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Modified lime-cement plasters with enhanced thermal and hygric storage capacity for moderation of interior climate

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ABSTRACT

The absorption or release of heat and moisture by interior surface layers of building envelopes under specific conditions can set effective limits to the extreme levels of indoor air parameters. Moderation of interior climate achieved in this way can contribute to a reduction of energy demands for building conditioning and overall operation cost using a straightforward material solution. In this paper, lime-cement plasters modified by two types of PCM based admixtures are designed specifically for the moderation of relative humidity and temperature fluctuations of the interior environment. The plasters are subjected to a detailed characterization procedure including the assessment of a complex set of basic physical, hygric, thermal and mechanical properties. Experimental results show that the application of small encapsulated PCM particles leads to an up to 10% increase of open porosity, as compared with the reference plaster. Contrary to this fact, the water vapor transport is slightly decelerated, what is attributed to the encapsulating polymer shell which creates impermeable barrier for water vapor transmission. Two contradictory factors affect the liquid water transport, namely the higher porosity of PCM modified plasters and increasing content of not-wettable polymer shells. The moisture storage capacity increases with the increasing amount of PCM in the mix. The moisture buffer value is improved due to the utilization of both PCM admixtures, the developed plasters can be classified as good moisture buffering materials. The thermal conductivity of modified plasters is greatly improved, as well as the heat storage capacity, the additional phase change enthalpy being up to 13 J/g. Although the inclusion of PCM into the lime-cement matrix decreases the mechanical strength, the achieved values of tested mechanical parameters are still satisfactory for the application of the designed plasters in building practice. In summary, PCM modified plasters can be considered a prospective solution for the moderation of interior climate in contemporary buildings.

1. Introduction

Indoor air temperature and relative humidity represent important parameters affecting the internal microclimate of contemporary buildings. They may also induce processes which have serious impact on both the working efficiency and health of occupants such as mold growth, respiratory and skin diseases, etc. [1]. Nowadays, it is generally accepted that indoor environment quality has a significant effect on modern life around the globe [2]. For example, the Americans spend approximately 90% of their time indoors [3], the French population spends at home 67% of the total time indoor [4]. Therefore, it is necessary to ensure high indoor air quality to guarantee the appropriate conditions for building occupants.

Due to the varying climatic loading, the indoor temperature and humidity exhibit significant daily or seasonal variation which can lead to overheating and extreme values of humidity, causing possibly even microbial growth on surface structures. In this way, the quality of interior climate, thus living conditions, can be negatively affected. The practical solutions to this problem are, however, rather energy demanding. A growing number of heating, ventilating and air conditioning (HVAC) systems are being installed in buildings to provide thermal comfort and improve indoor air quality

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for occupants. In the developed countries, energy consumption in both residential and commercial buildings is dominated by space heating, cooling, air conditioning and lighting. As reported by Song et al. [5], in 2010HVAC systems consumed in the developed countries ~43% of the total energy use in residential buildings and ~40% in commercial buildings. The energy consumption of buildings in the developed countries comprises 20–40% of total energy use; it is above industry and transport figures in EU and USA [6]. With the consolidation of the demand for thermal comfort, HVAC (Heating, Ventilation and Air Conditioning) systems and their associated energy consumption became an unavoidable asset, accounting for almost half the energy consumed in buildings and around 10–20% of total energy consumption in the developed countries [7]. Therefore, the integrated designs are required in active systems such as renewable energy facilities (i.e., photovoltaic, solar thermal) or energy efficiency HVAC systems [8,9]. Several studies have been focused on improving the efficiency of these technologies by incorporating thermal energy storage systems that implies an additional storage volume [10]. Nevertheless, also the other building components can find use in order to decrease the high amount of energy used by HVAC systems. One of the possibilities represents optimization of building envelope systems from the point of view of the dynamic thermal performance [11]. Fantozzi et al. [12] studied winter and summer performance of lightweight prefabricated building system and concluded that it is possible to improve the dynamic thermal performance of the outer walls by using an optimized stratigraphy characterized by an opportune sequence of resistive and capacitive layers.

Conceptually different solution of improvement of buildings dynamic hygrothermal performance represents application of advanced building materials allowing absorption or release of heat and moisture what can be used to moderate the extreme levels of temperature and humidity in the building interior. This energy storage (and/or release) concept can be classified as passive system compared to the active HVAC devices [13].

In late 90's of the twentieth century, the idea of improving indoor humidity conditions by using highly hygroscopic building materials was firstly introduced. Since the time, the moisture buffering properties of porous building materials became an important topic of building research [14].

According to the definition given in [15], the moisture buffer performance of a building is the ability of the inbuilt mat s to moderate variations in the relative humidity, whereas these variations can be seasonal or diurnal. The moisture buffer performance depends on the moisture buffer capacities of each material combination and furniture in the room, together with the moisture production and air change rate and ratio between the material surface area and the air volume. The moisture buffering capacity of building materials is increasingly recognized for its beneficial influence on the indoor environment [16], which has associated benefits of material durability, occupant health and comfort, and also the whole-building energy performance [17,18].

Presently, the application of sustainability principles in construction encourages the development of new materials and products with new functionalities and applications, able to improve hygrothermal, thus environmental performance of buildings [19]. In a society with a high growth rate and increased standards of comfort arises the need to minimize the current high energy consumption by taking advantage of renewable energy sources [20]. The materials of surface layers, i.e., plasters [21], facing slabs [22,23], or plasterboards [24] with incorporated phase change materials (PCM) have the ability to regulate the temperature inside buildings, contributing to the thermal comfort and reduction in the use of heating and cooling equipment, using only the energy supplied by the sun. PCMs provide a large heat capacity over a limited temperature range and they could act like an almost isothermal reservoir of heat [25]. As the temperature increases, PCMs change phase from solid to liquid. Since this reaction is endothermic, they absorb heat. When the temperature decreases, PCMs change phase from liquid to solid. This time they release heat as this reaction is exothermic.

A number of PCMs was directly designed for quite specific applications, respecting their phase change temperature, enthalpy, specific heat capacity, and maximum operation temperature. Here, PCMs are usually applied as components of composite materials possessing latent heat storage capacity. For a use in building materials exposed to common climatic loading, paraffins were found to have several advantages as non-corrosiveness, chemical stability, no phase segregation, congruent phase change, recyclability, and low cost [26,27]. Therefore, combination of the above given beneficial thermal properties of parrafins with hygroscopic matrix of building materials represents a prospective way to moderation of interior climate, i.e., moderation of interior temperature and relative humidity.

Among the commonly used building materials wood [28], gypsum board [29], brick [30], calcium silicate [31], or highly porous plasters [32,33] can be considered hygroscopic and/or capillary active. On the other hand, insulation materials such as XPS, EPS, PUR, PIR, or foam glass are non-hygroscopic and not capillary active [34]. In testing the hygroscopic properties of materials, the microstructure, specific surface area, adsorption/desorption isotherm, maximum adsorption value, sorption velocities, and moisture buffer value (MBV) belong to the most important parameters [35]. In general, the hygroscopic materials are characteristic by their high moisture buffering capacity that enables them to dampen humidity variations. Additionally, in the case of capillary active materials, occasional interstitial condensation can be redistributed and transported out of the material due to the high capillary activity.

In this paper, we introduce several composite materials with enhanced thermal and hygric storage capacity which can be applied as surface layers for the moderation of interior climate. In order to keep the cost within reasonable limits, the designed solution is based on a commercially available lime-cement plaster and paraffinic PCMs.

2. Materials and mix design

The commercial lime-cement dry plaster mixture Manu 1 (Baumit) consisting of hydrated lime, cement, sand and additives, which is frequently used in the Czech Republic for both interior and exterior renders, was used as the basis for the plaster mix design. In order to enhance the thermal storage capacity, two different types of phase change materials (PCM) were added to the mixes. The first was the polymethyl methacrylate microencapsulated paraffin mixture Micronal DS 5040 (BASF) which is a fine powdered material having the solid content 97–100% (according to DIN EN ISO 3251) and water content ≤3%. As specified in BASF product data sheet, its phase change temperature is around 22 °C (melting 23 °C, crystallization 22 °C) and enthalpy of fusion 96 J/g [36]. The second PCM applied was Rubitherm RT 22HC (Rubitherm). It is based also on paraffin mixture encapsulated in polymer shell but it is delivered in the form of water dispersion, with the solid content of about 35%. The enthalpy of fusion of this material is 200 J/g, the melting and crystallization temperatures vary from 20 to 23 °C with the maxima at 22 °C [37].

The particle size distribution (PSD) of the lime-cement dry plaster mixture, Micronal DS 5040 and Rubitherm RT 22HC, as measured by an Analysette 22 Micro Tec plus device (Fritsch), is presented in Fig. 1. Apparently, the PSD curves of all raw materials had a bimodal shape but their maxima were at rather different