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Enhancement of the thermal performance of perforated clay brick walls through the addition of industrial nano-crystalline aluminium sludge

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HIGHLIGHTS

- Characterization of innovative eco-thermo-efficient hollow clay bricks.
- Recycling of industrial nano-crystalline aluminium sludge.
- Eco-efficient bricks with improved thermal performance (*U*-value almost 10% lower).
- Combined experimental/numerical approach to assess thermal performance.
- Importance of mortar joints in the overall wall thermal transmittance value.

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ABSTRACT

One of the most common approaches to contribute to the sustainability of the construction sector consists in adding industrial by-products to raw materials. However, this generally presents the major drawback of leading to a loss of the product's properties. The study herein presented is part of a research project, developed in co-promotion with a manufacturer of perforated clay bricks, with the final goal of incorporating industrial nano-crystalline aluminium sludge in the raw material, but with the additional goal of improving the thermal properties of the original product.

A combined experimental/numerical approach has been used to assess the thermal performance of walls built with the new eco-efficient perforated clay bricks. First, tests were conducted on laboratorial prototypes and relevant parameters were measured. Next, a numerical analysis was performed using three-dimensional finite element models, calibrated and validated using the experimental results. Furthermore, the results were compared with other simplified models (2D) and its reliability assessed.

The obtained results show that the new eco-efficient perforated clay bricks exhibit better thermal performance than the original product, leading to almost 10% improvement of its thermal transmittance.

1. Introduction

The improvement of the thermal performance of buildings' envelope is essential to ensure the energy efficiency of buildings, responsible for 40% of energy consumption in developed countries [1]. A major share of the latter concerns the ambient conditioning inside (space heating and cooling) which presents an increasing trend given people's growing needs in terms of comfort. One of the most important components regarding heat losses in a building are the external walls, due to their very significant exposed area. For all these reasons, the development of new solutions (for external walls) with improved thermal performance is a highly relevant and up-to-date subject.

Furthermore, the European policies (e.g. the energy performance building directive – European Directive 2010/31/EU [2]) are pushing for the development of more efficient buildings and, therefore, for more efficient building components and materials. According to this directive all new buildings will be 'nearly zero-energy' by 2020. Consequently, both European and member states standards are being updated to copy with these more challenging targets. The following examples can be presented: the Portuguese buildings energy certification system [3], the basic document for limitation of energy demand of the Spanish building technical code [4], and the technical guidance 'document L' of the Irish building regulation [5].

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Previous studies have addressed the improvement of the thermal performance of external walls using different strategies with different aims: (i) improving the thermal transmittance coefficient or *U*-value; (ii) increasing the thermal mass (or thermal inertia); and/or (iii) correcting thermal bridges.

Regarding the thermal transmittance coefficient, the following solutions have been studied: (i) the use of alveolar bricks [6,7], and (ii) the adoption of lightweight steel framed walls [8], among others. Furthermore, other influencing parameters have also been analysed in this scope: (i) the number of wall panes [9], (ii) the number, relative position and thickness of insulation layers [10], and (iii) the adoption of an air–gap, and the ventilation level of the latter [11].

In what concerns the relevance of the thermal mass (or thermal inertia) of external walls for their thermal performance, this is mainly due to the fact that they are subjected to thermal dynamic loads [6]. Previous studies have been conducted aiming at improving the thermal performance of walls by adding some supplementary thermal mass, e.g. using Phase Change Materials – PCMs [12–14].

Regarding thermal bridges, there are also published studies (e.g. [15]) on the effect of mortar joints across insulation layers in masonry walls, under dynamic conditions. According to the latter work [15], thermal bridges can reduce the thermal resistance value in 53% and increase the transmission loads by 103%. Naturally, the significance of the increase of thermal bridges with the increase of the thermal conductivity of the material crossing the insulation layer is particularly relevant in the case of steel frames [16].

Focusing on the use of perforated clay brick units in external walls, there are two main approaches to improve their thermal behaviour. The first one consists in increasing the thermal path of heat flow by changing the perforation geometry of the bricks. This issue was addressed by [17] and it was found that a rhomboid layout of voids with the longer diagonal at right angles to the heat flux is the best internal layout. The second one consists in adding other materials to the raw material (clay or cement) during the production process in order to reduce its thermal conductivity. In [18] recycled paper mill residue and rice husk ash were used in the production of lightweight cement bricks. Besides the obvious environmental benefits, these authors also found out that the increased porosity of the resulting bricks, which led to their lightweight and thus lower thermal conductivity, did not change the needed compressive strength requirements. In [19], the properties of new cement bricks made of fly ash, quarry dust and billet scale are studied. It is reported that the use of these industrial wastes allows obtaining bricks with good and promising performance, not only regarding the ecological and environmental gain, but also in what concerns the obtained mechanical properties and durability.

The study herein described refers to the thermal characterization of building walls made of perforated clay bricks containing sludge from the aluminium industry in nano-crystalline form. The main motivation for the research project that supports this study was to solve an environmental problem by adding this industrial waste to the clay brick raw material, with the additional advantages of both improving their thermal behaviour and eliminating the costs associated to the waste disposal. The aluminium sludge is the waste that results from the anodising and lacquering processes of the aluminium alloys. These techniques are used to protect the metallic materials from corrosion and to provide some aesthetic effects. Currently, the aluminium sludge is classified as non-toxic and inert, but the deposition in landfill of considerably high amounts of this industrial waste is quite expensive.

This paper is organised in the following sections: (i) description of the wall system and components, (ii) experimental set-up and instrumentation for assessing both thermal conductivity and thermal transmittance, (iii) numerical approach, including the discretization domain, the boundary conditions, and the modelling of air layers, (iv) results and discussion, including a comparison between experimental and numerical values, and (v) conclusions.

2. Wall system and components

In this section the new hollow clay brick units are presented and the construction of the single pane masonry wall system is described.

2.1. Brick units

In the present study, two types of hollow brick units were analysed: (1) the 'original brick', made of clay without any addition of aluminium sludge; and (2) 'ecological brick', made of clay with an addition (5% in weight) of nano-crystalline aluminium sludge. The original brick units are manufactured by Preceram, S.A., under the commercial label "Thermal and Acoustic Brick 30 × 19 × 24". The geometry of the new 'ecological brick' is exactly the same of the original one (Fig. 1).

2.2. Wall construction system

The wall construction system consists of a single pane type, plastered in both faces with cement mortar (18 mm in each surface). Only the horizontal joints between bricks are filled with cement mortar, although a 100 mm air gap (splitting the mortar joint into two) is considered (Fig. 2), in order to minimize the thermal transmission through this material.

3. Experimental tests

The experimental tests performed and the results obtained, used to calibrate and validate the numerical study, are briefly presented in this section. First, the thermal conductivity of both ceramic materials ('original' and 'ecological') and mortars used in the finishing and joint layers of the wall are presented. Next, physical properties such as the density and the percentage of voids of the perforated 'original' and 'ecological' brick units are listed. Finally, it is explained how the wall thermal transmittance was assessed using the calibrated hot box apparatus and results for two test specimens – one produced with 'original' and the other with 'ecological' brick units, and considering readings before and after the mortar finishing layer was applied – are presented.

3.1. Ceramic material and mortar

Nowadays, there are several standards available with tabulated design values regarding hygrothermal properties of materials. Some examples are: ISO 10456 (2007) [20], EN 12524 (2000) [21] and DIN 4108-4 (2013) [22]. However, given the new materials being studied herein and the large variability associated with the properties referred to, it was decided to measure the hygrothermal properties of all materials used in this work.

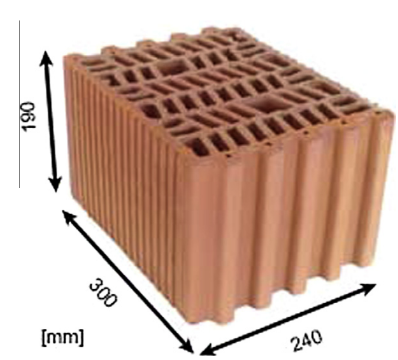

Fig. 1. Hollow clay brick unit geometry and dimensions.