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Original article

Evaluation of the effect of phase change materials technology on the thermal stability of Cultural Heritage objects

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ABSTRACT

The use of phase change materials (PCMs) in civil buildings as an effective thermal energy storage solution has been well documented in literature and proven in the field. When applied to Cultural Heritage, PCMs' technology needs to be adapted to specific requirements. Besides the important objectives of economic return and human comfort, the indoor microclimatic conditions have to be suitable for conservation purposes. The application of PCMs' technology to Cultural Heritage has been investigated within the European MESSIB (Multi-source Energy Storage System Integrated in Buildings) project. Firstly, several methodologies of incorporation of PCMs in different materials were studied and tested. The thermal properties of gypsum panels and silicon coatings incorporating micro-encapsulated PCMs in the form of powder and emulsion were analysed in the laboratory. Then, PCMs incorporated in gypsum panels in contact with a wooden panel were tested and their effect on the thermal behaviour of the wooden panel was evaluated under thermal cycles in a climatic chamber. PCMs incorporated in silicon coatings in contact with a painting were also tested. Moreover, gypsum panels containing PCMs were tested in the S. Croce Museum in Florence, Italy, where the microclimatic monitoring has shown thermal conditions potentially dangerous for the works of art preserved. The research performed both in the laboratory and on the field confirmed the effectiveness of the PCMs as thermal storage solutions, but also gave evidence on an important drawback when the material incorporating PCMs is in direct contact with an object of art.

1. Introduction

With the growing energy crisis, there is a renewed interest in those aspects of architecture which lead to thermal comfort in buildings with minimum expenditure of conventional energy [1]. Thermal energy storage systems using Phase Change Materials (PCMs) have been a main topic in research for the last decades and they have been recognized as one of the advanced technologies in enhancing energy efficiency and sustainability of buildings [2]. Moreover, their use in the building sector has gained importance, because of their energy cost reduction potential [1]. A large number of research studies and review papers provide a detailed characterization of PCMs, in terms of classification of materials and their properties, major applications in buildings and related problems [1–5]. In general, the use of PCMs in buildings has two main advantages: enhancing indoor thermal comfort for occupants due to the reduced temperature fluctuations and lowering global energy consumption due to the load reduction/shifting. Nevertheless, the success of their use depends on many factors such as the type and amount of PCMs, the encapsulation method, the location of PCMs in the building structure, the building design and orientation, the equipment design and selection, the climatic conditions and so forth.

During the last decade, research has been focused on suitable methods to incorporate PCMs within buildings. In particular, organic PCMs micro-encapsulated in construction materials (gypsum, plaster, concrete) has been widely promoted as a passive solution to reduce energy consumption and to improve thermal comfort [6–10]. Organic PCMs (such as paraffins, fatty acids, alcohols) are inexpensive and easily available, chemically stable, they melt congruently and the supercooling effect is reduced compared to inorganic PCMs. They have high latent heat and a wide range of melting temperatures which highly increases the number of

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applications in different buildings and locations according to the climatic conditions. In particular, paraffin waxes are considered as potential candidates for PCMs because of their properties.

The (nano-, micro- and macro-) encapsulation of the PCMs in physically and chemically stable polymeric nanoparticles is highly required in order to overcome some practical problems of dimensional instability, corrosiveness, low thermal conductivity, compatibility, etc. In this study commercially available PCMs micro-encapsulated in a stable polymeric shell have been used for thermal energy storage [4,5].

The most common and so far effective application of PCMs in the civil field turns out to be one of the main barriers for their use in Cultural Heritage (CH). The adaptation of PCMs' technology to Cultural Heritage is being studied within the European MESSIB (Multi-source Energy Storage System Integrated in Buildings) project [11], aimed at introducing an affordable multi-source energy storage capacity in buildings, integrated with conventional installations and building architecture.

In fact, the solution of incorporating the PCMs in construction materials is possible only for new or refurbished buildings, not always for historical ones, because this operation would require an invasive intervention on the building. Hence, the most feasible application of PCMs' technology in Cultural Heritage would be to place boards of different materials incorporating PMCs in contact with the roof/walls of historic buildings, only if not painted, nor decorated with sculptures or heritage elements. Another possible use of these boards would be for example at the occasion of temporary exhibitions inside museums: these panels can be sized according to the dimensions of the room and they can be easily installed and removed according to the specific needs. Even if there is a great amount of scientific literature concerning the use of PCMs for civil applications, no specific reference to Cultural Heritage has been found.

Last, but not least, in buildings devoted to the conservation and/or the exposition of works of art the use of PCMs has to be evaluated not only in terms of human comfort and energy saving benefits, but also taking into account conservation issues. The indoor thermo-hygrometric conditions have to be suitable for the conservation of the works of art, i.e. as stable as possible and at the same time within the ranges of safety for the heritage materials. In fact, it is well known [12] that an object tends to reach the equilibrium with the changing environmental conditions, with consequences depending on the amplitude and frequency of the changes, as well as on the characteristics of the object (material, dimensions, history, etc).

PCMs' technology in principle can surely accomplish the indoor thermal stabilization, but its use in Cultural Heritage needs to be carefully evaluated in terms of conservation conditions of the works of art, and it has also to be adapted to specific requirements, like low aesthetical impact, non-invasive installation and so forth.

In the present paper a potentially new application of the PCMs' technology to heritage objects has been evaluated. Model samples and real objects in contact with materials incorporating PCMs were monitored both in laboratory and on the field, and the effects of the use of PCMs on their thermal behaviour have been studied. Hence, the advantages and disadvantages related to this application of PCMs' technology have been evaluated with respect to conservation issues.

2. Laboratory experiments investigating the incorporation of PCMs in different materials

The effectiveness of the PCMs as thermal storage solutions when incorporated in different materials (gypsum, silicone) was evaluated in laboratory. The tests performed were aimed at getting a deeper knowledge on the thermal behaviour of the selected PCMs when embedded in a specific material.

2.1. Thermal behavior of PCMs incorporated in different materials analyzed by DSC

The PCMs selected for testing were paraffin based ones provided by BASF:

- Micronal® DS 5001 X is in powder form with melting temperature of approximately 26 °C, density = 250–350 kg/m^3 and latent heat capacity of ca. 110 kJ/kg;
- Micronal® DS 5029 X is in powder form with melting temperature of approximately 21 °C, density = 250–350 kg/m^3 and latent heat capacity of ca. 90 kJ/kg;
- Micronal® DS 5000 X is a water-based solution with melting temperature of approximately 26 °C, density = 0.9 g/cm^3, viscosity = 100–300 mPa·s and solid content = 45%.

The above-mentioned PCMs have been included in 2 different materials: silicon and gypsum.

The set of silicon samples is composed of a control silicon, silicon with Micronal® DS 5029 X (called silicon + PCM 21) and silicon with Micronal® DS 5001 X (called silicon + PCM 26). Dimensions: 20 × 20 × 0.5 cm with 10 wt% PCMs incorporated.

In the gypsum samples, PCMs were embedded in gypsum plasterboards: they were dispersed and mixed together with the gypsum powder in order to get a homogeneous distribution of PCMs into the bulk of the panel.

The set of gypsum samples (called gypsum samples set 1) used for DSC analyses was composed of gypsum control, gypsum with Micronal® DS 5001 X (called gypsum + PCM 26) and gypsum with Micronal® DS 5000 X (called gypsum + PCM 26 emulsion). Dimensions: 20 × 20 × 2 cm with 10 wt% PCMs incorporated.

Thermal behavior of PCMs, temperature and enthalpy for the phase change have been evaluated with Differential Scanning Calorimetry (DSC, Star^e SW 8.10, Mettler Toledo) of the silicon samples and gypsum samples set 1, using standard aluminum 40 μL crucibles.

2.1.1. Results

Fig. 1 shows the thermograms of the silicon and gypsum samples set 1. Table 1 summarizes the measured values of melting temperature and enthalpy.

The thermal transitions at 19.2 °C and 25–27 °C (on-set temperatures), respectively for the silicon containing PCM 21, and the silicon and gypsum containing PCM 26 observed in Fig. 1 are

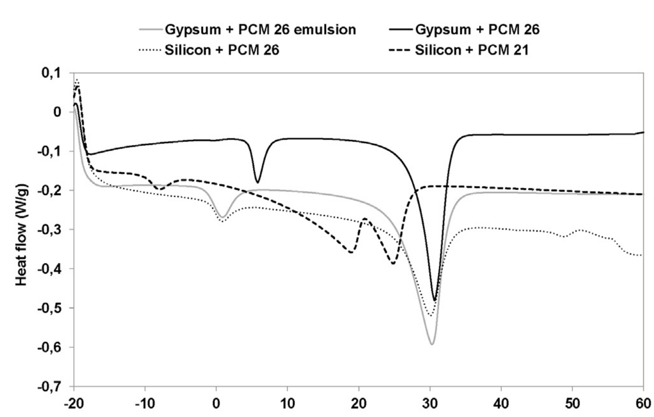

Fig. 1. Differential Scanning Calorimetry thermograms of the gypsum and silicon samples.