



Original Research Article

Experimental study of an innovative element for passive cooling of buildings

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ABSTRACT

The use of passive cooling techniques has been seen as one of the solutions that can help to reduce energy consumption in the building sector. An innovative element that allows the combined use of two passive cooling techniques, evaporative cooling and night ventilation, is proposed in the present work. In order to optimize the use of those techniques it was decided to include in the element configuration a core component with latent heat storage capabilities. Briefly it can be said that the element is composed by the accumulating core, consisting of a cement mortar vertical panel impregnated with paraffin, with two adjacent channels for air circulation. The element, whose configuration should allow its integration into the buildings envelope, has a parallelepiped shape with one air inlet and one air outlet in each of its opposite faces, the exterior and the interior ones. The core surface adjacent to the exterior channel is maintained continuously wetted by a water sprinkler system integrated in the element. The airflow in each channel is provided by tangential fans mounted on top of the element. The paraffin wax used corresponds to a commercial wax with phase transition range near 21 °C, slightly below typical comfort temperatures. A prototype of the element was constructed and subjected to a series of experimental studies that aim to know its response in operating conditions similar to real ones. These studies took place in a climate chamber for a wide range of conditions. The results suggest that the proposed element exhibits the potential for passive cooling of buildings. It was concluded that the paraffin wax incorporation in the cement mortar core has substantially improved the capacity of thermal energy accumulation of the element, that the evaporation process on the outside surface of the core provides a substantial temperature reducing of the core, and that its use also during night-time periods allows to cool the core well below the outside temperatures, thus maximizing the possibility of application of night ventilation.

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Introduction

Energy demand increased continuously in last decades and it is expected to continue to increase in the near future. Accordingly to the U.S. Department of Energy projection, world primary energy consumption in 2030 will be 44% higher than it was in 2006 [1]. On the other hand, one-third of the world population still has no access to basic energy services, which means that to ensure an equitable development on the planet, more energy is required. In 2007, 2.4 billion people were using charcoal, agricultural waste or animal waste as energy source for cooking, and 1.6 billion people worldwide live without electricity [2]. A significant portion of global energy consumption occurs in the building sector. For example, in the European Union, buildings consume more energy than any other sector of the economy, about 40% of the total energy consumed. Additionally, energy use for climatization purposes

accounts with the largest share in the global energy consumption of buildings, about 60% in the European Union [3]. It has been recently observed, with particular emphasis on developing countries, a growing demand for cooling in the building sector. Factors as the rising expectations of comfort of buildings occupants, the urban heat island effect felt in densely built cities, the increase of the internal heat gains of buildings, the reduction of the cost of cooling equipments, the increase in household disposable income and an architecture often little concerned with local climate characteristics have contributed to such phenomena [4–6]. A future increase of cooling demand is also estimated in the developing countries as personal income is expected to increase in these countries [7].

The present work proposes an element for passive cooling of buildings that allows the combined use of techniques such as, evaporative cooling, night ventilation and latent heat storage. The element configuration has been designed in such a way that permits its integration in the building envelope.

The study of passive or low energy solutions for cooling of buildings has received attention in several studies. The use of such

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cooling techniques combined with an architecture designed for local climate conditions can significantly reduce, or even eliminate, the need for other forms of cooling. It should additionally be noted that the use of passive cooling techniques represents the possibility of providing cooling at low cost to people with less economic capabilities which, in some locations, suffer intensely with extreme summer weather conditions. Evaporative cooling is one of the techniques that can be used in passive cooling of buildings. The indirect cooling of the interior of the building by evaporative cooling of an element of its envelope, such as the roof or a wall, represents a possible application of such technique [8–10]. Passive cooling of buildings through the use of night ventilation has also received the attention of many authors. Given the limited period during which the outside temperature is suitable for cooling, the use of mechanical equipment to promote the ventilation is often preferred to the use of natural ventilation technique [11–13]. Since the success of night ventilation dependent on the ability to discharge in the coldest air of the night the heat gains absorbed by the structural mass of the building during the day, the heat capacity of structural mass is a factor that influences significantly the performance of this technique. For this reason it has also been studied the possibility of combining the night ventilation with latent heat storage by direct integration of phase change materials in the thermal mass of buildings [14–16].

Experimental setup

The present work proposes an innovative element for passive cooling of buildings. It included the construction of a prototype of the element and its study in a climatic chamber where a wide range of conditions were experimentally imposed. The proposed element is composed by an internal panel, with $760 \times 600 \times 12 \text{ mm}^3$, made of cement mortar with paraffin. The paraffin, with solid/liquid transition temperature range near 21°C , was added to the cement panel by immersion of the cured panel in a liquid paraffin bath at 55°C . Table 1 shows additional properties of the used paraffin.

The mass of the cement mortar panel was 11.89 kg before paraffin incorporation and 12.46 kg after paraffin incorporation. This means that the immersion process resulted in a paraffin absorption by the mortar panel of about 4.8% by weight.

Once dry, the panel was sealed by applying a waterproof membrane to allow the continuously wetting of one of its surfaces when in operation. To optimize the evaporative cooling process to take place in that surface, it was still coated with one textile fabric previously selected [17]. This panel was mounted in the core of the element with two adjacent channels for air circulation, as can be seen in Fig. 1. The element has a parallelepiped shape with one air inlet and one air outlet in each of its opposite faces, the exterior and the interior ones. The exterior air channel draws air from the exterior and exhausts it directly to the exterior. In a similar way, the interior air channel draws air from the interior of the building and ventilates it again to the interior of the building. The airflow in

each channel is provided by tangential fans mounted on top of the element.

The exterior walls of the element are made of water resistant MDF (medium density fiberboard) and in its internal structure oak beams were also used. The element walls in contact with the interior and exterior of the building were isolated with extruded polystyrene boards. The core surface adjacent to the exterior channel is maintained continuously wetted by a water sprinkler system integrated in the element.

Type T thermocouples were distributed in the element core and channels to provide temperature measurements. Additionally, two heat flux sensors were placed in the core surfaces, one in one each, to measure the heat flux entering and leaving the element core. A closed water circulation system was used to distribute and collect the water used to maintain the core surface continuously wetted. After its construction, the prototype of the element was subjected to a series of experimental studies that took place in a climate chamber composed of two chambers representing indoor and outdoor conditions. These chambers were connected to independent air conditioning systems capable to control the temperature and humidity in each chamber.

Results and discussion

With the aim to evaluate the efficiency of impregnation of the cement mortar with paraffin in the different pore sizes, porosimetry tests were conducted with the cement mortar with and without paraffin. Tests were performed on a mercury intrusion porosimeter, Micromeritics, Autopore IV 9500, considering for mercury a contact angle of 130° and a surface tension of 0.485 N/m , at 25°C . Tested samples had approximate dimensions of 10 mm edge and 20 mm height, with masses between 6 and 9 g. Fig. 2 shows the incremental intrusion volume per unit weight of mortar, for different pore diameters, on a mercury intrusion cycle with progressive increase in pressure. The cement mortar presents typical pore size distribution of cement mortars [18] with an average diameter of $0.1 \mu\text{m}$, around which the largest number of pores are concentrated. It has also a small percentage of larger pores (capillary pores) with an average diameter of $160 \mu\text{m}$. It was not detect a significant number of pores in the ranges between 40 and $2 \mu\text{m}$. The cement mortar with paraffin presents a similar pore distribution, with a reduction of the intrusion volume for all pore diameters, which mean that the paraffin was uniformly impregnated. However, it appears that in the region of pores with smaller diameter, less than $0.05 \mu\text{m}$, the reduction is more significant, with negligible mercury intrusion.

A differential scanning calorimeter, Netzsch, DSC 204 Phoenix, was used to determine the specific heat of cement mortar without paraffin and the apparent specific heat of the cement mortar with paraffin. As can be seen in Fig. 3, the specific heat of the cement mortar has a value close to 0.75 J/gK , approximately constant in the temperature range considered. This value presents good agreement with values obtained in the literature for standard cement mortars with similar composition to the one here employed [19]. The figure also exhibits the apparent specific heat for the cement mortar with paraffin. As it can be seen, the incorporation of the paraffin in the cement mortar led to the appearance of a phase transition region corresponding to the solid/liquid transition of the paraffin at a temperature close to 22°C . The experimental measurements associated with the calculation of the specific heats were carried out with heating rates of 5 K/min , purge gas flow rate of 25 ml/min , paraffin sample of 7.5 mg and synthetic sapphire sample, according to the procedure used in [20].

The values of the thermal conductivities of the cement mortar and of the cement mortar with paraffin were also determined by

Table 1
Paraffin wax thermophysical properties.

Molar mass	244 kg/kmol
Melting temperature	22.0°C
Solidification temperature	20.0°C
Density at 15°C	870 kg/m^3
Density at 70°C	750 kg/m^3
Thermal conductivity	0.2 W/mK
Heat capacity between 11 and 26°C	172 kJ/kg
Specific heat in the solid phase	1.8 kJ/kg K
Specific heat in the liquid phase	2.4 kJ/kg K

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