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Possibilities for improving the equivalent thermal transmittance of single-leaf walls for buildings

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ABSTRACT

Recent years have seen several studies on the factors influencing heat transfer in single-leaf walls made of large lightweight clay blocks, the aim being to reduce energy losses and moderate the use of heating and air conditioning.

Those factors are the geometry of the block (internal voids and vertical joint), the execution of the wall (horizontal joint) and the thermal conductivity of clay.

This paper provides a comprehensive analysis of the various factors by making a comparative study of the equivalent thermal transmittance of the wall obtained with different geometries and different executions of the wall, depending on clay conductivity. Note that this parameter is the one on which it is easiest to act, by adding appropriate amounts of lightening additive in the manufacturing process.

Our findings reveal that a percentage decrease in clay conductivity produces a linear percentage reduction in the thermal transmittance of the wall, regardless of the type of block and wall mounting. In particular, a 50% decrease in the thermal conductivity of the clay leads to a 20% reduction in the equivalent thermal transmittance of the wall.

An equation has been obtained that enables the decrease in the equivalent thermal transmittance of a wall when the thermal conductivity of the clay is decreased to be estimated with an error of less than 3%.

1. Background

Sustainability in global energy generation depends mainly on three lines of action: the use of renewable energy sources [1,2], energy saving, and the energy efficiency of machinery and buildings.

Regarding this last line of action, the building sector has had to improve the techniques and properties of the materials used in the construction of enclosure walls so as to minimize energy loss and reduce energy requirements.

Low-density, lightweight materials are now being used. Recent studies have shown the influence that the cladding materials used in building walls have on CO_2 emissions and energy consumption [3]. Seeking to explore further improvements in wall construction materials, other studies have shown how the porous nature of clay bricks can improve thermal performance [4,5].

Lightweight ceramic blocks in single-leaf walls [6] meet these new requirements well. Masonry walls built with such bricks combine good sound insulation, high mechanical strength, exceptional fire resistance and high levels of heat insulation and comfort (thermal inertia). They are also fully sustainable and environmentally friendly, as they are made solely of fired clay, and their useful lifetimes can extend over several centuries.

Of all the different construction solutions for enclosures or envelopes, we focus on the single leaf with no inner cavity, characterized by large format blocks with appropriate interior and exterior cladding. There are three sections in these single-leaf walls that can affect their thermal performance: the cross-section of the blocks with their air-filled voids (the “clay/air cross-section”), where the geometry of voids and the type of tongue and groove system are influential; the cross-section of the blocks with the voids filled with bonding mortar (the “clay/mortar cross-section”); and the cross-section of the layer of bonding mortar itself, (the “bed joint cross-section”).

Researchers have recently shown increased interest in all the components of these sections. The resulting papers have individually characterized the influence of the type of internal void of

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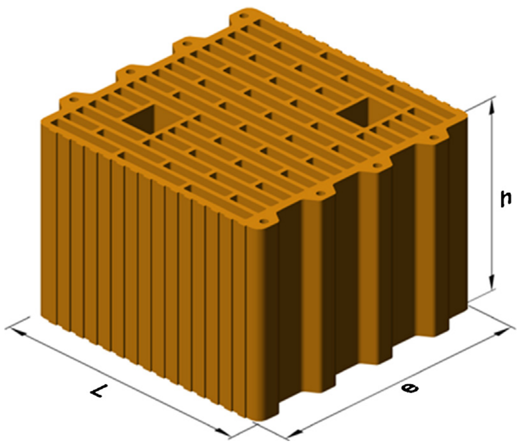

Fig. 1. Lightweight clay block.

the large format block [7–13] and the type of tongue and groove arrangement [14,15] in the clay/air cross-section and clay/mortar cross-section and, finally, the influence of the horizontal joint on the bed joint [16].

Other research has sought to reduce the thermal conductivity of the clay by including additives, and has shown that this decreases thermal conductivity by generating gas micropores in the volume of clay [17–21].

This paper seeks to analyze comprehensively the influence of all these factors so that it can be decided what parameter to act on to reduce the equivalent thermal transmittance of the wall.

Finally, an attempt is made to find a relationship between the equivalent thermal transmittance of a wall and the conductivity of the clay used, since this is a parameter on which it is possible to act easily by using a dispenser to adding suitable quantities of lightening additive to the clay during the manufacturing process, prior to the extrusion of the clay.

Single-leaf walls with large lightweight clay blocks were chosen for this study.

The numerical calculation method used to obtain the equivalent thermal transmittance U_{eq} (W/m^2 K) of a wall complies with Spanish UNE [22] and AENOR [23] standards as well as EN [24–30] and ISO [29–31].

2. Materials and methods

2.1. Proposed blocks

Fig. 1 shows the large block model to be studied, which has the following specifications:

1. Brick dimensions: 300 mm × 290 mm × 250 mm.
2. Interior wall thickness: 5 mm.
3. Exterior wall thickness: 8 mm.
4. Length of tongue and groove arrangement: 16 mm, avoiding a vertical joint in the wall.

Two different types of block are considered:

(a) The first (block a) with rectangular internal voids consisting of 17 rows perpendicular to the heat flow, in a quincunx, and with a voided tongue and groove arrangement, since this is the layout most widely used commercially and it has been studied previously [4–10]. The cross-section of this block is shown in Fig. 2a.
(b) The second (block b) with rhomboidal internal voids, consisting of 25 rows perpendicular to the heat flow and a simple tongue and groove arrangement. This block has recently begun to appear on the market after several studies [11–14,16]. The cross-section of this block is shown in Fig. 2b.

2.2. Horizontal joint in brickwork wall

The blocks described are examined with three different types of horizontal joint:

(a) A horizontal joint made with standard mortar and penetration, called a *full-bed joint*.
(b) A discontinuous joint with an air chamber (this type of arrangement is the one most widely used in building), called a *furrowed-bed joint.*
(c) A thin horizontal joint that uses a type of mortar grip that does not penetrate the junction blocks of consecutive rows, called a *thin joint*.

In this last arrangement, the clays used in the block should allow easy grinding, as the bonding mortar is applied in very thin layers of 3 mm, according to the standard [22]. This arrangement requires proper alignment of the blocks, suitable flatness between them and precision workmanship.

Each wall was built as follows:

(a) Normal arrangement using standard mortar (λ_m = 1.3 W/m K), with 10 mm bed joint thickness and 10 mm of penetration in each block. Two different horizontal joints were assessed:
   - full-bed joint
   - furrowed-bed with a 30 mm gap
(b) Assembly with a thin horizontal joint made of bonding mortar (λ_m = 0.83 W/m K), with 3 mm bed joint thickness and no penetration.

2.3. Fired clay conductivity

As mentioned above, clays today are lightened with various materials in order to reduce their conductivity. Several studies have been conducted on this matter [32,33], but they are all based on a clay with a specific composition and a given conductivity.

A recent study [21] has shown that adding up to 15% additive to a clay with no additive and λ = 0.745 W/m K can reduce its conductivity to λ = 0.445 W/m K, i.e. by 40%.

Considering this background of studies, we set out to check for a relationship between the conductivity of fired clay bricks (regardless of how they were made) and the equivalent thermal transmittance of a wall built using the blocks and arrangement proposed above.

The starting point for the study was a clay with a conductivity of λ = 0.600 W/m K, decreasing in steps of 0.05 W/m K to conductivity values of 50%, that is, to a figure of λ = 0.300 W/m K.

2.4. Calculations

The numerical calculations were carried out as per Spanish UNE [13] and AENOR [14] standard as well as EN [15–18] and ISO [19,20]. The finite elements method [34,35] was used to obtain the heat fluxes for the boundary conditions as per the standards, thus enabling the equivalent thermal transmittance of the envelope wall to be calculated.

The finite elements method was used to solve each of the first two characteristic sections of the wall (the “clay/air cross-section” and the “clay/mortar cross-section”) with the boundary conditions specified by the aforementioned standards, as shown in Fig. 3. The heat flow through each characteristic section, Q_i, was obtained.