Freiburg; has worked for 40 years on the development of pioneering solutions for sustainable building such as the Plusenergiehaus® and the projects Heliotrop®, Solarsiedlung and Sonnenschiff.

The Plusenergiehaus designed by us combines energy efficiency and active and passive use of solar energy, and also benefits from activated building mass. PCM lightweight walls were used in the Sonnenschiff commercial development in Freiburg, and a high degree of thermal comfort was achieved in the office areas. However, measurements did not show up a causal relationship with the PCM material. This may be because the mass of the construction was already very large. PCM use is an option for lightweight construction types. In this way, the energy storage potential of solid structures can also be applied to wood and steel constructions. The comfort zone can be considerably improved by also employing night ventilation. With careful planning, additional cooling equipment may not even be necessary.

Fig. 31 *PCM heating storage device. Source: Alfred Schneider GmbH*

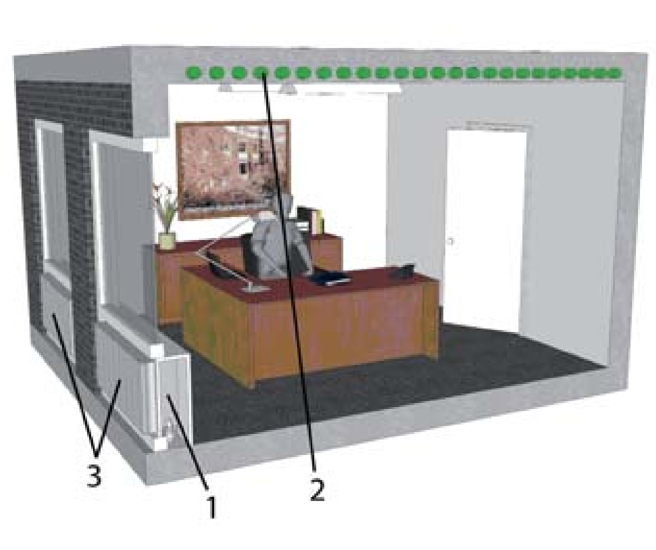


Fig. 32 *Arrangement for a cooling system consisting of a latent heat storage device (1), cooling ceiling with capillary tube mat (2), and facade heat exchanger (3). Source: TU Berlin, Hermann-Rietschel-Institut*

using the cooling ceiling. The principle here is that the water inside the capillary tube mats is heated up.

This heated water in the cooling circuit is then pumped to the latent heat storage unit. Here in the latent heat storage unit, the water is cooled and the PCM undergoes a phase change. The storage unit is regenerated once the latent material is fully melted or else when there is no longer a cooling requirement for the room. This process occurs during the night, making use of the low outdoor temperature. During this operating phase, the water circulates between the latent heat storage device and the facade heat exchanger. Inside the storage device, heat is transferred from the PCM to the water and then released by the facade heat exchanger to the surroundings by means of convection and radiation heat transfer. The latent material returns to its solid state and can then be used again for room cooling.

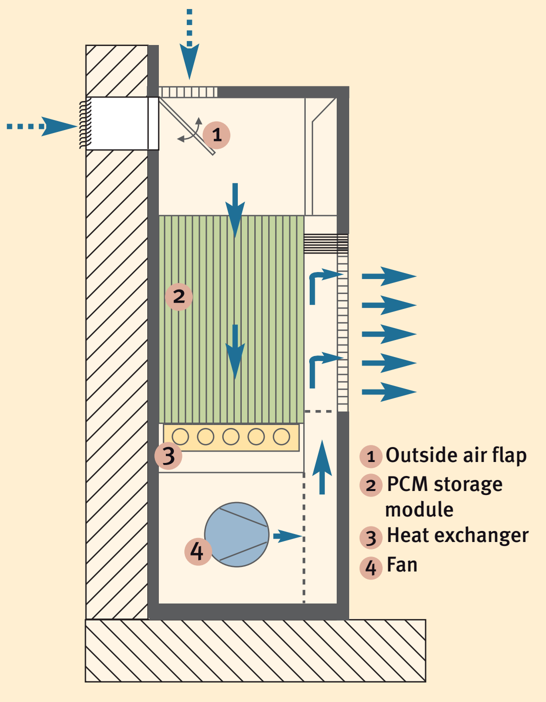


Fig. 30 *Schematic representation of the active PCM cooling module from Imtech. Source: Imtech*

In addition, the system allows for direct overnight cooling for all surfaces that enclose the room without having to open windows, which might be undesirable from a security viewpoint. Experimental and numerical investigations at the Technical University of Berlin showed a temperature reduction of up to 4 K for office rooms under typical load conditions. To achieve this significant temperature reduction, 2 kg of paraffin per square metre of room area was required. In addition, overnight cooling using water was employed for the surfaces that enclose the room.

Phase change fluids

Water is the most commonly used heat storage material that is fluid or can be pumped. In many cases, mixtures of water and glycol are also used. At high temperatures, oils are often used too. These liquid heat storage materials all store heat in the form of sensible heat.

If large heat storage capacities are to be achieved, the user can work with large volumes or else employ a large temperature increase or reduction. If a system is able to work with large temperature differences between the temperature actually required and the temperature available from the storage device, high heat storage capacities can be achieved using sensible heat-transfer fluids. If, on the other hand, only small temperature differences are possible, the amount of heat that can be stored by sensible heat-transfer media drops very considerably. For example, if the storage temperature may only be 10 K above or below the application temperature, then only 42 kJ/kg of heat can be stored using pure water. A PCM-containing liquid would be a major advantage for this type of application. When the melting temperature is suitable, the heat capacity can be increased in precisely the desired temperature range.

Water/ice mixtures, which can still be pumped up to a certain level of ice crystals, are already common on the market. However, material constraints mean that they can only be used under 0 °C. Above 0 °C, two different technologies are mainly used nowadays for adding

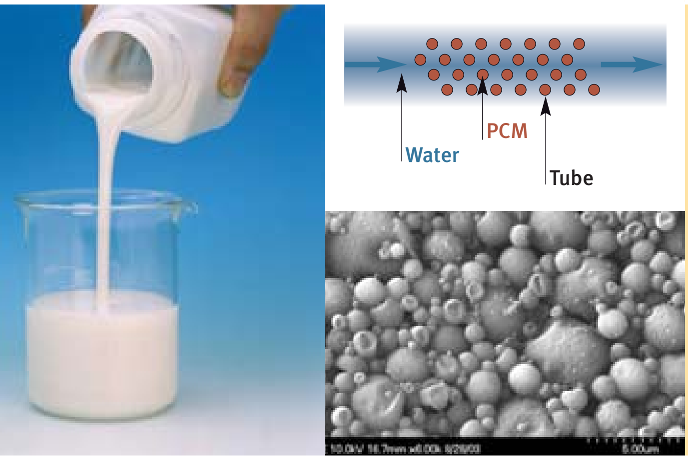


Fig. 33 *Phase change fluids (slurries) consist of a carrier fluid and a PCM suspended or emulsified in this fluid. The particle sizes present result in a white liquid. Source: ZAE Bayern (left), Fraunhofer ISE (right)*

paraffins to water: They are either micro-encapsulated and then suspended in water, or else an emulsion of paraffin in water can be created using appropriate additives. Both processes are intended to prevent the paraffin coagulating to form larger drops and separating out from the water once the paraffin has melted. At the same time, dispersion ensures that the paraffin can be pumped in both liquid and solid form.

Cooling systems are particularly well suited for the use of phase change fluids (PCM slurries), as they fulfil the requirement for low temperature differences in the system. In addition, storage of cold is advisable here in order to achieve more favourable operating conditions for the chillers used and to ease the load on the public electricity grid during the day. If, for example, a building is to be cooled to 20 °C in this time, it is possible to charge the cold storage device with a temperature as low as 0 °C during the night, but this would lead to lower coefficients of performance from the chiller used and also to higher storage losses. When using a phase change fluid with a melting range of between 10 °C and, for example, 20 °C and with double the storage density of water, the same storage density could be already be achieved by cooling the storage device to 10 °C. Another potential advantage of slurries is the relative ease with which they can be used as heat-transfer fluids in existing cold storage devices in order to increase their storage capacity.

In practice

Innovative recooler concept using PCM

Conventional systems for solar heating and cooling using absorption cooling equipment involve the release of waste heat by means of a wet cooling tower, which leads to considerable water consumption and a large amount of maintenance work. For this reason, the “Solar heating and cooling with compact absorption coolers and latent heat storage” (SolCool) research project is taking a completely new approach: In place of the wet cooling tower, a patented recooler concept using a dry air cooler and an innovative latent heat storage device is being tried out. The latent heat storage device with a phase change temperature of 29 °C stores a part of the waste heat during the day and then releases it at night. In addition, this high-capacity storage unit is available to provide short-term buffering of the solar yield during the heating period. Test runs at ZAE Bayern have shown that the use of a latent heat storage device means that recooling of the absorption cooler during cooling operation can be maintained at the required temperature level of 32 °C even when there are high outside temperatures. The increased power consumption caused by night-time discharging of the storage unit is small here, and is more than compensated by the shifting of the peak electricity requirement for recooling into low-load periods.
The solar fraction rises significantly during heating operation thanks to the use of the storage unit. On the one hand, excess heat can be buffered during the day for night-time use, and, on the other, losses from the collector drop during the charging process. The most significant factor here is the storage of latent heat at a constantly low temperature. In this way, increases in the collector temperature and the associated drops in the coefficient of performance – which occur with conventional sensible heat storage equipment – can be avoided. Over its two years in operation, the storage unit has completed around 300 heating and cooling cycles without any faults occurring. The unit leads to a significant improvement in system efficiency, especially during heating operation, thanks to its low storage temperature. The system is now being optimised with regards to the control policy and minimisation of the auxiliary energy requirement. The target is an electric COP – the ratio of the average electricity consumption to the useful cooling generated – of over 10 during cooling operation and around 8 during the heating period.

Fig. 34 *Low-temperature latent heat storage unit for the “SolCool” project. Source: ZAE Bayern*

Outlook

Intensive research work over the last two decades has identified many phase change materials that are suitable for use in latent heat storage. More than one hundred materials cover the temperature range of approximately –40 °C to about 130 °C and are available on the market; some of these materials have already been successfully used for more than 10 years now in various applications. The encapsulation techniques used here – micro- and macro-encapsulation – represent the state-of-the-art technology. There is also a recognised quality label from RAL for these products.

Sufficient, reliable experience values have not been available up to now for the various applications (solar energy, biomass use, cogeneration), meaning that the benefits of latent heat storage devices must be demonstrated in detail for each particular case. However, the results of a number of demonstration projects have already shown that significant energy savings and higher efficiencies can be achieved if sizing and design is carried out appropriately. Building materials that use micro-encapsulated PCMs are now available in a wide range of forms. Examples include gypsum plaster, gypsum boards, and composite materials with PCMs. These products were first installed in real buildings in 2004. Gypsum plasterboards are already being commercially produced and used on a large scale. Initial demonstration projects are now under way in the area of liquid storage media (PCSs), but further optimisation work and, above all, investigations regarding long-term stability are necessary in order to achieve market-ready products. Recognised planning tools and simulation models are making a significant contribution to better preparation and acceptance of these materials, as the advantages of these materials can be quantified and demonstrated.

Alongside material-related research and development, it will also be important in the coming years to gather further experience from demonstration projects and to evaluate this experience. The first pilot applications of PCM building materials were carried out as early as 2004, and since then energy savings and improved comfort have been demonstrated. For this reason, it is to be expected that these materials will become accepted as state of the art within a few years. The significant increases in energy costs worldwide, including in the USA, have led to the start-up of new companies in this market sector in recent times.

More from BINE

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- www.pcm-ral.de
- www.pcm-storage.info
- www.micronal.de
- www.glassx.ch
- www.effstock2009.com

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We can offer you assistance:

+49 228 92379-44

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