INTEGRATION OF PHASE CHANGE MATERIALS IN BUILDING STRUCTURES

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Abstract: The paper presents the results from the comparative measurement of indoor environment in two attic rooms. The effect of phase change materials was researched within the operative room temperature. System utilizes simple heating of the material and reversible changes of phase for heat storage. The phase change materials increase the heat storage capacity of the building. This fact has the effect of temperature in the experimental room and its maximum value during the summer. As PCM is used a microencapsulated paraffin in the experimental implementation. Its integration into building structures is a modification of plaster. Activation of phase change materials is carried out by capillary cooling. The paper presents the results of measurements for different modes of operation of passive cooling.

Keywords: Phase change materials (PCMs), Gypsum plaster, Capillary tubes, Latent heat storage, Passive cooling, Overheating, Indoor environment.

1 Introduction

The development of prices and consumption of energy has long-term continuous growth. For common Czech household price of electricity increased about 229 % between 2001-2011 [1]. Energy operating performance of the building is composed mainly of heating, cooling, ventilation, lighting and domestic hot water. One consequence of this development is the emphasis on reducing the operating costs of buildings in winter. This is achieved by insulation of the building envelope, optimizing air exchange and design sophisticated heating systems. The result is to provide thermal comfort while reducing operating energy consumption.

In the summer time there is often the overheating of buildings, particularly for the construction of lightweight materials or objects with high glass facade elements. Thermal stability of the internal environment in the summer largely depends on the heat gains from solar radiation that penetrates by the transparent parts of openings into the interior. It can largely affect the orientation of the object to the cardinal, rational glazing on the south and west sides, and proposing appropriate shielding devices. These design principles are often neglected when designing buildings and so air conditioners are used to ensure the summer heat stability. These devices, however, are inappropriate from an economic and environmental point of view. Mechanical cooling has affected the consumption of electricity in peak summer temperatures and in recent years there is a trend that differences between the amount of energy consumption in the winter and summer months begin to approach [2].

Energy storage plays an important role when the production or supply of energy don´t coincide with immediate demand for it. The energy storage is crucial for the development of such conversion of electrical or thermal energy from renewable sources. A typical example is the conversion of electrical and thermal energy from solar energy to covering the energy performance of buildings for housing.

The development and using of the passive cooling is one of the measures against overheating inside buildings, which should be directed attention to [3]. Passive cooling can be used as a supplement or, ideally, as a substitute for air conditioning. Additionally it is possible a reversible using for radiant heating in winter.

2 Thermal comfort a stability

Thermal comfort means that the thermal conditions reached when a person is neither cold nor too hot - the person feels comfortable [4]. This definition implies that thermal comfort is a subjective term and its level is different for each individual. Each person has got own somatotype, age, gender and otherwise dressed, so all these factors affecting thermal comfort. Others are air temperature, mean radiant temperature, humidity and velocity of flow.

Summer thermal stability directly depends inter alia on the thermal storage capacity of the building envelope. In the event there is no space or we do not want to increase the storage mass of the building in the plane of the mass, it can proceed to the application of materials with phase change material (PCM) and it is increased storage capacity of latent heat storage.

3 Heat storage

Building materials are able to store heat or cold for a while and then they have to be able to provide this heat energy back into the environment. In the literature we have met three ways heat storage:

- sensible heat storage
- latent heat storage
- thermochemical storage

The objects building with traditional technologies (brick, monolithic) have a relatively large heat capacity. This is due to the ability of these materials store a large amount of sensible heat and thus contributes to the summer heat stability. The stored heat in this case leads to an increase in temperature of the storage medium.

It is preferred to use the accumulation of latent heat for objects with a light envelope of low thermal storage capacity of the envelope and buildings constructed of lightweight building materials. For this reason it is necessary to integrate the structures with phase change materials (Phase Change Materials - PCMS). Using PCMS can increases thermal storage capacity of the building.

These materials are using physical phenomena in which the temperature of the substance does not change even when it is delivered or collected heat. Such action usually associated with phase change. For example, if you deliver thermal energy of the solid, whose initial temperature was below the melting point, the substance is heated at first. After reaching the melting temperature, the growth stops and remains at a constant level so until it retains the state of coexistence of solid and liquid phases. Once complete conversion of solid to liquid is over, the substance temperature begins to rise again [5]. Since the latent heat of the substance consumed or subscribed to increase or decrease the temperature of the storage medium: this is called the latent heat.

These storage systems can be called passive because for its operations they do not use non-renewable energy sources [6]. Passive cooling can thus be an alternative or complement to air conditioning and thus reducing the energy consumption for cooling.

4 The phase change materials

Organic and inorganic materials are used as PCMs in practical applications [7]. Their main representatives are paraffins (organic materials) and hydrates of salts (inorganic materials). Organic materials are characterized by chemical and thermal stability. Organic media are compatible with metals and have a lower thermal conductivity compared to inorganic materials. The main disadvantage is their flammability. Inorganic materials have higher enthalpy of phase change process. Inorganic media are non-flammable and have corrosive effects. The phase separation and supercooling is also a problem for inorganic media (Tab. 1).

Tab. 1: Comparison of organic and inorganic materials [8]

Organic materials	Inorganic material
Advantages	
No corrosives	Greater phase change enthalpy
Low or none supercooling	Non-flammable
Chemical and thermal stability	Cheaper
Disadvantages	
Lower phase change enthalpy	Supercooling
Low thermal conductivity	Corrosion
	Phase separation

Phase change process, suitable for use in construction, is from solid to liquid and vice versa. It is necessary therefore to deal with the proper encapsulation of heat storage materials. The encapsulation can serve as a construction element of the building structure. A compatibility problem between PCMs and container have to be verified and the container have to be sufficiently thermally conductive to be able to quickly transfer heat during charging and discharging. Encapsulations are usually classified by their size into macro and microencapsulation [9].
The possible methods of integration are:

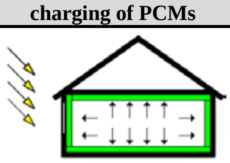
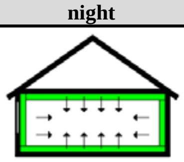
- PCMs penetration into building materials;
- micro-encapsulation;
- macro-encapsulation;
- dimensionally stable.

5 Activation of the phase change material in passive cooling systems

An important part of the design of each system with PCMS is to ensure the activation of this material. During the day, in a time of high heat loads the interior, a phase change material begins to charge after reaching a melting point (there is a latent transformation). It´s necessary to take away stored heat for repeating this process. The activation takes place at night when the temperature in the interior is under the PCMS crystallization temperature (Fig. 1). It is often necessary the natural convection of air supply by an another cold source for right taking place latent transformation throughout the volume. This source is consumed electrical energy, but the consumption of energy is transferred from day to night-time and it is thus removed from the network at the time of the lower tariff.

The charging and discharging of heat into and out of thermal storage is naturally reversible in the Czech Republic from autumn to spring.

Fig. 1: Scheme of charging and discharging of PCMs

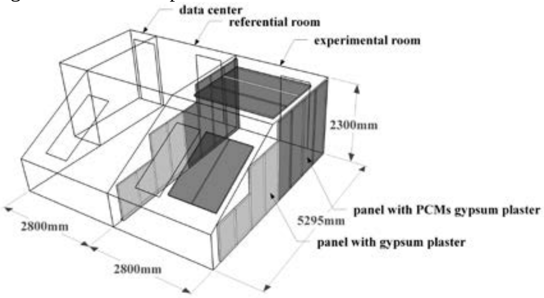
Passive cooling by charging of PCMs	Discharging of PCMs at night
	
$\Theta_i > \Theta_m$	$\Theta_i < \Theta_m$

A system that utilizes a special circuit of air in a wall cavity for the discharge of stored energy is much more suitable for residential buildings with occupants at night. On the other hand this system requires the special air cavity for cool air and therefore the use is limited by technical possibilities.

6 Verification of the effects of integration into the PCMS structures

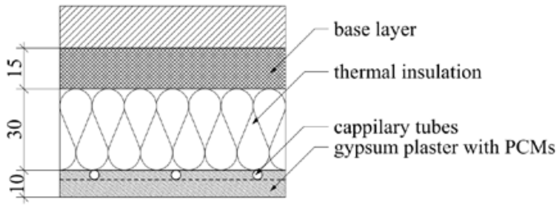
At Institute of Building Structures at Faculty of Civil Engineering are located two rooms for comparative measurements. The both rooms have the same geometry, composition of envelope and orientation of skylights (Fig. 2). By their size and location they correspond with for example an attic living room or an office. Packaging design are insulated mineral insulation in thickness 200 mm. There is a skylight in the sloping part of the ceiling in each room to ensure daylight and to fix a solar radiation. The volume of air inside each test room is 29,7 m^3.

Fig. 2: Scheme of experimental and referential rooms



There were located thermal storage modules in the experimental room. Panels are composed of a base layer made from recycled beverage cartons, polystyrene foam layer with thickness of 30 mm and modified plaster with thickness of 10 mm (Fig. 3).

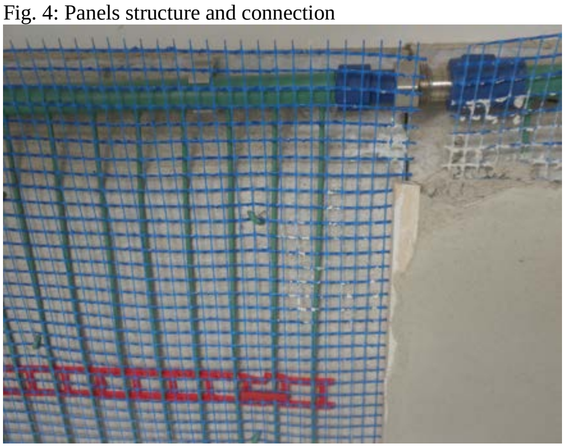
Fig. 3: The schematic sectional view of an accumulation panel



The plaster isn´t supplied commercially, but it was prepared to order by the manufacturer plaster mixture LB CEMIX Ltd. The plaster is included with phase change material Micronal DS 5008X from BASF. Quantity PCMS is 30 % of the total weight of the mixture.

For activating the PCMs the capillary tubes are mounted into a panel. The inlet and outlet pipe is connected through the distributor and collector to a heat pump (air-water) that is able to generate the required cooled water (Fig. 4).

Fig. 4: Panels structure and connection



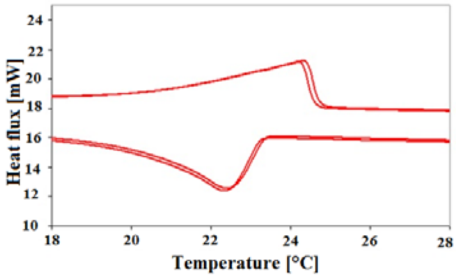
Assembled panels are installed on the side walls, oblique and horizontal ceiling in the area about 17 m^2. Air exchange in experimental and reference room was ensured during the entire period by opening skylights in the ventilation positions.

7 Results and discussion

7.1 Analysis of the material used the phase change

The melting point is one of the main characteristics of selecting a suitable representative for use PCMS because of the stabilizing interior temperature. The melting and solidification of the mixture of plaster and PCMS the temperature ramp 1 °C.min^{-1} were found with thermal analysis (Fig. 5).

Fig. 5: DSC curves for two cycles Micronal PCM ® DS 5008X for ramp 1 ° C.min^{-1}



The monitored quantity of sample buffer material named Micronal PCM ® DS 5008 X and plaster sample with 30 % buffer substances are compared in the Tab. 2. The measurement was carried out in a Perkin Elmer PYRIS1 equipped with a cooling device Perkin Elmer Intracooler 2P.

Tab. 2: Comparison of DSC analysis for PCM and gypsum plaster with 30 % PCM with a heating / cooling ramp 1 °C.min^{-1}

Material	PEAK temperature melting [°C]	ONSET temperature melting [°C]	Stored heat [kJ.kg^{-1}]
Micronal DS 5008X	24.3	19.8	86.8
Plaster with 30 % Micronalu	26.2	24.5	23.4
Difference	1.9	4.7	63.4
Material	PEAK temperature solidification [°C]	ONSET temperature solidification [°C]	Release d heat [kJ.kg^{-1}]
Micronal DS 5008X	22.4	23.3	-82.7
Plaster with 30 % Micronalu	24.6	25.5	-23.6
Difference	2.2	2.2	59.1

The comparison given in the Tab. 2 shows that the addition of micro pellets into plaster leads to reduced the storage capacity to a level of 27 %. Peak temperature was also moved as the melting and the solidification. This reduction in thermal storage capacity is quite essential and responsible mass proportion of PCMS in the plaster.

7.2 Effect of PCMs and capillary cooling to room temperature operative

Comparative measurements of the effects of capillary cooling system coupled with a thermal storage layer containing PCMs were realized in July and August 2012. The effect on the indoor environment depended on different types of setting control of activation of storage medium.
Three modes of operation room were studied:

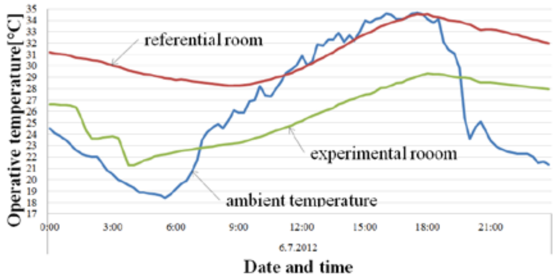
- PCMs are activated by briefly cooling performed during the night. This method is suitable for the summer without extreme values of maximum daily temperatures.
- PCMs are cooled at night and during the day it is cooled according to actual requirements for thermal comfort. This operation is suitable with high cooling loads during the day.
- Regeneration PCMs is carried out by natural air convection in the period when the temperature at night drops below the temperature range of phase change.

In the first mode was PCMs activation at night. The system worked in the following mode:

- during night periods from 1:00 to 1:45 a.m. and from 3:00 to 3:30 a.m. the chiller was switched on due to the activation of stored energy in PCMs;
- during day the chiller was switched off.

The temperature in the experimental room during the day wasnt' influenced in another active way. Integrated PCMs and 1.25 hour night cooling reduce the temperature peaks in the room about 4-5 °C (Fig. 6).

Fig. 6: Progressions of operative temperature in the testing rooms from 6. 7. 2012

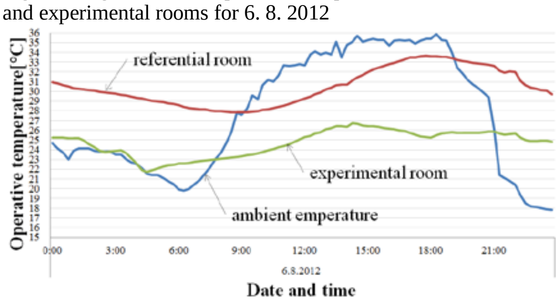


Other mode is activation PCMs during the night and cooling during the day. In the reporting period the system worked in the following mode:

- working of chiller was allowed by timer at the time of 0:00-5:00 and 7:00 a.m. to 10:00 p.m. In this mode the operating of chiller can also be controlled by a thermostat so that between 1:00 to 2:00 a.m. and 3:00 to 4:00 a.m. has been set cooling to 20 °C due to the activation energy stored in PCMs;
- in the other time the chiller started to work after indoor temperature reached 26.5 °C

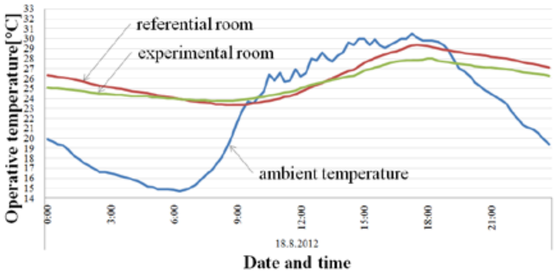
With this setting the temperature in the experimental room remained between 21 and 27 °C and the daily temperature peaks were reduced up to 7.5 °C (Fig. 7).

Fig. 7: Progressions of operative temperature in the referential and experimental rooms for 6. 8. 2012



Last mode is activation PCMs by natural air convection. In the reporting period PCMs was activated by natural air convection (cooling unit was off). There is no problem with activating the storage media in the period when the temperature drops during the night under the phase change temperature range of PCMs. Thus it is possible to reduce the temperature in the room during the day about 1.5 to 2.0 °C (Fig. 8). If the temperature doesn´t drop under the phase change temperature range, PCMs isn´t fully activated and the next day is reduced thermal storage capacity.

Fig. 8: Progressions of operative temperature in the testing rooms from 18. 8. 2012



8 Conclusions

The tested system combines the heat storage material with a phase change in the form of micro pellets, which are dispersed in the gypsum plaster, and capillary cooling for their activation so that the secondary effect is possibility of a direct cooling of the room. Individual building materials and components are assembled into modules that allow their installation in both new buildings and the renovation of existing buildings.

Passive radiant cooling is one of the ways to reduce energy consumption for cooling. Conventional air conditioners have to work in parallel with the effects of heat stress, i.e. at times of peak electricity consumption. The installed system can set with regimes respond to outdoor temperature conditions. This system primarily shifts electricity consumption into the night off-peak time. The time interval when the electricity is consumed from the network, it is also much less compared to common air-conditioning. It should be noted that the system cannot ensure a constant temperature in the interior, but it can maintain a state of indoor environment in the required temperature range and it can reduce temperature maxima.

The cooling system using the latent heat storage should be designed as a whole. It is necessary to select so cooling device which can activate recrystallization PCMS without affecting the internal environment and contribute to the required internal microclimate.

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