

PHASE CHANGE MATERIALS FOR PASSIVE COOLING OF ATTIC SPACES

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Abstract

Thermal comfort and thermal stability of indoor climate depend on the heat storage capacity of envelopes. The increasing of using lightweight structures can cause the serious discomfort of indoor environment due to the low heat storage of walls and ceilings. The solution of this problem is to involve air-conditioning during hot summer days. The using of air-conditioning increases consumption of electric power. The installation and incorporation of phase change materials can improve heat storage capacity of envelopes without need to rapidly increase the weight of building structures. Paper is focused on the possibilities of using of phase change materials and first results from in-situ measurements.

Key words: *passive cooling, indoor environment, phase change materials, lightweight structure, latent heat storage, attic space*

1. INTRODUCTION

As we know, many factors influence the indoor air temperature of a building. First group of factors include outdoor temperature, wind velocity or solar radiation. The second group include building structure's thermophysical properties like thermal storage capacity of walls, thermal conductivity of wall, thermal resistance of external walls. Indoor environment influence heat sources, air change rate and heating or cooling equipments (Zhang et al., 2007).

The increased use of electrical energy for cooling and heating purposes has led to a large difference in energy consumption between peak hours and off peak hours. Due to an increased use of comfort cooling and use of structures with low thermal storage capacity the seasonal electricity peak demand is serious problem in summer time. Thermal energy storage for space cooling of buildings is becoming increasingly important due to the rising cost of fossil fuels and environmental concerns.

2. THERMAL ENERGY STORAGE SYSTEMS

The thermal energy can be stored when energy from solar radiation is abundantly available and used when it is needed (Regin et al., 2008). The thermal energy storage systems can operate with sensible heat storage or latent heat storage. Of course we can use in many cases the combination of both.

2.1 Sensible heat storage

The most common way for thermal energy storage is to utilize the sensible heat change with temperature. Sensible heat storage systems utilizes the heat capacity and the change in temperature of the material during of charging and discharging. The amount of heat stored depends on the specific heat of the material, the temperature change and the amount of storage medium (Sharma et al., 2009). 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 (Lane, 1983).

2.2 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 (Lane, 1983). Solid-liquid transformations are the most commonly utilized. 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.

$$Q = \int_{T_1}^{T_m} mc_p dT + ml_m \Delta h_m + \int_{T_m}^{T_2} mc_p dT = m[l_m \Delta h_m + c_{ps}(T_m - T_1) + c_{pl}(T_2 - T_m)] \quad (1)$$

Q quantity of heat stored [J]

M mass of heat storage medium [kg]

T₁ initial temperature [K]

T₂ final temperature [K]

T_m melting temperature [K]

c_{ps} average specific heat between T₁ and T_m – solid phase [J.kg⁻¹.K⁻¹]

c_{pl} average specific heat between T_m and T₂ – liquid phase [J.kg⁻¹.K⁻¹]

l_m heat of fusion per unit mass [J.kg⁻¹]

Δh_m fraction melted [-]

Phase change materials (PCMs) are latent heat storage materials (Sharma et al., 2009). The thermal energy occurs when the material changes from solid to liquid, or liquid to solid. The latent heat storage is one of the most efficient method of storing energy (Farid et al., 2004). The latent heat storage method provides much higher storage density with a smaller temperature difference between storing and releasing heat. Heat is released during a change in phase of a material.

All material undergo phase transitions, thus have an associated latent heat. When a substance melts, vaporizes and sublimates, heat is absorbed. Thermal energy is released when the material solidifies. The temperature remains nearly constant during the phase change. PCMs with melting point between 20 and 28 °C are used for passive and active systems for heating and cooling in building. Structures with PCM can store a big amount of solar thermal energy during the hot days.

3. PCM IN BUILDING ENVELOPE

The idea of improving the thermal comfort of buildings with lightweight structures by integrating of PCMs into the building structures has been investigated by in various research projects over several decades (Sharma et al., 2009).

The PCMs are used for the storage of solar energy or peak electric energy. PCMs have been successfully incorporated into material of envelope such as gypsum wallboard, wooden board, lightweight concrete, slip-cement board, concrete structures or floor tiles to enhance the thermal energy storage capacity of envelope (Zhang et al., 2007). First advantage of envelopes with PCM is

that the envelope of a room offers large area for passive heat transfer. These envelopes can increase thermal storage capacity for utilization of solar energy. The second advantage is the elimination of energy consumption for ventilation because the PCM are directly in contact with internal environment.

The nighttime cooling storage can be achieved by natural ventilation. PCM incorporated into the lightweight envelopes can increase thermal storage capacity of these structures, thus reducing and delaying the peak heat load and reducing room temperature fluctuation.

PCM could be incorporated directly in building structures such as vertical walls, horizontal floor structures, on the top of suspended ceilings or in the composition of floor finishing (Figure 1).

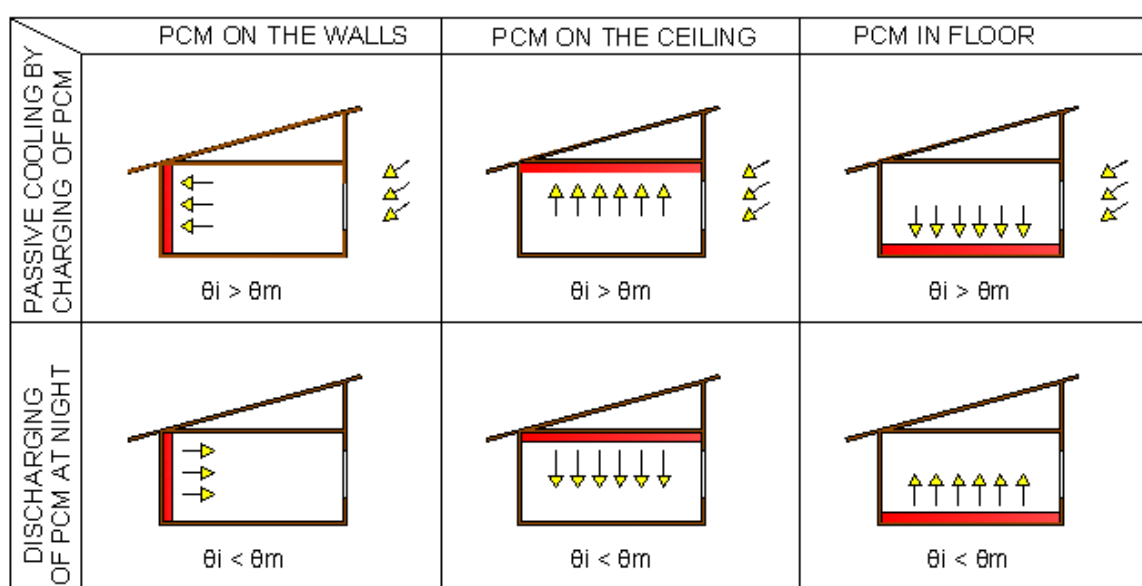


Figure 1. Scheme of charging and discharging of PCM incorporated in building structures

In passive systems the heat stored is automatically released when indoor or outdoor temperature rises or falls beyond the melting point. During the 1980s several forms of bulk encapsulated PCMs were marketed for passive solar applications. For example the wall boards are cheap and widely used in a variety of applications, making them very suitable for PCM encapsulation (Tyagi et al., 2007).

Successful utilization of PCMs and heat transfer depends on the developing of means of containment. The PCMs encapsulation with different geometries of capsules has own advantages and disadvantages (Regin et al., 2008). The heat exchangers for PCMs are similar to existing tanks used for energy storage. The density of stored heat is much more higher compared to other systems with sensible heat storage.

The well-known type of PCMs containment is macroencapsulation. The shape of macrocapsules varies from rectangular panels to spheres to pouches without a defined shape (Regin et al., 2008). The use of plastic film to encapsulate PCMs for heat storage applications is attractive because of the potential economy and versatility of these packaging materials (Lane, 1983). Installation can be on the top of suspended ceiling panels or under floor between joists. The pouches can be situated in the centre of fiberglass-reinforced polymer concrete tiles. The typical is using of PCMs sealed in aluminium panels or in panels from plastics. Our research is focused on the using of aluminium panels fixed on the internal side of lightweight envelopes.

Microencapsulation refers to techniques in which a large number of small PCMs particles are contained within a sealed continuous matrix (Regin et al., 2008). The composite gypsum wallboards with 20% or 50% of the RT20/montmorillonite composite can reduce the indoor temperature fluctuations (Fang et al., 2006). Instead of gypsum wallboards PCMs can be incorporated into the gypsum plaster that can be used in the same way like the common plaster. Presently the cost of the microencapsulation systems is higher compared to other storage methods.

4. INSTALLATION OF PANELS WITH PCM IN EXPERIMENTAL ATTIC ROOM

4.1 Testing attic rooms

For measurement and evaluation of influence of PCMs on indoor environment are necessary two identical spaces. Testing attic rooms were built in free attic space in the object of our Institute of Building Structures. For our research we used the measurement of the ambient and internal temperatures in the same time in the experimental room without PCMs and in the referential room with panels filled by PCMs. The external and internal structures of testing rooms were made only from lightweight materials. The thermal insulation of vertical walls is made from mineral wool with thickness 200 mm. The covering is made from gypsum wallboards. Suspended ceiling consists of internal gypsum wallboard and mineral thermal insulation. The floor finishing is made from slip cement boards.

Floor area of each room is 14.9 m² and volume of internal space is 29.7 m³. Day lighting is provided in every room by skylight with total dimensions 740 x 1400 mm. System allows change of quality and characteristics of glazing. Using of special sun blinds with electric drive is possible. Orientation of skylights and external envelope is south-west. The electric heaters for the heating in winter or autumn time were installed below the skylights.

4.2 Experimental room with aluminium panels

In experimental room were installed aluminium panels filled by salt hydrates. Aluminium panels are fixed:

- on the surface of three walls;
- under the horizontal suspended ceiling;
- under the sloped part of ceiling under the roof structure.

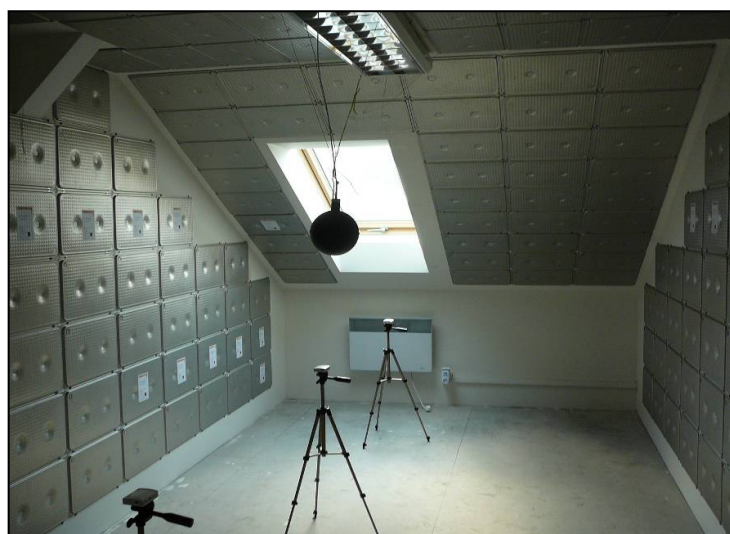


Figure 2. View of experimental room with PCM

We installed totally 240 panels with DELTA®-COOL24 from Dörken GmbH & Co. KG. Table 1. shows the properties of the aluminium panels. Double coated aluminium is the best material for heat conduction. The panels are statically stable and easy for cleaning.

Table 1 – Properties of aluminium panels

Specifications	Value
Melting range	between 22 and 28 °C
Storage capacity	app. 150 kJ/panel
Weight of panel	360 g
Weight of PCM	1125 g
Dimensions	455 x 305 x 10 mm

Panels were fixed only by the screws in each corner of panels. Installation of panels was finished at the end of August 2008. The panels are prepared for summer and winter measurement. The measurement will continue during this year with natural and mechanical ventilation. For measurement of internal temperatures were installed thermocouples FTA3900 and spherical thermometers in each room. For data acquisition was used data logger ALMEMO 5690-2M.

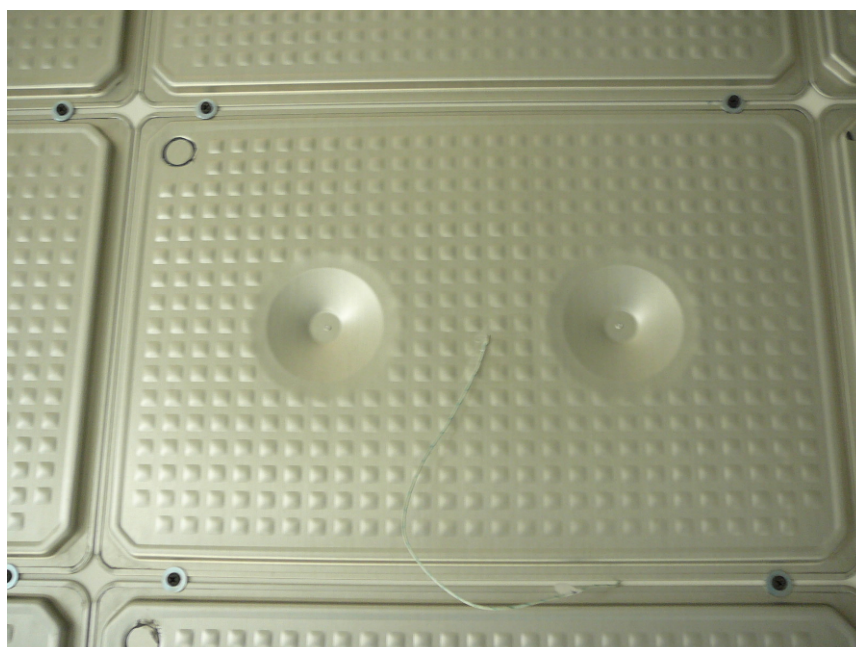


Figure 3. Detailed view of aluminium panel with thermocouple

5. RESULTS FROM PRACTICAL MEASUREMENTS

5.1 Results from summer measurement

The summer measurement started at the end of August 2008 after the installation of aluminium panels. The measurement is still running during autumn and winter season only with short term interruptions for maintenance. We started our measurement on August 30th 2008. But we can present measurement only from five days with higher ambient temperatures. Temperature fluctuation is shown in Figure 3. Measurement is running with natural ventilation by windows and doors without using of fans or air-conditioning systems. The chart in Figure 4. shows air temperatures in the testing rooms. It can be seen that latent heat storage significantly reduced the peak air temperature during day. The maximum temperature in the room with the PCMs was 26.2 °C while in the referential influence it was 30.1 °C.

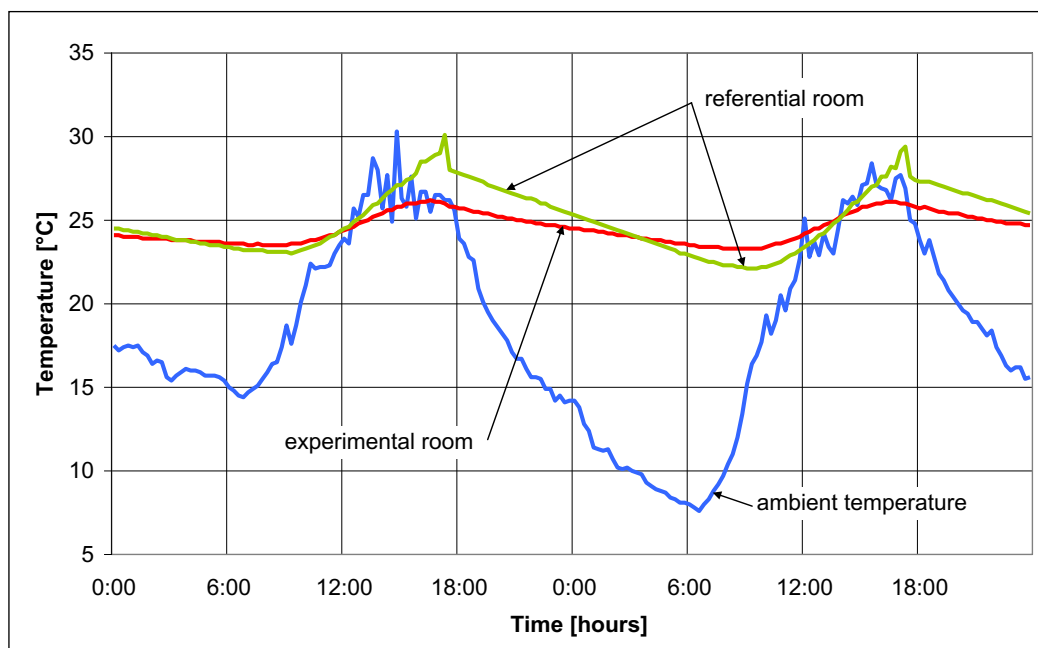


Figure 4. Fluctuation of internal and external temperatures during two hot days in September 2008

The solar heat gain through the skylights was the mean heat gain to the rooms though it is also possible to simulate internal gains as well. Maximum upsurge of internal temperatures was calculated for August 31st 7.3 °C in referential room while in experimental room the upsurge of internal temperature was only 4.0 °C.

5.2 Results from spring measurement

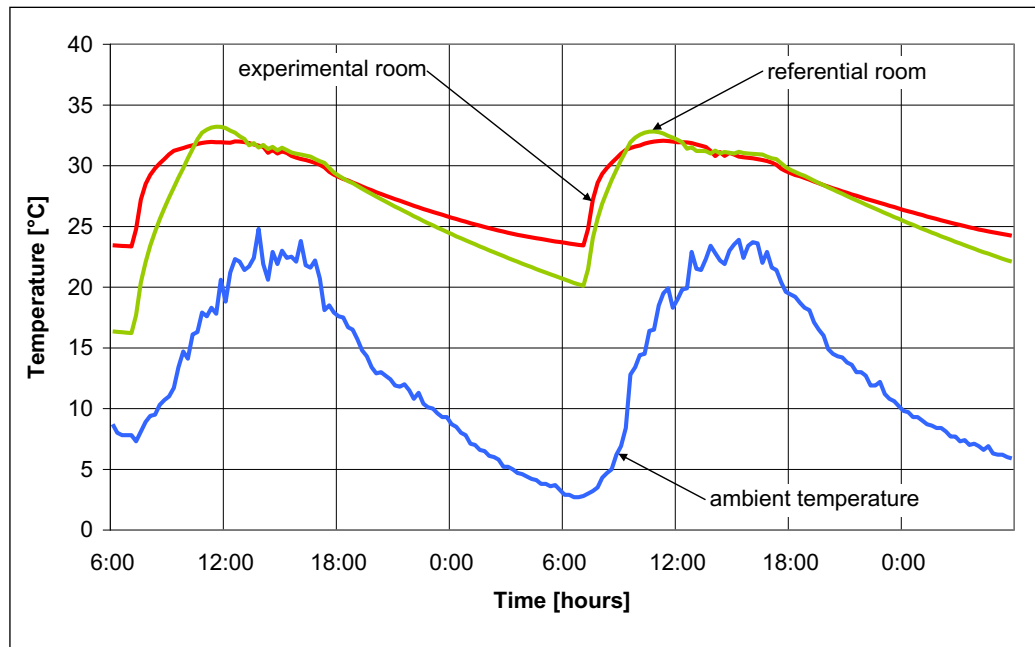


Figure 5. Fluctuation of internal and external temperatures during two cold days in April 2009

The measurement in April 2009 was focused on the thermal stability of attic spaces after the heating shutdown. In each room was installed panel heater for heating of internal space in the morning. The chart in Figure 5. shows air temperatures in the testing rooms. It can be seen that latent heat storage significantly reduced the drop of internal temperature of air during the nighttime.

6. CONCLUSIONS

The utilization of latent heat storage system using phase change materials is an effective way of storing thermal energy and has high energy storage density. The pilot summer measurement in September 2008 showed that the heat storage capacity of PCM had positive effect on the internal environment. The maximum temperatures in experimental room with installed aluminum panels with PCMs were lower than in referential room. During the cold season the thermal storage capacity of PCMs reduced the drop of internal temperature of internal air during the nighttime after the heating shutdown. All measurements were realized only with natural ventilation. The problem with insufficient solidification of PCMs was detected in hot summer days.

The measurement will continue in both rooms during the year 2009. In May the mechanical ventilation will be installed for intensive ventilation during the nighttime. The ability of envelope to store thermal energy is important for effective use of solar energy in buildings and reduce the fluctuations of internal temperatures.

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