Phase Change Materials – Overview

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Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

- Phase change materials (PCMs) are environmentally benign salts or organic compounds with variable environmental credentials, which store and release latent heat.
- PCMs are an alternative energy storage methodology to current latent heat exchange systems commonly used in buildings such as thermal mass.
- PCMs can be used for any heating and cooling requirement in buildings, vehicles or fabrics, including insulation and engine cooling, refrigeration, process cooling or contributing to process heat, and combined heat and power systems.
- A potential application in light weight construction offers passive energy exchange in the absence of fabric energy storage.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Utilising PCM's as an alternative or supplementary energy storage method in lightweight construction where thermal mass is absent or negligible.
- For temperature control in buildings (space and water), there are two types of application and research. One centres on the deployment of discrete modules, encapsulated in polymers, aluminium or steel, and positioned appropriately in the building for their function and properties, the other studies impregnation of PCMs into porous construction materials such as panelboard and concrete.

Cutting EDGe Strategies

The potential value of markets for PCMs is large. The following are areas where PCMs could offer significant economic, energy and carbon reduction advantages:

- Storage of thermal energy when electricity supply and demand are out of phase. This particularly applies to intermittent renewables, and they are particularly appropriate for combining with solar domestic hot water heating or passive solar space heating systems.
- Providing a thermal mass effect for lighter weight buildings.

Synergies and References

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BDP ENVIRONMENT DESIGN GUIDE

Phase Change Materials – Overview

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This paper introduces phase change materials (PCMs) as an alternative energy storage methodology to current latent heat exchange systems commonly used in buildings such as thermal mass. A potential application in light weight construction offers passive energy exchange in the absence of fabric energy storage.

1.0 Overview

Phase change materials (PCMs) are environmentally benign salts or organic compounds with variable environmental credentials, which store and release latent heat by changing chemical bonds through a phase transformation, unlike sensible heat storage materials[1] such as water or masonry, which change structure mechanically.

Initially, solid-liquid PCMs perform like conventional storage materials; their temperature rises as they absorb heat. However, when PCMs reach their melting point (phase change temperature) they absorb large amounts of heat without getting hotter. When the ambient temperature drops, the PCM solidifies, releasing its stored latent heat. PCMs absorb and emit heat while maintaining a nearly constant temperature.

Within the human comfort range of 20–30°C, PCMs store 5 to 14 times more heat per unit volume than sensible storage materials.

PCMs can be used for any heating and cooling requirement in buildings, vehicles or fabrics, including insulation and engine cooling, refrigeration, process cooling or contributing to process heat, and combined heat and power systems.

The challenge to greater use of PCMs is their packaging, cost and knowledge, both technical and among potential customer and user communities.

2.0 Technology Status

Phase change materials are either organic compounds or inorganic (salts). A range of materials and their properties have been mapped in detail. Examples of the former are paraffin wax and carboxylic acid, and of the salts, Glauber's salt (sodium sulfate decahydrate) and calcium chloride hexahydrate. The challenge is in overcoming the disadvantages listed below (Ure, 2003; Farid, 2001; Gates, 2000) and in effective and economic heat transfer mechanisms in the wider system in which PCMs do their work.

PCMs are mostly developed for industrial refrigeration and ice production. The scope for technical improvement lies in the materials in which the PCMs are contained and in the development of new PCMs.

2.1 Containers

Requirements for containers include:

- Small scale – in the range of about 25mm width/diameter – produces best performance (US Department of Energy, 2003) – however, larger containers can also be effective
- Good heat conductance
- Strength to contain changes in PCM volume with phase change (organics)
- Impermeable to fluids and corrosion-resistant

2.2 PCM Materials

Materials on which research on solid-liquid PCMs has concentrated include: linear crystalline alkyl hydrocarbons, fatty acids and esters, polyethylene glycols, long alkyl side chain polymers, glycerines and glycols, low melting metals and alloys, ammonium clathrates and semi-clathrates, and salt hydrides (US Department of Energy, 2003).

Research blending adjacent alkyl hydrocarbon chains has led to positive temperature PCM solid-liquid materials, with phase changes above 0°C. These have single melting temperatures without significant decrease in thermal storage.

	Advantages	Disadvantages
Organic	Simple to use Non-corrosive No supercooling No nucleating agent Recyclable	Generally more expensive Lower latent heat/density Often quite broad melting range High volume changes during phase change Can be combustible Some react with concrete (calcium hydroxide)
Salt-based	Higher thermal conductivity Well defined PC temperature Non-flammable Biodegradable and recyclable	Need careful preparation Need additives to stabilise for long term use Prone to supercooling Can be corrosive to some metals

Table 1. Advantages and Disadvantages of Organic and Salt-Based Material

1 Sensible heat is the heat energy stored in a substance as a result of an increase in its temperature.

For temperature control in buildings (space and water), there are two types of application and research. One centres on the deployment of discrete modules, encapsulated in polymers, aluminium or steel, and positioned appropriately in the building for their function and properties, the other studies impregnation of PCMs into porous construction materials such as panelboard and concrete.

2.3 Modules

Module performance at one UK installation in Nottingham shows what PCMs can deliver (Ure, 2003). The positive temperature PCM E21, contained in cylindrical modules suspended horizontally just below the ceiling of a small office, freezes/melts at 21°C. No air conditioning chillers were used. Monitoring took place over 12 months. An example sample week in June showed that the equipment maintained a peak room temperature of 20–21.5°C when ambient temperatures reached 23–25.5°C, and later in the week when ambient temperature dropped to 13°C and 10°C on two days, the room temperature was maintained at 16.5 and 13.5°C respectively. The system was optimised for cooling rather than heat, so a different configuration would lever additional benefits for heating.

A variation on the modular approach is a system installed in a house by the University of South Australia, which was monitored during 2005 (Bruno, 2005). The system comprises a roof-integrated air-based solar collector, a PCM thermal storage unit in the loft space, and a fan. When solar energy is being collected and when heating is required, air is passed through the collector and then into the home. When heating is not required, air is pumped into the thermal storage facility, melting the PCM, and charging it for future use. When solar energy is insufficient, room air is passed through the storage facility, heated and then pumped into the house. When the storage facility is frozen an auxiliary gas heater is used to meet requirements. Unlike conventional domestic space heating systems, this system also provides ventilation.

2.4 Integration into Materials

Impregnating PCMs into structural elements has also been monitored. These have been organic compounds, since salts need encapsulation. The surface tension of the organics means that they do not leak from the host material even when liquid. In general, significant improvements in thermal storage were recorded, although there were differences between materials. Figure 1 shows real results which illustrate the overall findings.

Studies have also measured the effect of PCM-integrating structures on room temperature. To illustrate, one (Farid, 2003) used encapsulated PCM with a melting point of 28°C in a concrete floor. The system provided uniform passive heating throughout the day and kept the floor surface near the desired temperature of 24°C. Another study, using both experiment and simulation on PCM in gypsum board, (Athientis et al, 1997), showed a reduction of room temperature in a passive solar building of 4°C during the daytime, and that the system could reduce the heating load at night significantly. It was shown experimentally that the significant reduction in the room radiant temperature was due to the absorption of solar gains in the PCM board.

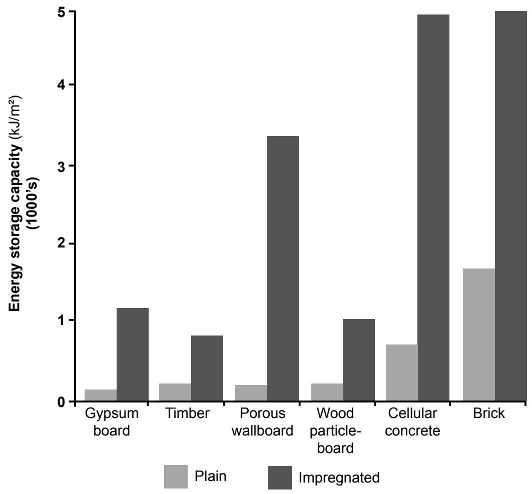

Figure 1. Energy Storage Capacities of Building Materials with and without PCMs (carboxylic acid)
(Kaasinen, 1992 via Kelly, 2000)

There are side benefits of integrating PCMs into building structures. An important one is that PCM-impregnated materials absorb less moisture than untreated materials, so are less vulnerable to damage, for example through freeze-thawing. A problem with incorporating PCM in the building envelope is that it is difficult to exchange a high rate of heat between the air and the PCM. The means of air transport through the room provides a very inefficient way of heat transfer. Air movement close to the walls, which determines the amount of heat being transferred, is relatively small. This means that the PCM may not completely melt or freeze.

3.0 Market Status

As mentioned above, cold storage for space cooling and refrigeration is the biggest market for PCMs. PCM sales are not monitored separately so it is not possible to give a value for this market.

The potential value of markets for PCMs is large. The following are areas where PCMs could offer significant economic, energy and carbon reduction advantages:

- Storage of thermal energy when electricity supply and demand are out of phase. This particularly applies to intermittent renewables, and they are particularly appropriate for combining with solar domestic hot water heating or passive solar space heating systems.
- Providing a thermal mass effect for lighter weight buildings.

PCMs themselves are not expensive, but the packaging and processing to achieve reliable, consistent performance puts a cost premium onto the products. An additional barrier to a wider market is lack of awareness of the technology, how it can be used, and its benefits.

PCMs are also used for clothing. Outlast Technologies Inc. has over 20 patents which incorporate microencapsulated PCMs into coatings for clothing. The company appears to be on its own in this field. There is clearly potential for PCMs to be applied to household items such as curtains, carpets, rugs or blankets.

Council House 2 (CH2) is a 10-storey office building with ground-floor retail spaces and underground parking in Melbourne (refer http://www.ch2.com.au). The building employs a number of systems for heating and cooling. It also makes use of a 15ºC PCM to reduce overall space cooling energy. The PCM is encapsulated in 30,000 stainless steel balls which are divided into three 10 m^3 tanks. The balls have a diameter of 100mm.

Other possible commercial applications of PCMs include paving materials to minimise night-time icing, while reducing surface damage from freeze-thaw cycling.

4.0 Relevant Legislation

Currently, the Building Code of Australia does not reference PCMs. In the UK, revised Part L of the Building Regulations and the Energy Performance of Buildings Directive, both effective in 2006 include are two key sets of more stringent requirements for which PCM products can provide compliance solutions.

5.0 Environmental and Economic Benefits

5.1 Energy Efficiency

Per unit volume, PCMs store and release between 2 and 14 times the amount of thermal energy which latent heat-storing materials do.(Ure, 2003; Kelly, 2000) For example, calcium chloride hexahydrate, at its melting point of 29°C, can store/release 190kJ/kg of energy. To store the same amount of energy, water would have to be heated so that its temperature increases by 45°C and the temperature of concrete would have to increase by 190°C.

In addition, because PCMs can absorb free energy, PCM thermal storage can shift most of the electrical load for buildings with mechanical air conditioning from peak to off-peak periods. If applied to enough buildings, this would reduce the requirement for peak power generation, and therefore greenhouse gas emissions, and any upgrading of transmission networks which would otherwise be necessary.

There is research to be done to measure the u-values of PCMs in structures and more efficient ways to transfer stored heat from them into spaces. This would enable us to calculate potential carbon savings.

5.2 Materials Efficiency

The corollary of the energy efficiency is that much less material is needed to store, upgrade and release thermal energy if PCMs are used. PCMs therefore have the potential to significantly reduce the tonnage of material mined or imported for construction, by up to 14 times. Figure 1 illustrates this potential.

5.3 Benign Chemistry

PCM salts are not pollutants or toxins, and are expected to be readily biodegradable, according to PCM safety datasheets. Their maximum harm factor is as eye irritants if directly in contact with the eye.

6.0 Improving PCMs Environmental Credentials

While PCMs themselves have advanced environmental credentials, the materials in which they are encapsulated as finished thermal storage products could be improved.

Organic compounds have a more heterogeneous environmental profile, including their origin and embodied energy, so each should be considered before use.

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Biography

Phil Sheppard is Operations Director at the Centre for Sustainable Engineering in the United Kingdom, which was established in 2004 to support businesses developing innovative and more sustainable technologies. The Centre is designed to exploit opportunities offered by significant predicted growth in demand for many sustainable technologies, both in the UK and internationally. The centre aims to deliver expert information and evaluation services with the support of its partners, to provide an overview of the various fields, to provide technology transfer support and undertake applied research. The Centre's activities focus on new and emerging materials and product and process technologies that integrate the use of energy, materials, water and chemistry with the environment.

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