

HEAT STORAGE FOR ENERGY DEMAND REDUCTION IN LOW-ENERGY BUILDINGS



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Summary

Currently we can see trend to use light-weight building materials for external or internal structures. The rooms, whose envelopes are made from light-weight materials, often don't execute requirements on the thermal stability in summer time. Increase of the thermal storage capacity of the building materials has a major effect on the thermal stability of indoor climate. Common massive structures, like masonry, concrete walls or floor slabs, can store thermal energy by their own thermal storage capacity. It depends especially on the mass of each structure. Low-energy building with light-weight envelopes has small thermal storage due to a low mass of load-bearing and non-bearing structures. In case of storing energy, e.g. from solar radiation, designers have to design a special bulky storage equipment. We can reduce volume of these containers by using Phase Change Materials. Installation phase change materials is one of the ways how to improve thermal storage properties of the light-weight envelopes. The principle is that instead of increase the mass of the envelopes is used latent heat of the phase change materials with low melting point.

Keywords: Light-weight structures, thermal heat storage, phase change materials

1 Heat Storage

There are three methods of storing thermal energy [2]:

- sensible heat storage;
- latent heat storage;
- thermochemical heat storage.

They differ in the amount of heat that can be stored per unit mass or volume of storage medium, in the melting point of medium and relative state of development of storage technology at the present time.

1.1 Sensible Heat Storage

In this type of heat storage thermal energy is stored by changing the temperature of the storage medium [2]. The amount of heat stored depends on the heat capacity of the medium, the temperature change and the amount of storage medium. Sensible heat storage can utilize solid or liquid storage medium. Process can be describe by equation (1).

$$Q = \int_{T_1}^{T_2} mcdT = m \cdot c \cdot (T_1 - T_2) \quad (1)$$

Q	quantity of heat stored [J]
m	mass of heat storage medium [kg]
c	average specific heat between T_1 and T_2 [$\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$]
T_1	initial temperature [K]
T_2	final temperature [K]

The most popular liquid medium is water, which must be contained. Usually water is used like a liquid heat transfer medium and often water itself is employed. For a solid storage medium can be employed a stone, a concrete structure or a brick masonry. Sensible heat storage is the least efficient method of the heat storing, since much less of the thermal energy is involved in the temperature raising of a material than in the melting a crystalline compound or in the breaking chemical bonds.

1.2 Latent Heat Storage

In latent heat storage the thermal energy is stored by means of a reversible change of a state or a phase change of the storage medium [2]. Solid-liquid transformations are the most commonly utilized, though the solid-solid transitions have been investigated. Latent heat storage systems also make use of some sensible heat capacity in the system. The heat of fusion usually predominates, but considerable the heat can be added by sensible storage.

$$Q = \int_{T_1}^{T_m} mc_p dT + ml_m \Delta h_m + \int_{T_m}^{T_2} mc_p dT = m[l_m \Delta h_m + c_{ps}(T_m - T_1) + c_{pl}(T_2 - T_m)] \quad (2)$$

Q	quantity of heat stored [J]
m	mass of heat storage medium [kg]
T_1	initial temperature [K]
T_2	final temperature [K]
T_m	melting temperature [K]
c_{ps}	average specific heat between T_1 and T_m – solid phase [$\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$]
c_{pl}	average specific heat between T_m and T_2 – liquid phase [$\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$]
l_m	heat of fusion per unit mass [$\text{J} \cdot \text{kg}^{-1}$]
Δh_m	fraction melted [-]

Latent heat is less familiar in the human experience than sensible heat. Latent heat storage has the advantages of a higher heat capacity that can reduce a volume and a weight of the storage unit.

The use of the phase change materials (PCMs) for latent heat storage has lagged behind the sensible heat storage. This is partly because the latent systems represent a higher level of the technology.

1.3 Thermochemical Heat Storage

Thermochemical systems rely on the energy absorbed and released in the breaking of the reforming molecular bonds in the completely reversible chemical reactions [2]. Stored heat depends on the amount of the storage medium, the endothermic heat of the reaction and the extent of conversion.

$$Q = a_r m \Delta h_r \quad (3)$$

Q quantity of heat stored [J]
 m mass of heat storage medium [kg]
 a_r fraction reacted [$\text{J} \cdot \text{kg}^{-1}$]
 Δh_r heat of reaction per unit mass [-]

Thermochemical heat storage has the advantages of more compact systems, long-term storage with a little loss and a room temperature storage without insulation. However products must not be corrosive to materials of a construction and all the chemicals, which are used must be safe and environmentally appropriate. The thermochemical storage technology is relatively more sophisticated than sensible or latent heat storage.

2 Phase Change Thermal Storage

Phase change materials (PCM) have considerably the higher thermal energy storage densities compared to sensible heat storage materials and are able to absorb large quantities of energy at a constant temperature during the phase change.

For liquid solid transformation like PCM [1] can be use:

- inorganic compounds
 - salt hydrates with melting point from 0 up to 150 °C
 - other inorganics with high melting temperature
- organic compounds
 - paraffins
 - non paraffin organics: fatty acids, other non-paraffin organics

2.1 Organics

Organic PCMs have the poorer heat transfer properties, lower density and greater fire hazard. In general they are more expensive than inorganics. Paraffins are mineral oil products. They consist mostly of the organic family alkanes which have the general formula $\text{C}_n\text{H}_{2n+2}$. This family of saturated hydrocarbons has compounds with similar properties.

Paraffins exhibit many desirable characteristics as a PCM for storage purposes:

- are available abundantly;
- are non-corrosive and non-toxic;
- have high latent heat of fusion;
- are chemically stable;
- have low density;
- have low volume change during melting;
- are self nucleating.

2.2 Salt hydrates

This is an important group of inorganic substances in the temperature range from 0°C up to 150 °C (**Fig. 1**). As a group they offer good heats of the fusion and the heat transfer properties are generally good. All these materials display a vapour pressure due to their water content. All should be hermetically sealed in containers.

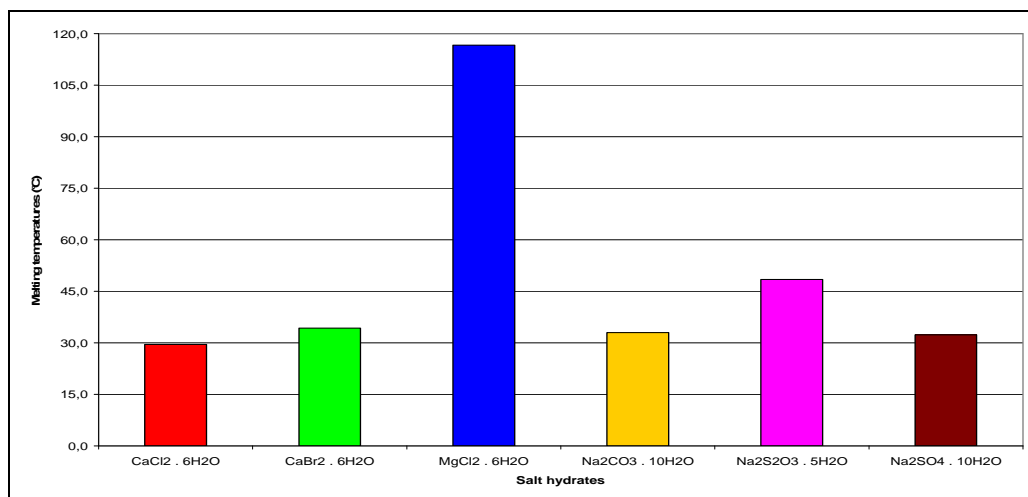


Fig. 1 Melting temperatures for selected salt hydrates

Two problems with these PCMs were investigated:

- incongruent melting
- supercooling

Water of crystallization released during thawing is not sufficient to dissolve the solid present. The solid settles down at the bottom of the container due to its higher density. During the reverse process a substantial part of the settled salt is unable to come into the contact with water required for its crystallization. The energy density of the storage reduces after the several charge and discharge cycles.

The second problem is supercooling. On cooling the solidification or crystallization does not take place at the melting point. Due to the supercooling the PCM does not discharge the stored thermal energy at the melting point as it was expected to do. The supercooling in salt hydrates can be considerably reduced by promoting of the nucleation by one of the following means:

- adding a small amount of nucleating agent which has crystal structure similar to PCM;
- mechanical means such as rough container walls and rough heat exchanger surface to promote heterogenous nucleation.

Salt hydrates are generally compatible with plastic containers, except that some plastics are not serviceable at the melting points of some of higher-melting PCMs.

2.3 Phase Change Materials in Light-weight Structures

PCMs can be encapsulated into a plastic film. The use of a plastic film to encapsulate PCMs for heat storage applications is attractive because of the potential economy and versatility. Pouches with phase change materials are placed in an energy storage box,

supported by the racks. Flat pouches can be laid on the top of suspended ceiling, e.g. from gypsum boards. The next development member is usage HDPE pipes. These pipes are filled with phase change material and sealed hermetically. This form provide strong and leak-proof barrier for provision properties for long time.

Another possibility for PCMs encapsulation is used by the French company Cristopia. Company offers energy nodules with diameter 77, 78 and 98 mm. For encapsulation is used blend of polyolefins. Penwalt Corp. produce roughly spherical pellets. The encapsulate is a tough polymeric coating, which can be varied in thickness, depending on the specific application. German company Ruritherm GmbH offers paraffin based phase change materials with melting temperature from $-3\text{ }^{\circ}\text{C}$ to $100\text{ }^{\circ}\text{C}$. Company supply PCMs as fibre boards, granulate and powder.

3 Practical Measurement

Aim of our research at Brno University of Technology was the verification of positive effect of the PCM on thermal stability in the buildings in the summer season. For this purpose we needed two identical experimental objects for verification of behaviour of PCM. For the verification of the properties of the PCMs salt hydrates were erected two identical experimental objects in village Vrtežir situated west from Brno. Each of them has composition of the envelopes from light-weight materials. In each object was in the external wall installed single glazed window. As phase change material was used salt mixture on the base calcium chloride hexahydrate in object No. 1. We installed PVC tubes filled in salt mixture in object No. 2. We situated 6 tubes with diameter 63 mm under the ceiling. The length of each tube was 1,0 m. Each end of the tubes was closed by PVC plug. There was a space for flowing of indoor air between tubes and ceiling. On the picture (Fig. 2) there is a view of tubes with PCM. Last year instead of the tubes with PCM we used boards from gypsum plaster with encapsulated PCM (Fig. 3).



Fig. 2 View of tubes with the salt hydrate mixture



Fig. 3 View of wall boards with PCM

Experiment was successful because maximum daily temperatures in object with PCM were lower than in object without PCM. For example maximum daily temperature in object No. 1 (without PCM) was $36,1\text{ }^{\circ}\text{C}$ for day 10.9. and in object No. 2 there was maximum daily temperature $32,3\text{ }^{\circ}\text{C}$. So the difference is $3,8\text{ }^{\circ}\text{C}$. On the other side temperatures

during the night in object No. 2 were higher than in object No. 1. It was due to the solidification of the salt hydrate. Heat stored in the salt was loosed to inner space.

Tab. 1 Thermal properties of used materials

Material	Melting point [°C]	Latent heat [kJ/kg]	Specific heat - liquid [kJ/kg.K]	Specific heat - solid [kJ/kg.K]
Salt mixture	25,5 to 27,0	192,0	2,2	1,4
Wall board	23,0 to 27,0	18,0	1,0	1,0

4 Conclusions

Generally we can say that phase change materials have two effects on the thermal stability of the indoor climate. During the day these materials cause decrease of the temperature due to the phase change solid-liquid and during the night they cause increase of indoor temperature during the phase change liquid – solid.

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