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PATENT NEWS ARTICLE

Solid and Homogeneous Thermal Wall of Cored Lightweight Concrete Blocks Solidarized *in situ*

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Abstract: The exterior walls of buildings play a major role in the road for a near-zero energy building. Nowadays, in Portugal, the ETICS system is the most used technology to ensure the thermal insulation of exterior walls of buildings. However, the ETICS system has low resistance to impacts and requires a self-supporting sheet of wall, among other disadvantages. Here, the concept of new technology for exterior walls of residential and commercial buildings is presented. It consists of a hybrid technology for the easy and quick execution of a single sheet wall, which may provide high thermal efficiency for buildings. This hybrid technology relates to parallelepiped-shaped cored lightweight concrete blocks comprising two parallel sides separated by one or more solid connectors in which the connectors allow the filling of the block core with lightweight concrete. No bed or head joints are used to connect the blocks because the wall made of cored blocks gets solid and homogeneous when filled with lightweight concrete. When the block thickness is 30 cm and the thermal conductivity of the lightweight concrete is lower than 0.09 W/m.ºC, in Portugal, this type of exterior wall does not require the application of extra thermal insulation materials.

Keywords: Buildability, connector, cored block, lightweight concrete, prefabrication, thermal insulation, wall.

1. INTRODUCTION

The energy efficiency of buildings is one of the key factors in the roadmap for environmental, economic, and social sustainability [1-3]. According to ‘Facts and Figures’ of Goal 11 and Goal 12 from the sustainable development goals of the UN Agenda 2030 “828 million people live in slums today …” and “households consume 29 percent of global energy and consequently contribute to 21 percent of resultant CO_2 emissions” [4]. Yet, according to the European Commission [5], (i) 75% of the European Union (EU) buildings are energy inefficient, and (ii) 40% of all energy consumed in the EU is used for heating and cooling buildings. Regarding environmental sustainability, there is no carbon neutrality without buildings with low energy needs because, today, greater energy consumption means greater burning of fossil fuels, and hence greater CO_2 production. Regarding economic sustainability, the EU is a strong importer (which deranges the trade balance) of fossil fuels to use in the energy production process. With respect to social sustainability, the lack of energy efficiency in buildings increases social inequality because the most vulnerable people are the most affected by the quality and comfort of housing and they are the ones with the family budgets more conditioned by the energy bills. Thus, the European agenda intended that from January 1st, 2021, all new European buildings should use very low or almost zero amounts of energy for heating and cooling. Therefore, it is crucial to develop affordable insulation systems for exterior walls that keep the energy in the building, *i.e.*, that allow commercial and residential buildings to use energy more efficiently.

In Portugal and in several other countries, as widely popularized in the second half of the 20th century, the current construction of the exterior walls of buildings involved the execution of two brick walls with a cavity of air in the middle, that is, the execution of two brick masonry walls. It is to be noted that sometimes, a concrete block was used for the outer part of the wall. In order to respond to thermal requirements, from the 1990s onwards, thermal insulation (EPS or XPS sheets) was introduced in the cavity. This solution (double wall) has fallen into disuse for several reasons, including the need for ventilation of the cavity, it did not solve the thermal bridge problems, there was a hollow sound when knocked, *etc*.

Currently, the most common solution for the exterior walls of houses in Portugal is the execution of a masonry wall with cored blocks of lightweight concrete produced with expanded clay with notable thermal and acoustic insula-

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tion properties [6]. To materialize the wall, the blocks are arranged in courses and are connected by head joints and bed joints of mortar being 1 to 2 cm thick. But, in this solution, there are discontinuities in the wall due to cores. Besides, the wall is not prepared from a homogeneous material due to joints of mortar, with these heterogeneities reducing the thermal efficiency of the wall due to thermal bridges. To reach the minimum thermal insulation requirements, a board of thermal insulation is normally applied from the outside of the wall's ETICS system, a well-known system widely known from the registered trademark 'Cappotto™'. This system consists of fixing thermal insulation (usually EPS at least 6 cm thick) covered by a reinforced fiberglass mesh for the final finish. It should be noted that the ETICS system is expensive and is placed only to meet thermal requirements as it needs a support structure (thermal insulation boards are not self-supporting) and has low impact resistance. On the inner part of the wall, only the final finish is applied (usually sprayed plaster or plasterboard).

As a variant of the previous solution, which is based on the execution of a masonry with lightweight expanded clay concrete blocks, the ETICS system can be substituted (which uses EPS boards fixed with mechanical bushings and a reinforced surface finish) by applying a mortar designed with characteristics of thermal insulation; for *e.g.*, the registered trademark 'Isodur™' is a thermal mortar that is applied like a plaster. This solution has as its main advantages solving the thermal bridges problem with a material that provides a superior surface resistance to impacts, and it is sold dry in bags allowing being applied on site. So, on site, this bagged material is mixed with the correct content of water in a mixer that pumps the material to project onto the walls. However, this technology is faced with great difficulties in configuring itself as an effective alternative to the typical ETICS system with ESPS boards because it is quite expensive, among other disadvantages. From the economic point of view, the material itself (Isodur™ [7]) is an expensive material; it is a material designed to be used as a plaster. In volume, the material alone is around 250 EUR/m^3, which compares with the 100 EUR/m^3 of EPS in boards. It is applied in two phases: (i) the base layer with several centimeters where the thermal insulation itself is made, and (ii) the final finishing layer with a few millimeters. Moreover, productivity is reduced due to technical difficulties associated with cleaning the construction site because of the release/loss of EPS spheres during projection. In addition, this material has a lower thermal resistance than the thermal insulation of the EPS board used in the hood-type solution. Because of that, it is necessary to have a very large plaster thickness with Isodur™ to meet the minimum thermal requirements, which in turn makes the final solution more expensive, making it unattractive.

A less common solution, but which is sometimes used in basements or in the construction of the reinforced concrete superstructure using tunnel formwork technology, is the solid reinforced concrete wall, in which the typical masonry of thermal blocks is replaced by a solid wall of reinforced concrete. Also, in this case, in order to meet the thermal requirements, it is necessary to apply thermal insulation which, once again, can be materialized through the ETICS system (fixing EPS board) or projection of a thermal insulation plaster mortar.

It should be noted that, in the solutions mentioned above, the thermal insulation itself (that is, the material that most contributes to the thermal insulation of the wall) is not self-supporting. Rather, it is fixed to a substrate with a self-supporting capacity. Thus, as an alternative to these solutions, we also have composite panels formed by a lightweight concrete core with EPS granules and surface coating boards (usually calcium silicate or magnesium oxide). This solution has not been able to get itself in the market due to various technical problems associated with construction technology; among others, the main thing is the ability to connect and unify the panels. Metal dowels and glue mortar are usually placed in the connection between the panels. However, the connection is inefficient and does not lead to a quality finish for residential buildings; hence, this type of solution is more associated with warehouse walls or places where the opening of cracks and the finish may be of inferior quality. In addition, in order to have an insulating capacity greater than the minimum requirement, these panels normally need to be at least 25 cm thick. However, such thickness when combined with the typical size of the panels (230 cm high and 60 cm wide) leads to heavy panels that are difficult to handle and fix on-site. Notwithstanding these problems, this technology is both self-supporting and thermally insulating.

There are still other less common solutions using self-supporting and thermally insulating blocks, namely, (i) solid blocks (not hollow) produced with light concrete with EPS granulate, and (ii) blocks of autoclaved concrete. However, these blocks continue to be (in essence) a masonry and need head and bed joints of mortar (or another type of binder) between the course of blocks and between blocks of the same course. This leads to discontinuities and inhomogeneities of materials, which in turn leads to thermal problems (thermal bridges) that are only well resolved when the ETICS system is added. That is, in practice, these two types of solid blocks, although they may have better thermal properties, resemble, and present the same problems as the current blocks of expanded clay. Hence, these solutions were not able to replace the most common solution (expanded clay blocks).

There are also non-self-supporting solutions, in which the execution of the walls requires a skeleton with support capacity; examples of these solutions are (i) the light steel framing technology consisting of a steel skeleton filled with glass wool and ETICS system on the outside; (ii) technologies that use strong wooden skeletons filled with glass wool or straw bales or other thermally insulating materials; (iii) plasterboard plates supported on a steel skeleton with the interior filled with glass wool; and (iv) composite panels. All these solutions are construction alternatives; however, they are not the most common in Portugal because they are not solutions aimed at the Portuguese traditional construction with reinforced concrete pillars, beams, and slabs.

Being aware of the distinct technologies mentioned above, their advantages and disadvantages, the goal of this paper is to present an alternative technology for the exterior walls of buildings. Therefore, this paper regards the invention named "solid and homogeneous thermal wall of cored lightweight concrete blocks solidarized *in situ*" patented in

Portugal with the register code 'BBCA/1A' and 'PT116197(A)' with the original title (in Portuguese) 'Parede térmica, maciça e homogénea de blocos vazados solidarizados *in situ*', published in the Portuguese bulletin of industrial property Nr. '2021/09/27', with the publication Nr. 'PT 116197 B' and with the international classification 'E04B 2/84 (2006.01) E04B 2/02 (2006.01)', with the inventor being the author of the present article [8]. Although the invention is at the concept stage yet, *i.e.*, TRL2. However, when implemented, it is expected to be cheaper, easier, with quicker execution, and involving the wall dispensing from requiring the application of thermal insulation. Roughly speaking, the invention consists of a hybrid technology for the execution of a single sheet wall constructed with light blocks prefabricated with lightweight concrete and will not have bed joints or head joints connecting the blocks. Depending on the block's thickness and the material of the block, the wall may not require the application of thermal insulation.

2. METHODOLOGY

Under the patent process, other inventions with similarities to the one presented in this document have been analyzed. Among others, the most remarkable is Document FR 2836498 A1 [9] that discloses a hollow block with an "H" transverse profile made of concrete with "Lego™" type connections at the top and bottom. It is also referred to fill the empty spaces of the block with concrete. Documents, WO 2005033429 A1 [10] and CN 203654591U A [11], disclose hybrid technologies for the execution of walls through systems of core blocks filled with thermal insulating materials. Document CN 203654591U A [11] describes the system for building walls by concreting *in situ*. Document DE823195C [12] discloses a hollow block with a "double T" cross profile made of heavy or light concrete. It is also referred to as the respective wall composed of a succession of these blocks in which there is a phase difference of half a block between layers. Document FR1274218 A [13] discloses a hollow block with an "H" transverse profile where the cavities are filled with concrete and, horizontally, there is a recess in the connector to support an iron beam transversally. In relation to document FR 2836498 B1 [14], the invention has the advantages of allowing the shape of the connector to be optimized (cylindrical, elliptical, lozenge, *etc*.) in order to reduce the amount of air trapped after filling with concrete and to allow the filling of hollow blocks on site with the same material to join all the blocks and make the wall solid and homogeneous. Furthermore, the invention does not present any restriction on the displacement of blocks between successive layers, which differentiates it from document FR 2836498 A1 [9].

2.1. Detailed Description of the Invention

The present invention relates to a cored block with a parallelepiped shape, forming a formwork element for the construction of self-supporting exterior walls and other structures of civil engineering works. According to Figs. (**1-12**), the block comprises two parallel side sides (1) separated by a massive connector (3), in which

- the connector is positioned at a distance from the inner edges (5a,5b) of the lateral sides (1) forming a space at the top (2a) and at the bottom (2b) that allows the passage of filling material (6);

- the connector has a rectangular (3a), cylindrical (3b), elliptical (3c), diamond (3d), or other configuration that reduces air retention after filling the block core with a filler material (6).

As for the elliptical/cylindrical shape of the connectors, this allows the concreting (filling) of the interior of the wall to be easier to perform, namely with regard to the reduction/elimination of any voids that may appear near the connectors, providing less difficulty in filling of the spaces next to the connectors.

On the other hand, the manufacturing process (block molding) becomes easier as the inner corners/edges of the block are reduced (more difficult to perform in molding/production).

Preferably, the block is made of a material chosen from the group: lightweight concrete lightened with EPS granulate; lightweight expanded clay-lightened concrete or any other material with acoustic properties (*i.e.*, any other material that leads to an Rw of at least 30 dB when a solid, homogeneous wall 30 cm thick is constructed of that material) and low thermal conduction (thermal conductivity of the material not exceeding 0.25 W/m.ºC).

Preferably, the filling material (6) of the hollow core (4) is lightweight EPS granulate-lightened concrete, expanded clay-lightened concrete, or other material with acoustic properties (*i.e.*, any other material that conducts at an Rw of at least 30 dB when a solid and homogeneous wall 30 cm thick is constructed with this material) and low thermal conduction (thermal conductivity of the material not exceeding 0.25 W/m.ºC).

Preferably, the core block has the following dimensions: length (A) from 20 to 120 cm, preferably 60 cm; width (B) from 10 to 45 cm, preferably 30 cm; height (C) from 10 to 60 cm, preferably 30 cm; hollow core thickness for filling with filler (D) from 4 to 35 cm, preferably 14 cm; and with 20% to 50% voids, preferably 35.5%. Still, preferably, the inner margin (5a) is 2 to 25 cm, preferably 6 cm; the inner margin (5b) is 2 cm and 50 cm, preferably 6 cm.

The present invention further relates to a solid and homogeneous thermal insulating wall comprising a plurality of hollow blocks, in accordance with the above descriptions, wherein the blocks are stacked vertically without restriction in displacement between the consecutive layers.

2.2. Production

In general, the dry concrete manufacturing process used in the construction of blocks is divided into two places, the factory and the construction site, and comprises the following steps:

a) In factory:

1. Prepare dry lightweight concrete mixes.

2. With dry lightweight concrete:

2.1. Bag and prepare for transport.

2.2. Mix with water, manufacture the blocks, and prepare for transport.

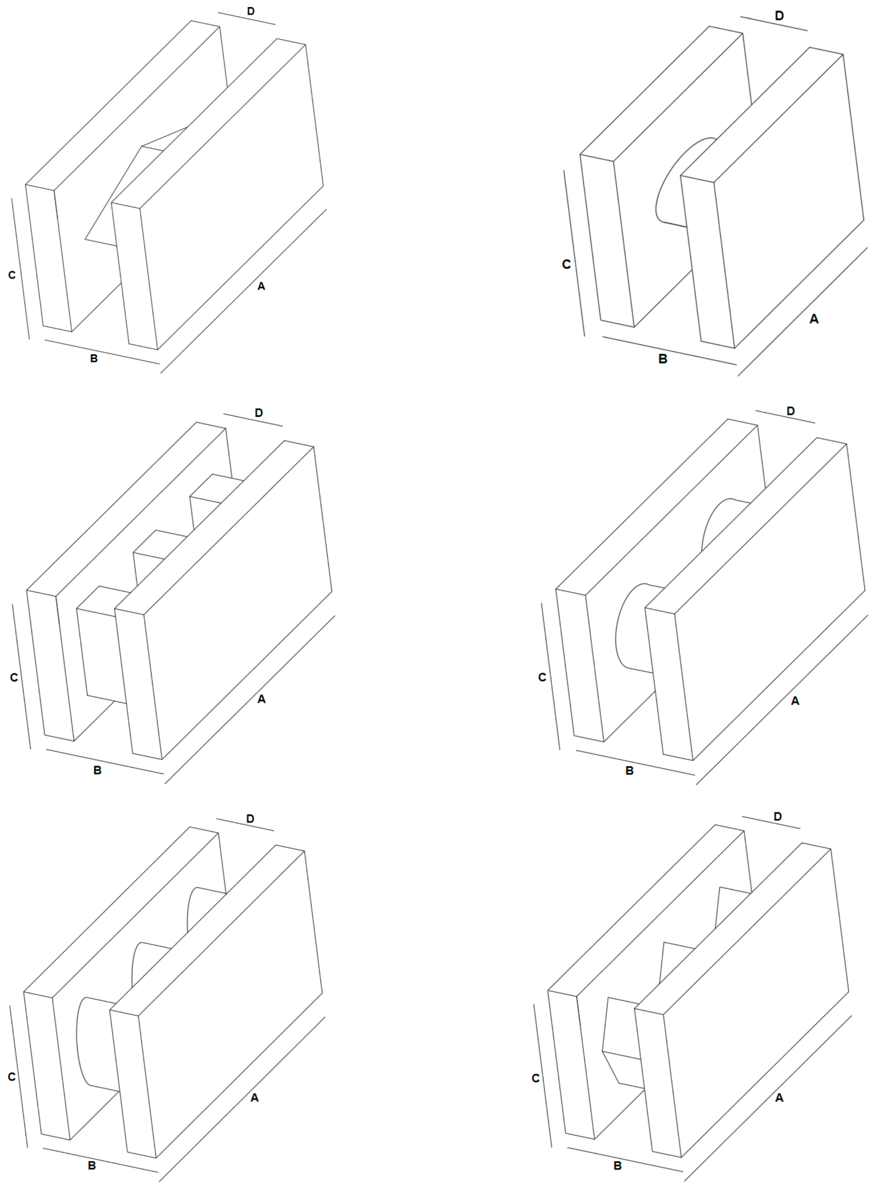


Fig. (1). Representation of cored blocks according to the invention (A – length, B – width, C – height, D – core thickness).

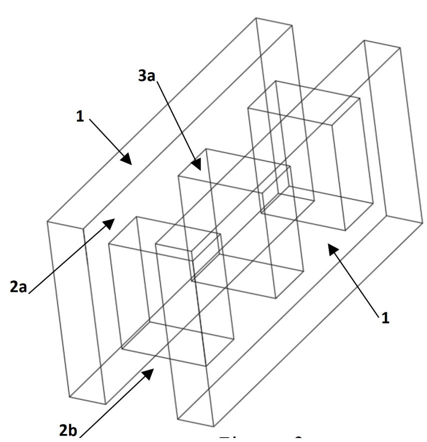


Fig. (2). Drawing of the parallelepiped-shaped cored block.

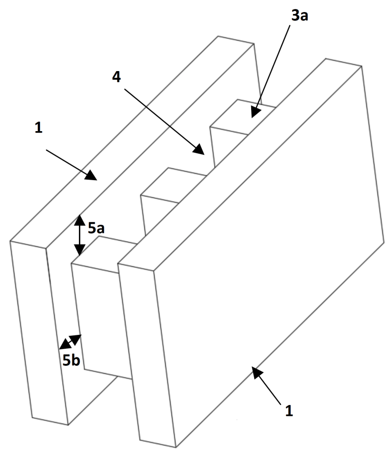


Fig. (3). Illustration of the parallelepiped-shaped cored block according to the invention in which the block comprises two parallel lateral sides separated by three solid rectangular connectors.

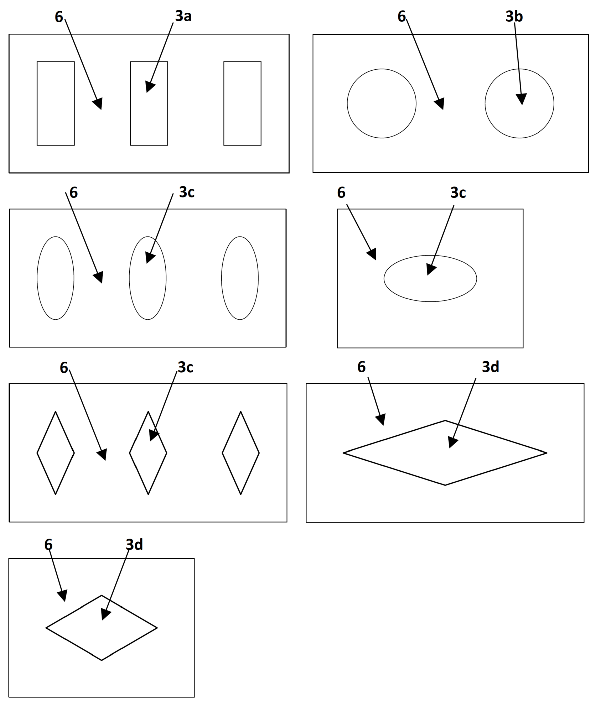


Fig. (4). Representation of the different forms of connectors to be used in a hollow block according to the invention.

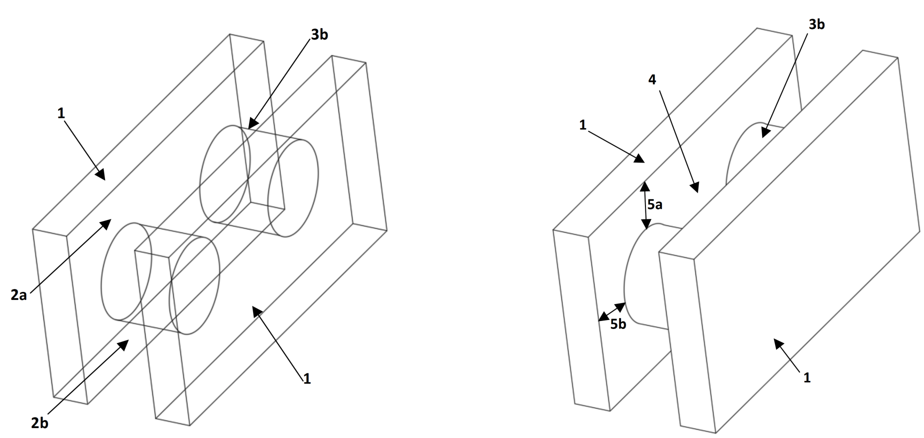


Fig. (5). Representation of a core block according to the invention in which the said block comprises two parallel lateral sides separated by two solid cylindrical connectors.

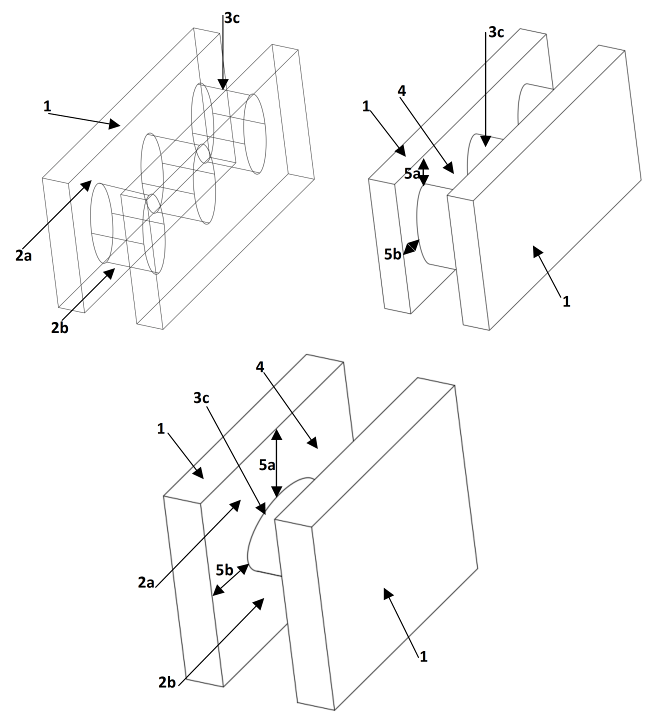


Fig. (6). Representation of core blocks according to the invention in which each block comprises two parallel lateral sides separated by at least one elliptical-shaped connector.

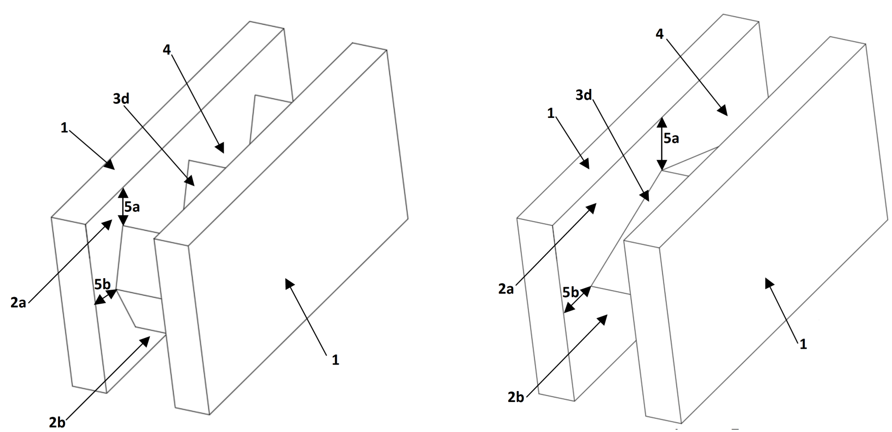


Fig. (7). Representation of core blocks according to the invention in which each block comprises two parallel lateral sides separated by at least one massive diamond connector.

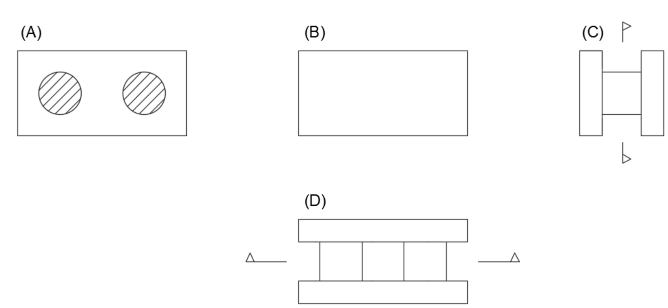


Fig. (8). Representation of a block with 2 cylindrical connectors: (**A**) Sectional view, (**B**) Main elevation, (**C**) Side elevation, (**D**) Top elevation.

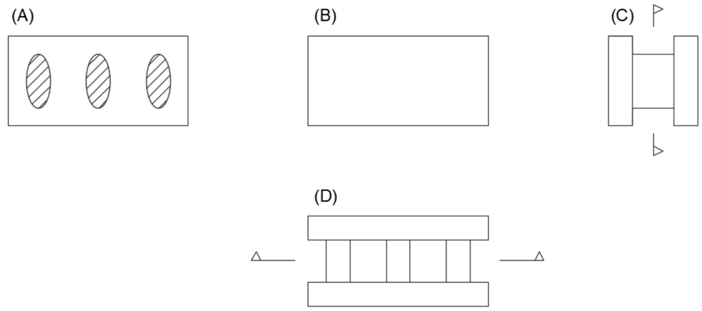


Fig. (9). Representation of a block with 3 elliptical connectors; (**A**) Sectional view, (**B**) Main elevation, (**C**) Side elevation, (**D**) Top elevation.

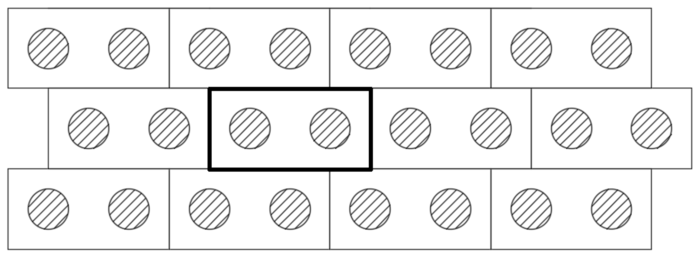
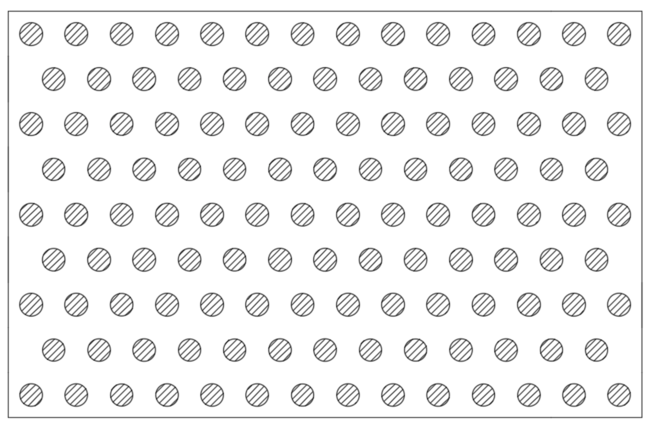
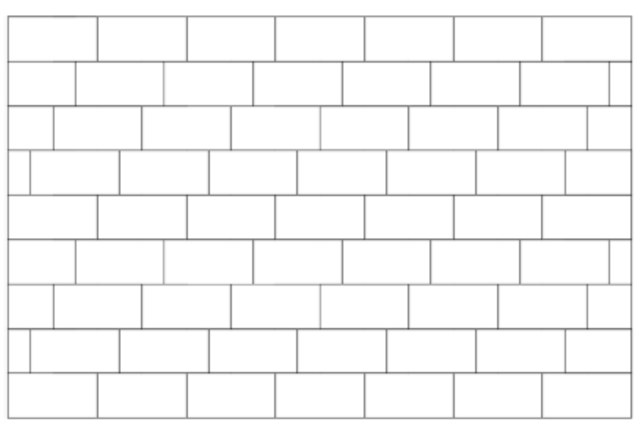


Fig. (10). Representation of a wall sawn in half before filling the core of the blocks. At the core of the wall, the in-situ concrete filler fills the entire contour of the block.

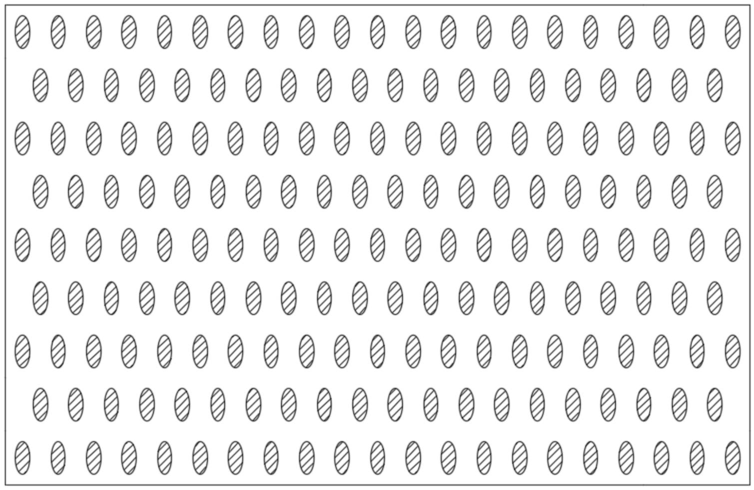


(A)

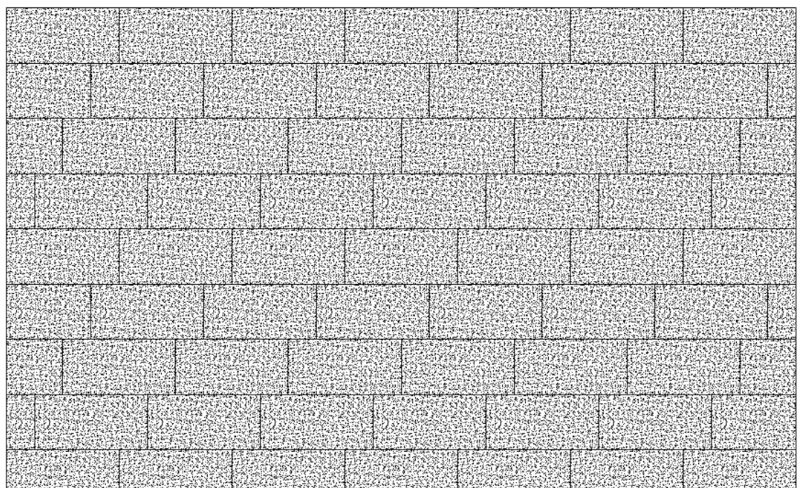


(B)

Fig. (11). Representation of a wall with cylindrical blocks according to the invention: (**A**) Exterior view, (**B**) Sawn wall after filling the core.



(A)



(B)

Fig. (12). Representation of a wall with elliptical blocks according to the invention: (**A**) Exterior view, (**B**) Sawn wall after filling the core.

b) At the construction site:

3. Receive and properly store blocks and bags of lightweight concrete.

4. Position the 1st row of blocks properly.

5. Mix the bagged lightweight concrete (dry) with water in a mixer with a pump and hose (similar to the preparation of Isodur® / sprayed mortars) and fill the voids (core) of the blocks by pumping.

6. Place a row of blocks duly cast in the previous row (without placing any mortar between the rows).

7. Fill the voids (core) of the blocks of the last placed row.

8. Repeat steps 6 and 7 successively until the wall is complete.

In particular, for the production of the lightweight concrete composition used in the blocks and wall of the present invention, the manufacturing method according to the following steps is used:

1) As a reference composition (materials and quantities), the following masses are used to obtain 1 m^3 (see point 7): 300 kg of cement, 1000 liters of EPS granulate, and 100 kg of sand. However, other materials and other amounts may be used.

2) Mix the amounts of dry-produced composition with the correct amount of water. In case it is the reference composition, mix the amounts defined in the previous point with 175 liters of water.

3) Produce the blocks in the factory using the fresh concrete produced in the previous step and using moulds.

4) On site, correctly position the first row of blocks on the ground (typically on a slab or reinforced concrete beam).

5) On site, in a pumpable on-site mixer (with characteristics similar to those used to mix and project Isodur™), mix the bagged dry concrete with the correct dosage of water and fill the core of the blocks of the first course (pumping light concrete).

6) On site, position/lay a new course of block on top of the previous course without any mortar between the blocks.

Table 1. Properties of the lightweight concrete for several dry densities.

Dry density [kg/m^3]	200	400	600	800	1000	1200
Compressive strength [MPa]	0.1	0.2	0.5	1.0	2.0	3.0
Thermal conductivity [W/(m.ºC)]	0.06	0.10	0.13	0.22	0.40	0.50

7) On site, fill the voids (cores) of the blocks by pumping light concrete produced with the same material with which the blocks were produced.

8) Repeat steps 6 and 7 until the wall is complete.

The product manufactured by the above method must be produced dry in order to be able to be marketed in bags, so that on site, it is only necessary to add water and mix and use it to fill the core of the blocks. By making this mixture, a concrete capable of being used in the prefabrication of blocks can be obtaibed. For the reference composition, the concrete after hardening should have a thermal conductivity close to λ=0.11 W/m.°C.

Various types of blocks can be produced, and in the case of the reference block with the reference composition, it must measure 60x30x30 cm from the outside and present 35.5% of voids, three rectangular connectors, and weigh 14 kg.

3 RESULTS

3.1. Expected Properties

As mentioned above, the invention titled "solid and homogeneous thermal wall of cored lightweight concrete blocks solidarized *in situ*" is at the technology readiness level 2 (concept level). Therefore, the results presented in this section are estimative based on calculations for an exemplar of a wall with 30 cm thickness. Thus, with the procedure aforementioned, a solid and homogeneous wall is obtained (of a single material and without empty cavities) whose properties depend on the properties of the lightweight concrete used and the wall thickness (which corresponds to the thickness of the blocks). In the case of the reference composition and with the reference block (it is 30 cm thick), the wall will have a mass of 120 kg/m^2 and a thermal resistance of 2.727 m^2.°C/W, which will correspond to a final thermal conductance of U=0.34 W/m2.°C (when standard plasters are applied). It should be noted that the technical information will depend on two factors: (i) the composition of lightweight concrete and (ii) the geometry of the block, namely its thickness. By consulting the technical sheet of EPS lightened concrete, presented by the company Ibera – Indústria de Betão, S.A. (a concrete producer from Portugal) [15], the following information can be obtained: (Table **1**)

In other words, it is possible to produce (or purchase) concrete with a thermal conductivity of 0.06 W/m2.°C, a density of 200 kg/m^3, and a compressive strength of 0.1 MPa.

However, consulting other companies and scientific studies, it appears that the values of the Ibera company are slightly better than those presented by other producers. But it is easy to find the popularity of lightened concretes with EPS granulate with a thermal conductivity of λ=0.070 W/m.°C when it has a density of ρ=200 kg/m3; λ=0.085 W/m.°C when ρ=250 kg/m^3; λ=0.100 W/m.°C when ρ=300 kg/m3, *etc*. It is important here to refer to the values λ=0.05 W/m.°C and ρ=300 kg/m^3 of Isodur^{TM}. The table below is an example of information from a company, not only for the density and thermal conductivity, but also the dosages proposed to obtain these values (Table **2**).

At the concept level of this invention, the author believes that a lightweight concrete with EPS granulate with a density of 200 kg/m3 should be an edge situation (it should be difficult to produce the block and difficult to fill it on site). However, a composition close to Isodur^{TM} is already totally realistic (in the limit, the blocks can be manufactured with Isodur^{TM} and fill the voids on site with Isodur^{TM} ; although the material has been developed for design, it could possibly fulfill the various requirements, with the exception of price).

Thus, it is considered feasible, at this stage, to consider as a reference a composition with 400 kg/m^3, made with 1000 liters of EPS granules, 300 kg of cement, 100 kg of sand, and 175 liters of water, capable of having a compressive strength of at least 0.1 MPa and a thermal conductivity of less than 0.11 W/m.°C.

In this sense, using the reference composition with the aforementioned characteristics (*ρ*=400 kg/m^3, λ=0.11 W/m.°C), a block 30 cm thick (that is, having the same thickness as the blind box) with its interior already filled would have a thermal resistance of 2.727 m2.°C/W. If we consider a typical wall with 2 cm of stucco as the interior finish and 2 cm of hydraulic plaster on the outside, we can obtain a coefficient of thermal transmission for the wall of U=0.34 W/m2.°C; that is, a lower maximum limit in the most demanding climatic zone in Portugal.

As for the blocks themselves, they could be produced in different sizes and with different types of connectors, but as a reference, we have the block 30 cm thick, 60 cm long, and 30 cm high (with three rectangular connectors) and an index of voids to be filled on site (35.5%). In this situation, the reference block is 14 kg and the final wall (before the cladding) is 30 cm thick and 120 kg/m^2.

Finally, through the calculations, one can obtain technical information for the reference situation (reference block and reference composition):

i. Lightweight concrete block with EPS granulate with external dimensions 60x30x30 cm, 35.5% voids, and 14 kg weight.

ii. Lightweight concrete with dry bagged EPS granulate to be applied on site produced with the following composition per m^3: 1000 liters of EPS granulate, 300 kg of cement,

Table 2. Properties of the lightweight concrete for several compositions.

Density (kg/m^3)	Thermal Conductivity (W/mºC)	Water (l)	Sand (Kg)	Cement (Kg)	EPS (l)
200	0.070	100	-	200	1000
250	0.085	125	-	250	1000
300	0.099	150	-	300	1000
400	0.105	175	100	300	1000
500	0.110	175	200	300	1000

and 100 kg of sand. On site, these quantities can be mixed with 175 liters of water.

iii. Lightweight concrete wall with 30 cm thick EPS granulate with U=0.34 $W/m^2.°C$ and mass 21.6 kg/m^2.

3.2. Claims of the Invention

Based on the previous description and the estimated results, the following claims were conceived for the invention "solid and homogeneous thermal wall of cored lightweight concrete blocks solidarized *in situ*":

(A) A cored block with a parallelepiped shape, forming a formwork element for the construction of self-supporting exterior walls and other structures of civil engineering works; the said block can be characterized in that it comprises two parallel side sides separated by one, two or more massive connectors in which:

(A.i) the one, two or more connectors are positioned at a distance from the inner edges of the lateral sides forming a space at the top and at the bottom that allows the passage of material filling;

(A.ii) the one, two or more connectors have a rectangular, cylindrical, elliptical, diamond, or other configuration that reduces air retention after filling the block core with a filling material.

(B) A cored block of parallelepiped shape according to claim 1 will comprise two parallel side sides separated by two or more massive connectors wherein:

(B.i) the connectors are separated from each other forming a hollow core and positioned at a distance from the inner edges of the lateral sides, forming a space at the top and at the bottom that allows the passage of filling material;

(B.ii) the connectors have a rectangular, cylindrical, elliptical, lozenge, or other configuration that reduces air retention after filling the block core with filler material.

(C) A cored block according to claim 1 or 2 can be characterized in that the block is made of a material chosen from the group: lightweight concrete with EPS granulate; lightweight expanded clay-lightened concrete or any other material with acoustic properties (*i.e.*, any other material that leads to an Rw of at least 30 dB when a solid, homogeneous wall 30 cm thick is constructed of that material) and low thermal conduction (thermal conductivity of the material not exceeding 0.25 W/m.ºC).

(D) A cored block according to claim 1 or 2 can be characterized in that the filling material of the hollow core is made of lightweight concrete lightened with EPS granulate, lightweight concrete lightened with expanded clay, or other material with acoustic (*i.e.*, any other material that leads to an Rw of at least 30 dB when a solid, homogeneous wall 30 cm thick is constructed of that material) and low heat conduction (thermal conductivity of the material not exceeding 0.25 W/m.ºC).

(E) A cored block according to claim 1 or 2 can be characterized in that its dimensions are as follows: length from 20 to 120 cm, preferably 60 cm; width from 10 to 45 cm, preferably 30 cm; height from 10 to 60 cm, preferably 30 cm; hollow core thickness for filling with filler from 4 to 35 cm, preferably 14 cm; and with 20% to 50% voids, preferably 35.5%.

(F) A cored block according to claim 1 or 2 can be characterized in that the inner margin is from 2 to 25 cm, preferably 6 cm; the inner margin is 2 cm and 50 cm, preferably 6 cm.

(G) A cored block according to claim 2 may preferably contain 3 connectors, with the spacing between the connectors as 12 cm or another distance as long as it allows the passage of the material for later filling.

(H) A solid and homogeneous thermal insulating wall comprising a plurality of hollow blocks according to claims 1 or 2 can be characterized in that the blocks are stacked vertically without restriction in displacement between the consecutive layers.

4. DISCUSSION

4.1. The Invention in the Construction Market

The present invention fills a gap between several technologies and materials available in the construction market for the execution of exterior walls of residential buildings (in fact, it is not only residential buildings, such as villas and apartments, but all buildings that have to meet thermal requirements). Thus, the present invention is positioned and competes with solutions (self-supporting, but not structural) for exterior walls of buildings, namely with exterior wall solutions that are applied to structures typically used in the construction of buildings in Portugal (pillars, beams, and slabs – reinforced concrete structure).

In the present invention, the connectors between the pads of the pad are never at the end of the pad. This fact causes the filling/concreting of the interior of the wall to always make a 'cut'/'break' between the block material and the filling material. In other words, with the solution of the present invention, there is no straight line of block material between the inside and outside. 100% of the inner edges of the block faces are filled with filling material. This means that in the invention, there is the technical advantage that small defects in the block or small adjustments in the embedding of the blocks are always guaranteed to be clogged and solidified by the concreting of the interior. This means that in the invention, it is impossible to have a crack, contrary to what happened in the example of plastic blocks, in which a small defect in the joint leads to a crack at the ends.

The present invention provides multifunctionality of the wall made with the blocks and an ease and speed of construction compared to existing solutions. The present invention uses a single material to make the entire wall cloth, which manages to combine self-supporting capacity and thermal resistance, eliminating the need for a hood. In this invention, the wall is homogeneous and without material discontinuities, so the use of mortar is eliminated and, consequently, all the problems associated with its application (thermal bridges) typical of masonry construction. It is self-supporting, quick, and easy to implement and does not require the hood to meet the thermal requirements. Just the blocks need to be cast and the same material is to be pumped for its interior to fill, which may lead the wall to solidify. There is also no need for formwork to obtain a solid and massive wall with high thermal and acoustic resistance.

There is also the technical advantage of the connectors not being at the ends of the block; in the present invention, the connectors that join the sides of the blocks are far from the ends (either in the vertical direction or in the horizontal direction) so that there is no straight path of access to the passage of air or even water between the inside and outside of the wall (through a possible crack). In other words, with the configuration of the invention (whatever the shape of the connector), there is no straight line of block material between the inside and the outside, that is, 100% of the inner edges of the block cloths are filled with material – core filling. This means that in the invention, there is the technical advantage that small defects in the block or small adjustments or errors in the casting of the blocks are always guaranteed to be clogged and solidified by the filling (concreting) of the interior, and all without resorting to mortars.

As mentioned above, connectors can have various shapes, such as rectangle, circle, ellipse, or rhombus, as long as they lead to the following technical advantages:

a) Allow the concreting (filling) of the interior of the blocks to be easy to perform, namely with regard to complete filling, that is, without voids occurring near the connectors;

b) Facilitate the manufacturing process (block molding) without edges and corners, or when existing, being easy to mold/produce.

4.2. Differences from Other Solutions in the Construction Market

The present invention presents the following differences from other solutions available in the construction market:

1. The double wall consists of two masonry panels with an air gap in the middle, while in the invention, there is only one wall panel (so, no air box).

2. Regarding the masonry solution of lightweight expanded clay concrete blocks and capoto:

a. In the invention, the ETICS system is not necessary, since the thermal insulation is completely ensured by the self-supporting material itself. The solution already known is only thermally efficient when the ETICS system (or alternatively Isodur™) is applied.

b. In the solution already known, the self-supporting wall is materialized by masonry of typical construction (that is, rows of blocks connected together by a string of mortar). Already in the invention, the mortar joints (source of heterogeneity and causing thermal bridges) disappear; the single wall is self-supporting and uses a hybrid construction technology between masonry and *in situ* concreted wall (the cored blocks after casting serve as formwork when their voids are filled with the same material with which the blocks are produced).

c. In the invention, the single wall is solid and consists of a single material (homogeneity), whereas in the solution already known, the voids of the hollow blocks are not filled (discontinuities).

d. In the invention, the outer layer of the wall can be painted with hydraulic plaster, whereas in the current solution, hydraulic plaster cannot be applied; hence, the surface resistance to shocks/impacts is much lower, which is one of the problems of the already known solution.

e. In terms of cost (labor included), with a 25 cm thick block and an 8 cm ETICS thick, with plaster on the inside and painting on both sides, the price is around €75/m^2. In the invention, with a 30 cm thick block, with stucco on the inside, hydraulic plaster on the outside, and painting on both sides, the price should be around €60/m^2 (estimated around 20% lower).

3. Isodur™ is a mortar with thermal insulation characteristics that is applied as a plaster on a self-supporting wall cloth. The invention uses lightweight concrete lightened with EPS granulate or expanded clay or other lightweight material. Although there are similarities with Isodur™, they are different materials. Isodur™ is white and has been developed to be projected on vertical walls while lightweight concrete with EPS granulate (or expanded clay) has a gray matrix and will be developed not to be projected on vertical walls, but to fill block molds in the factory and to fill the voids in the blocks on site. Furthermore, Isodur™ was not developed to be used as a self-supporting material, but to be applied on a self-supporting wall cloth. In the invention, lightweight concrete with EPS (or expanded clay) granulate ensures the wall's self-supporting requirement. However, lightweight concrete with EPS granulate (or expanded clay) must have density and thermal insulation characteristics similar to those of Isodur™.

4. With regard to reinforced concrete walls, in the invention, lightweight concrete without any reinforcement is used instead of the traditional concrete of normal density. As with the solution already known, the reinforced concrete walls

need to be complemented by a hood-like solution to meet the thermal insulation requirements (it has already been mentioned that this is not necessary in the invention, as the self-supporting sheet meets the thermal requirements). In addition, the concrete walls (even if they were made of light concrete and without any reinforcement) are cast *in situ* using formwork, while the invention uses a hybrid technology that uses prefabricated hollow blocks in the form of masonry to avoid the use of the formwork at work.

5. Composite panels formed by a lightweight concrete core lightened with EPS granulate and surface coating boards (usually calcium silicate or magnesium oxide) cause a sandwich panel, although the core material of this solution can be relatively close to the lightweight concrete lightened with EPS granulate of the invention. The following differences need to be taken into account:

a. Use of cored blocks instead of sandwich panels. This leads to completely different dimensions between the units used. This in turn leads to each panel being much heavier than each block, which obviously leads to difficulties and different handling and construction techniques.

b. The voids of the blocks are filled on site to fill the voids and, in parallel, solidarize/connect all the blocks. The panels are connected using dowels and mortar/cement-glue connections. In other words, in the invention, we have a hybrid masonry-wall concreted *in situ* solution while with the sandwich panels, there is no *in situ* concreting and there is no resemblance to masonry. It should be noted that in masonry, we have several units to be positioned one on top of the other, and in the solution with the panels, each panel fills the entire height of the wall, and the panels are positioned side by side.

6. There are also differences in relation to other less-known solutions, but these present certain parallelism with the invention as they are self-supporting and thermally insulating blocks, namely:

a. Solid blocks (not cast) produced with lightweight concrete with EPS granules differ from the invention since solid blocks are produced in the factory. At the same time, these blocks continue to be applied as masonry, that is, using mortar between courses to unite the units (remember that the course of mortar causes heterogeneity in the wall and creates thermal bridges in the wall, that is, these blocks only are thermally effective with the ETICS solution). As mentioned, in the invention, as it is a hybrid technology, the row of mortar between the rows of blocks disappears and the voids are only filled on site. In addition, because they are produced in bulk, these blocks are heavier and more difficult to handle than the blocks of the invention. The invention also has the advantage of enhancing the ability of lightweight concrete with EPS granulate to be marketed in dry bags.

b. As for the solid blocks of autoclaved concrete, as the name implies, the material used to manufacture the blocks is totally different from that of the invention.

7. Finally, with regard to non-self-supporting solutions, the differences are immediate due to the fact that in the invention, we have a self-supporting material and there is no need to use any additional structure.

CONCLUSION

There are several technologies for the construction of the exterior walls of buildings. In the present paper, an innovative technology at the concept level is presented. This innovative technology is based on a solid and homogeneous thermal wall of cored lightweight concrete blocks solidarized *in situ*. It is materialized by parallelepiped-shaped cored lightweight concrete blocks comprising two parallel sides separated by one or more solid connectors in which the connectors are positioned at a distance from the inner edges of the sides. This forms a space in the upper part and in the lower part that allows the passage of filling material. The connectors have a configuration that reduces air retention after filling the block core with a filler material. The main advantages of the invention are listed as follows:

i. The end product of the invention consists of a hybrid wall that (i) uses blocks, but is not masonry and that (ii) is cast-in-place, but no formwork is necessary.

ii. The wall is built with a single sheet, which is easy and quick to execute.

iii. The wall is built with light blocks prefabricated with lightweight concrete and without bed joints or head joints. The end product is a massive and homogeneous wall made from only one material.

iv. It dispenses the wall from requiring the application of thermal insulation as it provides high thermal efficiency for buildings; the thermal conductivity of the material used might be lower than 0.07 W/m.ºC.

v. It provides a solution for new buildings to use ‘very low or almost zero amounts of energy for heating and cooling’. This invention provides a solution for walls of buildings with very low heat transfer coefficients.

CURRENT & FUTURE DEVELOPMENT

Since the technology is at the concept level (TRL2), more research is required at various levels: (i) proof of concept at the laboratory level, (ii) proof of concept on a construction site (a full-scale application), (iii) proof of concept at the industrial production scale, including the corresponding economic analysis.

LIST OF ABBREVIATIONS

EPS	=	Expanded Polystyrene
EU	=	European Union
Kg	=	Kilogram
W/(m.ºC)	=	Watt per Square Meter per Degree Celcius
XPS	=	Extruded Polystyrene Insulation

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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