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# Thermal conductivity of gypsum with incorporated phase change material (PCM) for building applications

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**Abstract**

The paper presents the results of thermal conductivity measurement of gypsum-based composites incorporating microencapsulated phase change material (PCM). Samples of different concentration of PCM were analyzed in the temperature range typical for building indoor conditions. The investigation showed the major impact of both PCM content and temperature on thermal conductivity. The materials under investigation are used in manufacturing structure elements for building applications. Gypsum wallboards, thanks to the contribution of PCM, have substantially increased thermal capacity (thermal inertia); properly incorporated in the building envelope such materials can stabilize indoor temperature (thereby improving thermal comfort) and, as they operate as thermal energy storage elements, reduce energy requirements of buildings.

*Keywords:* phase change materials, building materials, thermal conductivity

## 1. Introduction

Energy consumption in building sector accounts of about 40 % of the total energy use [1]. Of this around 60 %, is used for space conditioning (heating and cooling). These numbers underline the savings achievable in total energy consumption through relatively minor reductions in energy demand in the building sector.

Substantial decrease in energy use in building can be achieved by improving the insulation properties of building envelopes (walls, roofs), thereby reducing unwanted heat losses or gains. Another approach focuses on the accretion of thermal inertia of the building's structure, thus increasing the potential to accumulate thermal energy. In buildings with high thermal inertia excess heat, which is generated in large amounts for instance in office spaces, can be accumulated in walls and ceilings without an undesirable substantial increase in indoor temperature. In addition heat from external sources, such as solar radiation, can also be stored in this way. Accumulated heat is then used during the night to prevent a drop in temperature. Cold too can be stored in the structure during the night (utilizing low air temperature), thus reducing the demand for air conditioning during daytime activity.

Increase in the thermal inertia of building structures can be easily obtained by the use of phase change materials (PCMs) that have very large thermal capacity due to the phase change (melting – solidification) that occurs during use. Even a small amount of these materials raises thermal inertia substantially without increasing the mass of the structure. Interest in the application of PCMs in buildings

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has increased over the last decade, basically due to improvements in capsulation technologies for these materials and the invention of new types of construction materials containing PCMs. Many review papers can be found in the literature [2–9]. In these papers both technologies and the properties of the PCMs under consideration are discussed in detail.

There are three ways of incorporating PCMs in building structures:

• Blending PCMs with construction materials such as concrete or gypsum during the manufacture of bricks or plasterboards,

• Incorporation of macro-capsules with PCM in free spaces inside building, e.g. above suspended ceilings or under floors,

• Incorporation of PCM in parts of furniture or window blinds.

Of these methods only the first two have practical significance. The first method is the subject of intense scientific research, whereas the second is relatively simply to use; its development is limited only by materials with adequate properties (mainly phase change temperature which must be consistent with the application). The composites of base building materials with PCMs should satisfy both mechanical and thermal requirements, with their properties being strongly dependent on many factors, such as the form and concentration of PCM, its chemical composition among many others.

PCM research and development over the last five decades (the first tests were performed in 1960s) has explored several techniques [2, 3, 10] but only two seem promising for the future:

• Use of microencapsulated PCMs – polymer-coated micrometer-sized beads. This method prevents direct contact between the PCMs (mostly hydrocarbons) and the concrete or gypsum, and possible chemical deterioration of the composite. In addition, there is no risk of PCM leakage after its melting.

• In the second method special porous polymers of high porosity (up to 80%) are filled with PCM. The structure of the porous materials provide stability for these composites even when PCM melts. These composites are known as "shape stabilized PCMs".

## 2. The aim of the work

The choice of PCM is central to developing building envelope materials which will effectively accumulate heat. The most important factors are melting temperature (ideally in the range 19 to 26°C) and latent heat. Secondary properties such as thermal conductivity, cyclic stability, solidification without supercooling must also be taken into consideration [4–6].

Where organic PCMs are used the concentration of PCM in the final product is limited mainly by mechanical properties and fire resistance issues. Due to these limitations the amount of microencapsulated PCM in plasterboards and concrete bricks does not exceed 30 %. Thermal conductivity is a property of great importance in the final product. In the building envelope these elements work as thermal storage units, i.e. they absorb and release heat in a daily cycle. To be effective, during one cycle they should be fully charged (all PCM should melt) and then fully uncharged (all PCM should solidify). Charging and discharging depends on the thermal conductivity of the composite. It is well known that PCMs have rather small values of thermal conductivity, of 0.1 to 0.3 W/(m·K). Much research work centers on improving the effective thermal conductivity of PCM based products, basically through highly conductive additives.

Research study conducted at the Institute of Heat Engineering is focused, among others, on investigating the physical properties of building composites made of gypsum and microencapsulated PCM. Some results related to thermal capacity were published in [11, 12].

This paper presents results of the measurement of thermal conductivity of gypsum and microencapsulated PCM composites. These data are highly important when investigating performance characteristics of buildings elements made of such composites through numerical simulation of transient heat transfer processes.

Composites under investigation were made of gypsum mortar (Knauf) with addition of microencapsulated PCM produced by BASF – Micronal DS 5008 X. This PCM is specially designed for building applications. It is made of hydrocarbon – paraf-

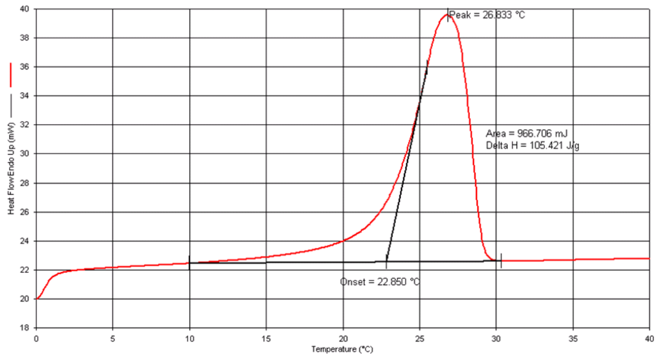


Figure 1: DSC curve for Micronal DS 5008 X

fin (organic PCM). Its basic properties are: melting point 23.5°C, latent heat 102.6 kJ/kg, specific heat of solid 2.42 kJ/(kg·K) and specific heat of liquid 2.30 kJ/(kg·K). Producer's data were confirmed in DSC measurement – Fig. 1 shows an example DSC curve for this PCM.

For the purpose of thermal conductivity measurement, samples of various concentrations of PCM were prepared (with sample of pure gypsum as a reference). The PCM accounted for 10, 20 and 30 % of total weight (in terms of mass of dry constituents). The final PCM concentration was slightly lower (due to water content): 9.04, 18.3 and 27.6 % respectively. Samples were dried for a few weeks in ambient temperature. They could not be dried in higher temperatures (typically 105°C) because of PCM which melts in about 23°C, and in case of too high temperature could deteriorate the sample owing to volume change with temperature.

## 3. Thermal conductivity measurement technique

Thermal conductivity was measured using miniature plate apparatus (Poensgen type), where heat flow in steady state through the sample of a square cross-section, along with temperature differences between face surfaces are recorded.

The measurement stack in this apparatus is shown in Fig. 2. The sample is placed between the electric heater and copper plate. The hot plate above the electric heater assures unidirectional heat flow from the heater down through the sample. The copper plate below the sample provides uniform temperature distribution on its surface – this temperature is recorded by the thermocouple placed in the plate. Lower, the

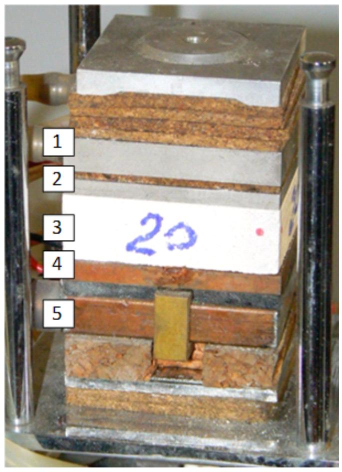


Figure 2: Measurement stack in plate apparatus; 1 – hot plate, 2 – electric heater, 3 – sample, 4 – copper plate, 5 – cold plate

cold plate removes heat flowing through the sample. The desired temperature range of the test is established by setting temperature levels on the thermostats that supply the hot and cold plates. Unidirectional heat flow is achieved by adjusting the electric power supply to such a level that temperature of the heater is equal to the hot plate temperature.

Thermal conductivity is determined from the following formula

$$k = \frac{U \cdot I \cdot \delta}{a \cdot b \cdot (T_h - T_c)} \tag{1}$$

where: $U$, $I$ – voltage and current supply of electric heater, $\delta$ – thickness of the sample, $a$, $b$ – lengths of sides of a sample, $T_h$ – temperature of the electric heater (upper surface of the sample), $T_c$ – temperature of the copper plate (lower surface of the sample).

For each sample, measurements were done in three temperature ranges:

- Upper temperature of the sample of about 24°C (since satisfactory accuracy requires a 10°C difference the lower temperature was about 14°C), in this case the PCM inside the sample was in solid state,
- Mean temperature of the sample of about 24°C, in this case approximately half the PCM melted, the rest remained in steady state,
- Lower temperature of the sample of about 24°C (upper surface temperature was about 34°C), in this case the whole PCM was in liquid phase.

Side dimension of the samples were between 50 and 52 mm, while their thickness was about 16 mm.

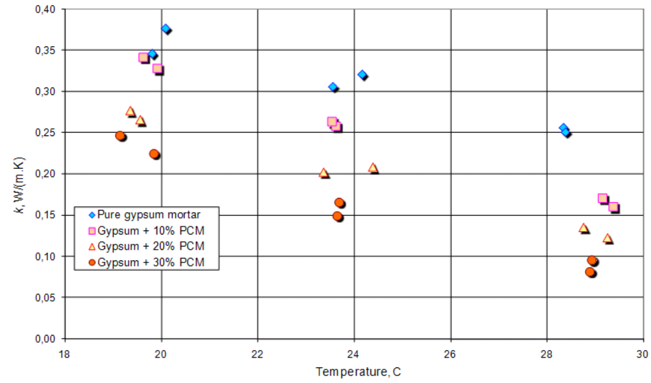


Figure 3: Thermal conductivity of gypsum-PCM composites as a function of temperature

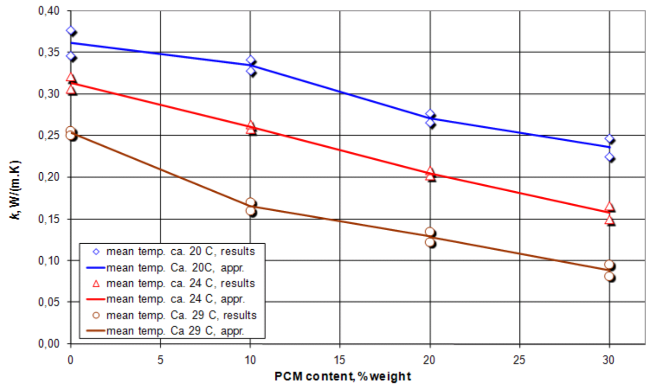


Figure 4: Thermal conductivity of gypsum-PCM composites as a function of PCM concentration

## 4. Results and discussion

The collected results of the measurements are presented in the following figures. Fig. 3 shows the results of all measurements, i.e. thermal conductivity vs. mean temperature of the sample. At least two tests were done for each sample and for each temperature level. In practice, in order to reach steady state both thermostat temperatures and heater voltage were adjusted simultaneously. As a consequence the mean temperature of the sample differed slightly from the assumptions set out above. It is worth noting that good repeatability of the results was obtained using very simple apparatus.

Fig. 4 shows variations in the thermal conductivity of gypsum-PCM composites with the concentration of PCM (for three temperature levels).

The results show the strong influence of both temperature and PCM concentration on thermal conductivity of the composite. The decrease in thermal conductivity with temperature is associated with the thermo-physical properties of pure gypsum mortar. The thermal conductivity of 100 % gypsum drops from about 0.35 to about 0.25 W/(m·K) in the temperature range under consideration, i.e. from 19 to 30°C. Similar trends are visible in the case of composites with PCM. It can be concluded that change of phase of PCM (melting) does not have a substantial influence on thermal conductivity. However, concentration of PCM has a significant impact on thermal conductivity. In the case of 30 % concentration of PCM thermal conductivity for higher temperatures drops below 0.1 W/(m·K), i.e. below the thermal conductivity of pure paraffin. This behavior is associated with the thermal contact resistance on the surface of PCM inclusions – a large amount of micrometer size beads with a large interface area.

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