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Thermal analysis of the application of pcm and low emissivity coating in hollow bricks

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ABSTRACT

This paper discusses the possibility of increasing the energy performance of thermal brick through integration with two different technologies: the first is based on the insertion of phase change material (PCM) inside the enclosures of the bricks, while the second involves covering the internal surface of the enclosures with low emissivity coating. PCM was employed to increase the thermal mass while the low emissivity coating reduces the overall heat transfer coefficient value. To demonstrate the effectiveness of the solutions, energy evaluation was carried out on the bricks using both theoretical and experimental analyses. Stationary and dynamic analyses were performed. The investigations were made in accordance with Italian, European, and international standards: theoretical analyses were based on the finite elements method, while the experimental tests were carried out with the heat flow meter method. Finally, a comparison is made between the theoretical and experimental data and the error is estimated.

1. Introduction

1.1. Climatic context and building envelope

In the Mediterranean area, one of the most widely adopted technologies for the building envelope involves walls made with hollow clay bricks or blocks, used for their thermal, structural and acoustic properties.

At intermediate latitudes energy consumption to maintain comfort conditions inside the building is either a result of heating during the winter and of cooling during the summer. Warm seasons are characterized by high daytime temperatures and strong solar radiation, which cause high fluctuations in the thermal loads, with critical peaks of energy demand during the day.

In particular during the warm season the envelope should have an adequate thermal inertia in order to reduce and shift the thermal gain, and to increase the internal thermal comfort. In this season, during the day the thermal mass stores part of the incoming heat, reducing the peak and the overheating of the interior. During the night hours, with lower air temperatures, the stored energy is released, partly towards the inside and partly towards the outside of the building. The discharge phase is strongly influenced by the night temperature and also by the presence of indoor ventilation. Processes of thermal mass charge and discharge are also influenced by the thermal resistance of the building envelope and by the position of the thermal mass and the insulation layer. The reduction in internal temperature fluctuations, and a reduction and a delay in the peak energy demand are consequent to these energy storage processes.

On the contrary, during cold seasons a steady state condition is prevalent due to a lower external temperature and to the absence of direct solar radiation. In this condition, the thermal resistance is the main parameter involved in reducing the conduction heat loss, and in controlling the internal thermal temperature.

However heat balance is a more complex issue and generally thermal inertia and resistance both contribute to increasing the thermal performance so as to guarantee internal thermal comfort in the building, especially in intermediate climatic conditions.

Moreover, the aim to reduce energy consumption for building heating and cooling in order to reach environmental goals, has led public administrations to increase the minimum standard of performance for building components. For this reason research in the building field has focused on increasing the performance of construction components in order to comply with international regulations.

Traditionally, in order to increase the thermal inertia of the building component it was necessary to increase its thickness and weight. On the contrary, higher thermal resistance is made possible either through the insertion of thermal insulation materials, or by increasing their thickness. As far as clay or concrete hollow brick is concerned, the design optimization [1–6] is based on changing the configuration of the cores, either by modifying the number of holes, their arrangement and the void fraction and, in some recent cases, by filling the holes with insulation materials [7].

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Nomenclature

λ_{eq}	equivalent conductivity of the cavity (W/m K)
c_{eff}	effective heat capacity (J/kg K)
c_p	specific heat capacity (J/kg K)
c_L	latent heat of fusion (J/kg)
d	size of cavity in the direction of thermal flux (m)
b	size of cavity across the thermal flux (m)
R_g	overall thermal resistance of the cavity (m^2K/W)
h_a	convective coefficient (W/m^2 K)
h_{ro}	radiative coefficient (W/m^2 K)
E	emissivity coefficient of the cavity (–)
ε_1	emissivities of the emitting surfaces (–)
ε_2	emissivities of the receiving surface (–)
t	time (s)
T	temperature (°C)
T_{amb}	ambient temperature (°C)
q	thermal heat flux (W/m^2)
C	thermal conductance (W/m^2 K)
U	thermal transmittance (W/m^2 K)
I	solar radiation (W/m^2 K)

This paper proposes the improvement of the energy performance of alveolar block either through the insertion of phase change materials in some enclosures of the brick in order to significantly increase the thermal inertia of the wall or through the use of a low emissivity coating technique applied on the brick by covering the enclosures with low emission and absorption paint, thereby reducing the overall heat transfer coefficient value of the brick.

1.2. Phase change materials

Owing to their high latent heat of fusion and, to a lesser extent, to their specific heat, these materials act as heat accumulators. During melting and solidification PCMs absorb and discharge heat, keeping their temperature unaltered and thus avoiding the overheating of the building components in which they are contained. The advantages derived from the use of PCMs as regards energy behavior is in their heat storage ability, utilizing lower values of weight and thickness than traditional systems. PCMs are categorized as organic, inorganic and eutectic materials, with a large number of materials having different specific characteristics, such as melting point temperature, latent heat, specific heat and chemical properties [8].

The principal applications in the building field are in:

- underfloor systems, to control the temperature and store energy in the winter, and to store energy and maintain thermal comfort during the summer [9–12];
- walls to increase thermal comfort, reduce energy consumption for cooling and exploit solar energy [13–19];
- air exchange systems to stabilize the internal temperature, storing in the warm hours and releasing energy during the night, combined with night time ventilation [20,21];
- heat storage units in cooling and heating systems [22–25].

Most investigations have been carried out by studying the insertion of PCMs in several dry and lightweight [13,14] construction materials, but only a few studies have been performed on brick constructions, which are typical of the Mediterranean area.

Alawadhi [15] investigated the introduction of PCM in bricks, obtaining results which indicated a theoretical reduction in the heat flow entering the indoor space in summer. This research study was conducted through a numerical analysis of a 0.25 × 0.15 × 0.15 brick with cylindrical vertical holes and a void fraction of 37.5%. The brick contained three PCM cylinders inserted in the holes. The amount and location of the PCM cylinders in the brick was also investigated. The study was carried out for extremely hot external conditions, in particular using the climatic data for Kuwait City. Three types of paraffin were examined as PCMs: *n*-octadecane, *n*-eicosane, and P116, with a melting point of 27 °C, 37 °C and 47 °C respectively. The results indicate that the overall heat flux reduction for the outdoor and indoor PCM cylinder locations is 17.49% and 10.16%. The best performance was obtained by *n*-eicosane placed at the centerline of the brick.

An experimental analysis [16] carried out in the Mediterranean climatic context demonstrates the good performance, energy savings and technical viability of using macroencapsulated PCM in typical construction solutions. It was carried out on two different bricks: conventional and alveolar. The PCM was not integrated in the brick, but was used as an additional panel containing RT 27 paraffin and SP-25 A8 hydrate salt positioned on the outer surface of the conventional brick and on the internal side of the alveolar wall. Both of the envelopes containing PCM demonstrate the capacity to reduce energy consumption compared with the same envelope without PCM. The experimental data show how PCM allows electrical energy consumption to be reduced by about 15%.

Heat transfer in PCM is complex, especially due to the transition phase, when the material stores or releases latent heat. Numerical methods to evaluate the energy performance of PCM have been investigated in a number of studies and in particular the effective heat capacity method [14] and the enthalpy method [17] have been widely implemented. In the first method, the effective heat capacity is directly proportional to the stored/released energy during the phase change and the specific heat. In the second, the enthalpy is a function of temperature and it is considered as a dependent variable along with temperature. In this paper the heat capacity method is used. In literature, numerical analyses on PCM are carried out with the finite difference method (FDM) [14], the finite elements method (FEM) [17], and the finite volume method (FVM) [26]. In order to evaluate the application of PCM on an entire building and to estimate and predict the energy levels of thermal comfort, investigations on the implementation using software such as TRANSYS [19,27], ENERGY PLUS [28], ESP-r [29] have been carried out.

1.3. Low emissivity application

Membranes and low-emissivity or reflective coating are technologies based on the properties of some materials used in various fields in order to reduce the thermal transmission or the absorption of solar radiation. In the range of temperatures which are typical of building components, the thermal energy is mainly transmitted by irradiation and, for this reason, several recent applications have made use of products based on low emissivity material to reduce the heat exchange and improve energy performance.

In the building field, low emissivity materials are used to reduce the transmittance of double glazing, through the application of metallic coating of some microns in thickness [30]. Moreover, multilayer membranes built with low emissivity foils are used as thermal insulation for walls and roofs, to decrease the thickness and increase the thermal resistance [31].

In a theoretical study on the thermal behavior of fired clay hollow bricks [32], the reduction in the emissivities of cavities was proposed as a solution for improving the thermal insulation of brick. The evaluation was carried out on traditional small-size and large-size brick, through the variation in the emissivity of the surface between 0.3 and 0.7, and demonstrated an important increase in the thermal resistance. The study demonstrates that the improvement is variable and depends on the configuration and the dimension of the wall. For cavity surfaces with an