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Review

Phase change materials for building applications: A state-of-the-art review

Ruben Baetens [a,b,c], Bjørn Petter Jelle [a,c,*], Arild Gustavsen [d]

[a] Department of Materials and Structures, SINTEF Building and Infrastructure, NO-7465 Trondheim, Norway
[b] Division of Building Physics, Department of Civil Engineering, K.U.Leuven, Leuven, Belgium
[c] Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway
[d] Department of Architectural Design, History and Technology, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway

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ABSTRACT

Phase change materials (PCMs) are regarded as a possible solution for reducing the energy consumption of buildings. By storing and releasing heat within a certain temperature range, it raises the building inertia and stabilizes indoor climate. Within this work, a state-of-the-art review is given on the knowledge of PCMs today for building applications.

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1. Background

Since the European Union decided to reduce their greenhouse gas emission by accepting the Kyoto-protocol of the UNFCCC—United Nations Framework Convention on Climatic Change in 1997, many serious steps have been taken. A promise was made that emissions 8% lower as the levels in 1990 would be reached in 2008–2012 and levels 20% lower in 2020 (United Nations, Kyoto protocol to the united nations framework convention on climate change, 1998).

In 1999, the total energy consumption in Europe was 1780 million tons of oil equivalent, for which 35% was used in the residential and commercial sector. It became clear that reducing the heat losses of buildings or in general the total energy consumption of buildings

* Corresponding author at: Department of Materials and Structures, SINTEF Building and Infrastructure, Høgskoleringen 7 B, NO-7465 Trondheim, Norway. Tel.: +47 73 593377; fax: +47 73 593380.
E-mail address: bjorn.petter.jelle@sintef.no (B.P. Jelle).

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can have a major impact on the total greenhouse gas emissions in Europe. Traditional insulation materials were and are being used in thicker or multiple layers in order to achieve higher thermal resistances, but resulting in more complex building details, an adverse net-to-gross floor area and possible heavier load bearing constructions. But simultaneously, another strategy won interest.

A certain performance of insulation is generally expressed in static terms as the thermal resistance or thermal transmittance of the exterior building envelope, describing the heat flow for a static temperature difference between two faces. However, such a static point of view can be extended by introducing a dynamical term, the heat storage coefficient K (W/(m^2 K)), to come to the index of inertia. This heat storage coefficient depends on the thermal conductivity, the volumetric heat capacity and the seasonal heat flow wave. As a result, the index of inertia expresses the resisting ability of the building envelope to a periodical heat flow wave. Phase change materials have been addressed and studied widely to influence (i.e. increase) this index of inertia and as such result in a lower energy consumption for buildings.

In this work, an overview is given on the different kinds of phase change materials (PCMs) and their specific properties and possibilities for building applications. Several more PCMs are known, but only those suitable for building applications will be treated in the text. Secondly, an outline is given on current possible building applications of PCMs such as enhanced gypsum wallboards or concrete.

2. Introduction to phase change materials

The main property of phase change materials is the storage of heat energy in a latent form, leading to greater heat storage capacity per unit volume than that of conventional building materials. When the ambient temperature rises, the chemical bonds of the material will break up whereby the material will change from solid to liquid. This phase change is an endothermic process and as a result will absorb heat. As the ambient temperature drops again, the PCM will return to the solid state and give off the absorbed heat. This cycle stabilises the interior temperature, cuts off-peak cooling loads and decreases heating loads, not by affecting the thermal resistance of the building envelope but by influencing the (surface) temperatures.

Including such phase change materials in building constructions, some specific thermal, physical, kinetic and chemical properties are desired:

i. From a thermal point of view, a suitable phase change temperature range, a high latent heat of fusion and a good heat transfer towards the PCM are desired. The desired phase change temperature will depend on climatic conditions and the desired comfort temperature.
ii. From a physical point of view, a favourable phase equilibrium, i.e. no phase segregation, a high density and small volume changes at the phase change are desired for easy incorporation in existing building materials or structures.
iii. From a kinetic point of view, no supercooling and a sufficient crystallization rate are desired to make optimal use of the properties and possibilities of PCMs. Supercooling, i.e. the process of lowering the temperature of a liquid below its freezing point without becoming a solid, could strongly affect the performance of the PCMs based on the chosen suitable phase change temperature by influencing this temperature.
iv. From a chemical point of view, a long-term chemical stability of the PCM despite cycling, compatibility with construction materials, non-toxicity and no fire hazard is desired.

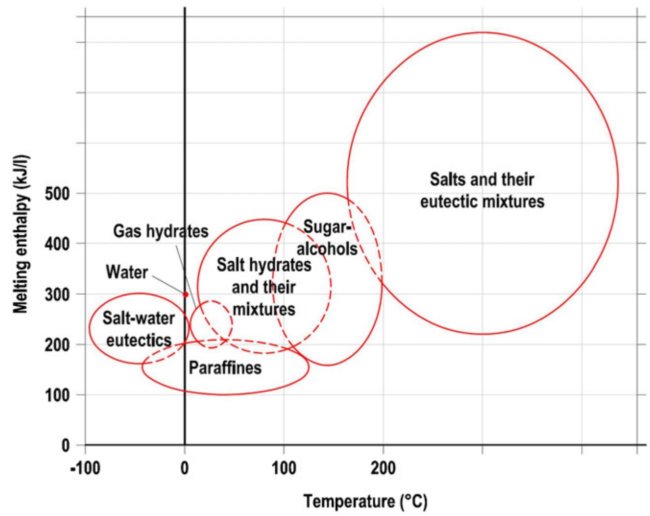

Fig. 1. The melting enthalpy and melting temperature for the different groups of phase change materials (redrawn from [43]).

Phase change materials can be divided into different subcategories based on their chemical composition. Three groups are commonly made: (i) organic compounds, (ii) inorganic compounds and (iii) inorganic eutectics or eutectic mixtures. The group of organics can be divided in paraffins and non-paraffins. Each group has its typical range of melting temperature and its range of melting enthalpy (see Fig. 1) and an overview of common PCMs from each group is given in Table 1.

Research has until recently primarily been concerned on inorganic compounds, i.e. hydrated salts, which requires support and containment, and cannot be directly incorporated into a building material. One crucial question for these materials was which container was most suitable for the specific phase change material, because degradation through time will occur due to cycling. However, the use of organic PCMs has been investigated in the last decade [1,2,45], demonstrating the possibility of impregnating porous building materials with it and in this way creating a direct-gain storage element [3].

2.1. Organic phase change compounds

Organic phase change materials are in general chemically stable, do not suffer from supercooling, are non-corrosive, are non-toxic and have a high latent heat of fusion. Organic PCMs can be subdivided in two groups: paraffins (i) and non-paraffins (ii).

Commercial paraffin waxes (i) or $CH_3(CH_2)_nCH_3$ are inexpensive and have a reasonable thermal storage density of 120 kJ/kg up to 210 kJ/kg. Paraffins are available in a wide range of melting temperatures from approximately 20 °C up to about 70 °C, they are chemically inert, have a low vapour pressure in the melt and do not undergo phase segregation. Differential scanning calorimetry (DSC) has also shown that technical grad paraffin waxes do not show any indication that thermal cycling can significantly degrade its thermal performance.

However, paraffins have a low thermal conductivity of about 0.2 W/(m K) which limits their application [4] and have a large volume change during the phase transition [5]. Metallic fillers and matrix structures are used to improve the thermal conductivity, while plastic containers and different geometries of containers are used to overcome the volume change during melting and freezing, but these issues remain to be solved for applying the paraffin PCMs in buildings.

The non-paraffin organics (ii) include a wide selection of organic materials such as fatty acids, esters, alcohols and glycols. They

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