Revista de la Construcción
ISSN: 0717-7925
revistadelaconstruccion@uc.cl
Pontificia Universidad Católica de Chile
Chile

LEITE, L.; SOUSA, H.
Geometric improvement of the existing bagacina (lapilli) concrete masonry base unit and development of a new masonry system composed by accessory units for the construction in the Azores islands
Revista de la Construcción, vol. 12, núm. 1, abril, 2013, pp. 62-74
Pontificia Universidad Católica de Chile
Santiago, Chile

Mejoramiento geométrico de la unidad base de la mampostería de hormigón en bagacina (lapilli) existente y desarrollo de un nuevo sistema de mampostería compuesto por unidades accesorias para la construcción en las islas Azores

Geometric improvement of the existing *bagacina* (lapilli) concrete masonry base unit and development of a new masonry system composed by accessory units for the construction in the Azores islands

Autores

LEITE, L.
Faculdade de Engenharia da Universidade do Porto
luis.melo.leite@fe.up.pt
Portugal

SOUSA, H.
Faculdade de Engenharia da Universidade do Porto
hipolito@fe.up.pt
Portugal

Fecha de recepción 04/06/2012

Fecha de aceptación 17/01/2013

Resumen

El archipiélago de las Azores es una región remota de pequeñas dimensiones y con bajos niveles poblacionales donde las cuestiones de la sostenibilidad y de la autonomía han sido siempre importantes y presentan consecuencias económicas significativas. Actualmente, la industria de la construcción utiliza muchos productos importados; sin embargo, los productos de mampostería son casi exclusivamente suministrados por industrias locales. Para su producción, la mampostería utiliza una escoria volcánica natural –lapilli, conocida localmente como *bagacina*– como agregado, aunque no de forma optimizada.
El objetivo de nuestro estudio fue el de mejorar la unidad base de mampostería existente mediante cambios geométricos e idear un nuevo sistema de mampostería, que incluye unidades accesorias configuradas para satisfacer funciones murales específicas, cuyas restricciones fueron derivadas de características específicas de las islas, del proceso tradicional de construcción y de los más recientes requisitos de desempeño con el fin de obtener un sistema inclusivo.
Hemos concluido que mediante la adopción de una configuración geométrica diferente para la unidad base del hormigón de *bagacina* esta aseguraría una mayor sostenibilidad. Esta sostenibilidad proviene del uso mejorado de un recurso local y de las potenciales consecuencias de esta mejoría, tal como la posibilidad de reducir el uso de productos importados como sean los materiales para el aislamiento térmico de las paredes.
También se identifican necesidades adicionales para mejorar la mampostería de hormigón de *bagacina*.

Palabras clave: Bloques de hormigón ligero, lapilli, Azores.

Abstract

The Azores archipelago is a small and remote region with low population levels where the issues of sustainability and autonomy have always been important and present significant economic consequences. Currently, the construction industry uses many imported products; however, masonry products are almost exclusively provided by local industries. For its production, masonry uses a natural volcanic scoria –lapilli, locally known as bagacina*– as an aggregate, though not in an optimized way.*
The goal of our study was to improve the existing masonry base unit through geometric changes and to design a new masonry system, comprising accessory units shaped to provide specific wall functions, the constraints of which derived from specific island features, from the traditional building process and from the more recent performance requirements in order to obtain an inclusive system.
We concluded that by adopting a different geometric shaping for the bagacina concrete base unit it would ensure greater sustainability. This sustainability comes from the improved use of a local resource and from the potential consequences of this improvement, such as the possibility of reducing the use of imported products like wall thermal insulation materials.
Further needs of development to improve the bagacina *concrete masonry are also identified.*

Keywords: *Light-weight concrete blocks, lapilli, Azores.*

1. Introduction

The Azores archipelago is a small and remote region with low population levels where the issues of sustainability and autonomy have always been important and present significant economic consequences. The archipelago was considered the second best destination, in the islands and archipelagos category for sustainable tourism, by National Geographic Traveler (Tourtellot, 2007) and is under the MIT Green Islands Project (MIT Portugal, 2011), which looks for sustainable energy solutions using natural resources. Nevertheless, sustainability is a complex concept that is hard to fulfill, even more when applied to a multidimensional activity as the construction industry.

Focusing on the Azorean masonry industry, it exclusively comprises concrete blocks, due to the absence of clay, and provides nearly all the masonry used in the islands' building construction. The concrete blocks are made with cement and volcanic scoria – lapilli (commonly known as *bagacina*) and tuft. The use of *bagacina* as aggregate, due to its properties, makes a lightweight concrete, providing masonry with thermal advantages. However, the existing block geometry has substantially remained the same since the 1970s and does not result from options that consider local conditions or today's requirements. Moreover, current masonry has no diversity. The same unit is used in different ways. There is no modern logic of a masonry system with accessory units that enhance wall construction quality and behavior.

Regarding the use of masonry, and particularly its use in the building envelope, since the 1970s that the current solution consisted of a single-leaf wall built with *bagacina* concrete blocks, filling a concrete frame structure (Figure 1), finished with plaster and paint. In the 1980s and 1990s, building construction increased in such a way that this solution became predominant in the built environment. It also met the reference U-value of the first national thermal code (Portugal, 1990), introduced in 1990. In 2006, with the more severe thermal code revision (Portugal, 2006), in order to meet European objectives (Parlamento Europeu, 2003), this building envelope single-leaf solution was no longer viable and the construction of new types of envelopes, such as cavity walls associated with the use of products like wall thermal insulation, took its place. This represents an unprecedented change in the local process of building exterior walls, thus substantially increasing its complexity. Under these circumstances, masonry performance is sub-optimal regarding the raw material potential and the feasibility of single-leaf solutions for building envelopes. Furthermore, due to the climate, the thermal requirements of exterior walls are not severe compared to mainland Europe; therefore, thermal improvement of masonry should avoid the general use of wall thermal insulation products.
Taking this scenario into account, the goal was to develop a new geometry for the existing masonry unit and integrate it into a new masonry system formed by accessory units shaped to perform particular wall functions, providing an appropriate building solution for the Azores, matching both local conditions and current requirements and enabling again the construction of single leaf exterior walls that comply with the present thermal code (Leite, 2008). The masonry base unit and the system accessory units should improve local masonry quality and versatility by optimizing material properties through the way they are shaped and assembled (Sousa, 1996; Bastos et al., 2005; Sousa et al., 2011). This improvement is performed while considering only geometrical changes and verifying the impact in the thermal properties of the base unit; other issues such as stability or acoustics performance were not considered as part of the developed work.

Figure 1. *Example of a single-leaf wall built with bagacina concrete blocks*

The optimization of masonry characteristics is crucial because it can deliver a more rational process of production and construction, regarding a natural resource use and the building performance. Along with environmental and performance issues, local economy and knowledge would benefit, preferentially if material and products import dependence reduces. Furthermore, codes in general as well as research and teaching take into account little of the Portuguese archipelago's specificity, due to size and scale factors. Thus, maintaining a simple and comprehensive building system (that allows an easy interaction with several constructive details and code requirements) would be advantageous, considering the existing type of construction (small and medium-sized buildings) and regarding construction quality enhancement.

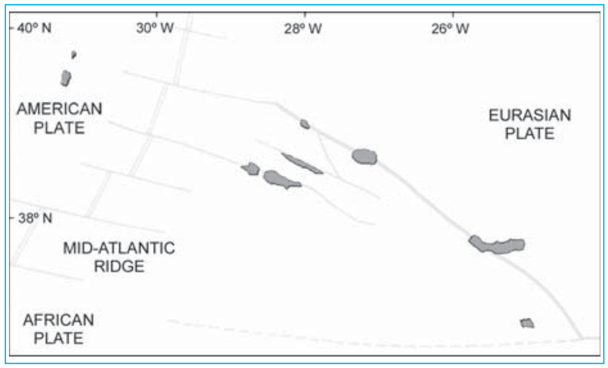
The remainder of this article is organized as follows: first, an extended contextualization is presented, which includes the characterization of geographical factors influencing wall behavior in the Azores and the present level of knowledge and development of the existing masonry; then, the relevant data from this contextualization is cross-checked with current code requirements, in order to create a support basis for the improvement of the masonry base unit and the new accessory units design; finally, the improvement of the existing base unit and the proposed system is fully presented and discussed.

2. Background

2.1. Geographical factors and building construction

The Azores archipelago consists of nine islands with a total area of 2345 km^2 which extend for 600 km in a South-west direction. It is situated between 39°43'23'' and 36°55'43'' North latitude and 31°16'24'' and 24°46'15'' West longitude, at a distance of 1900 km from the European mainland's west coast. It is located in the Mid-Atlantic Ridge and on the boundary between the American, Eurasian and African tectonic plates (Figure 2). This context is responsible for the islands' seismic and volcanic activity. The seismic activity is constant with a generally low intensity interrupted by more violent occurrences. It has an unstable climate that is influenced by its topography, which is very mountainous for its size. The Azores anticyclone is the dominant climatic factor, providing very diverse conditions, from sultry days with a relative humidity close to saturation, to cool and dry days. The climate is temperate and moist and, at higher altitudes, cold oceanic and very rainy. The combination of rain and wind, sometimes intense, leads to a significant exposure to wind-driven rain. The average annual rainfall, which varies with altitude, is much higher in mountainous areas than in coastal areas. Coastal areas are also favored temperature-wise, with an average summer high of 23 degrees Celsius and winter lows averaging 11 degrees Celsius. The temperature gradients are low, as the average annual figure is around 6 degrees Celsius. The south coast is additionally favored in terms of solar exposure. Due to these factors, villages are predominant in south coasts and do not exist at altitudes over 350 m.

Figure 2. *The Azores archipelago*

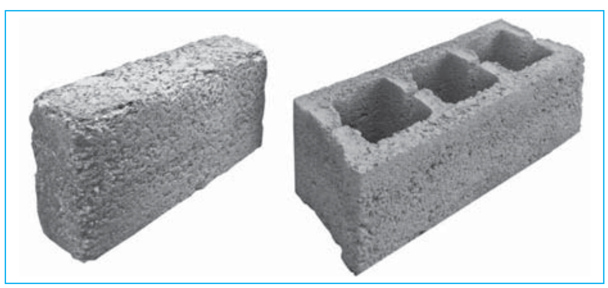


This context highlights the importance of stability, watertightness and hygrothermal comfort requirements due to the seismic activity, the impact of wind-driven rain and the wall dryness problem. These issues are interdependent because vibrations can lead to cracking, making the walls more susceptible to water penetration, increasing their moisture content which, in turn, reduces thermal resistance.

2.2. The bagacina concrete block state of the art

The *bagacina* concrete block production began in the early twentieth century. Originally only solid blocks were produced; from the 1970s on they also consisted of vertically perforated blocks (Figure 3). The block concrete is composed of cement and one or two aggregates of volcanic origin – tuft and *bagacina*.

Figure 3. *The bagacina concrete blocks, solid (left) and perforated (right)*



The *bagacina* consists of lava fragments discharged during volcanic eruptions, with a high concentration of gases, which gives them a porous structure resulting from the retention of gas bubbles as they cool down. They are porous, of low density, and show high values of water absorption; the density increases with decreasing particle size, inversely proportional to the water absorption, the granule size distribution curves are continuous with greater changes in larger particle dimensions. The chemical composition is similar to basalt. The aggregate may be black to dark grey, often glazed and enameled, and red-brown when oxidized (Figure 4). The reds are more difficult to extract because they are compacted, while the black comprise loose debris (Fraga, 1988). The *bagacina* cones dominate the Azorean landscape (Figure 5) and a sustainable extraction operation is possible, given the size of the archipelago and the construction industry, if included within a specific plan and preferably optimizing its utilization.

Figure 4. *The bagacina, black aggregates (left) and red aggregates (right)*

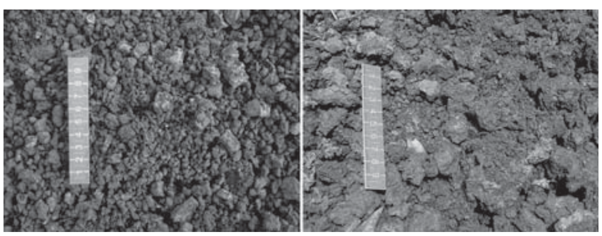


Figure 5. *A bagacina cone in the landscape*

Regarding the *bagacina* concrete production, aggregates are stored outdoors, their size is ensured by the concrete mixer sieve and their moisture content has a limited control. Mixed in with the *bagacina* are other occasional stone detritus such as pumice or basalt. Also, some cure processes are not completed at an appropriate location. The concrete composition percentages vary among producers and not all productions use volcanic tuft because, unlike *bagacina*, it is not found throughout all the islands (Caetano, 2007). It is a lightweight concrete whose density ranges from 1400 to 1550 kg/m^3 (SRES, 1986; LNEC, 1998).

2.2.1. The blocks' geometry and characteristics

In general, the masonry base unit thicknesses (100, 150, 200, 250 and 300 mm), length (500 mm for the 100, 150 and 200 mm thicknesses and 400 mm for the 250 and 300 mm thicknesses) and height (200 mm) are the same among manufacturers. Also, the blocks web configuration is mainly the same, showing 2 or 3 longitudinal webs, i.e. just the external perimeter (shell) and occasionally a division in the middle. On the contrary, web thickness varies widely, ranging from 25 to 55 mm (Figure 6). Besides the base unit, some manufacturers produce accessory blocks consisting of two variants, one with a flattened top and another with a configuration that allows a block to be cut in two halves. Despite these variants, the existing units do not form an overall comprehensive system that provides solutions for the several current constructive situations that a masonry wall has in its development.

Figure 6. *Existing units overall dimensions (mm) all have 200 mm height (LNEC, 1998)*

The initial production was largely empirical. In 1980, as outcome of a severe earthquake, a local normative code was imposed to control production, but it was not fully effective (Portugal, 1980), also it imposed some conditions that are not in compliance with today's requirements. Currently, despite CE marking (IPQ, 2007) little is known. The existing knowledge about the blocks' characteristics is based on an acceptance test report for a specific construction development (SRES, 1986) and a thermal characterization of the production of three companies on a single island (LNEC, 1998), which do not constitute a representative sample of the general production. These characterizations show that there is no dimensional stability in the production of blocks, the blocks showed deviations from the average dimensions exceeding 2 mm. The average tensile strength, in tests of compressive resistance, show significant variability, with a standard deviation of 40.7% in solid cubes and 23.23% in perforate samples, perforated blocks ranged from 2 to 7N/mm^2 (considering the apparent area, the resistance decreases with an increased perforated area). The U-value of 250 and 300 mm thick blocks plastered (for use in single-leaf exterior walls) complied with the provisions of the previous thermal code (reference value of 1,90 W/m^2.K) (Portugal, 1990), yet presently only those of 300 mm are within the limits of the actual reference value (1,40 W/m^2.K) (Portugal, 2006); however, they are very close to it (1,37 W/m^2.K). In this thermal characterization, it was considered as material thermal conductivity, 0.55 W/m.K for the *bagacina* concrete and 1,5 W/m.K for laying mortar.

3. Approach

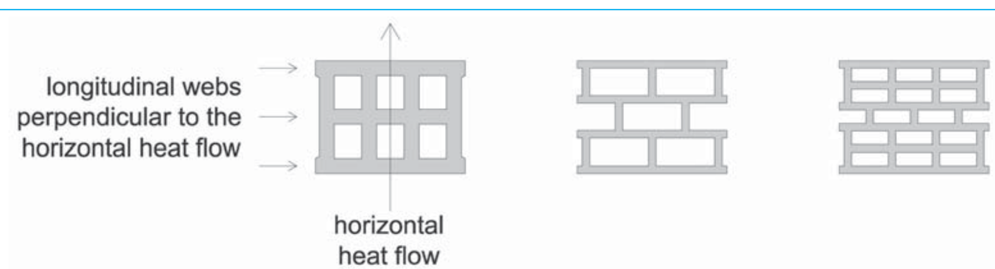
3.1. Masonry base unit and system geometric and modular approach

The current European codes promote improvements in production, design and performance of masonry. As evidenced previously in the background section, there are local factors which highlight the importance of stability, watertightness and hygrothermal comfort requirements. Therefore, stability (CEN, 2005; CEN 2003) and watertightness (CSTB, 1994; BSI, 2005) codes, as well as geometric features influencing thermal behavior (Sousa, 1996; Bastos et al., 2005; Sousa et al., 2011), were analyzed in order to obtain a design basis.

The stability code (CEN, 2005; CEN 2003) defines minimum thicknesses in the geometric requirements for shear walls and minimum sections for concrete confinements, as well as requirements for their position and interaction. It also defines joint criteria; in particular that the filling of the joints must cover at least 40% of the unit thickness and the vertical joints should be filled through pockets. Dimension parameters of the French (CSTB, 1994) and British (BSI, 2005) codes on the watertightness of an external single-leaf wall were also considered. These codes provided a geometric design basis that was cross-checked with the existing production.

Regarding thermal performance, based on studies that show the optimization of masonry properties through the way the blocks are shaped and assembled (Sousa, 1996; Bastos et al., 2005; Sousa et al., 2011), an analyses of the contribution of more air spaces perpendicular to the horizontal heat flow was carried out in the thicker blocks (i.e., the ones with single leaf exterior wall potential). This analysis was made considering two variants: 4 and 6 longitudinal webs (current 250 and 300 mm thick blocks have just 2 or 3 longitudinal webs) (Figure 7). The method given under reference (ISO, 1996) was used for the U-value calculation in order to maintain the same method of the known characterization (LNEC, 1998) and allow comparable results; also, with the same purpose, the apparent thermal conductivity of the *bagacina* concrete and mortar was kept.

Figure 7. *The 300 mm thick block, from left to right: example of existing unit, the proposed 4 longitudinal web version and the proposed 6 longitudinal web version*



The masonry system development started with the existing base unit improvement, by verifying and modifying the geometry, according to stability and watertightness dimensional requirements and thermal performance aspects influenced by the blocks configuration. The method of laying masonry, particularly mortar joints configuration, was also considered. The remainder system design was grounded in the same requirements and in the inclusion of features that apply to distinct situations in current construction of small and medium-sized buildings (such as the execution of concrete confinements, openings, blind recesses and thermal bridge protection), as well as in principles of geometrical modeling (half-sized blocks), in order to optimize the constructive interaction in a broad sense.

4. Exposure and results

4.1. The base unit improvement

The improved base unit's overall dimensions followed the existing widespread dimensional parameters, as they have proven adequate: 500 mm in length for the 100, 150 and 200 mm thicknesses, and 400 mm in length for the 250 and 300 mm thicknesses. Except the existing overall height of 200 mm was changed to 190 mm, which enables a total vertical modulation of 200 mm, given the 10 mm thick mortar horizontal joints.

Regarding the external single-leaf possibility, the 240 mm thickness is the minimum for shear walls (CEN, 2005; CEN 2003) and also meets the more stringent parameters of the French (CSTB, 1994) and British (BSI, 2005) codes on the watertightness of an external single-leaf wall. Therefore, the existing masonry thicknesses of 250 and 300 mm for an external single-leaf wall are appropriate, in terms of stability –regarding the dimension parameter– and watertightness. In relation to thermal performance, the possibility of increasing thermal resistance in these two thicknesses (250 and 300 mm) was checked. The following geometric and dimensional strategies were adopted, the web thickness was reduced to 20 mm, minimum by code (currently ranging from 25 to 55 mm), and its density increased with more longitudinal webs perpendicular to the horizontal heat flow, creating more air spaces and increasing thermal resistance. The thermal contribution of more air spaces perpendicular to the horizontal heat flow of the 250 and 300 mm thick blocks were analyzed considering two variants: 4 and 6 longitudinal webs, as shown in Figure 8. As result, both 4 and 6 longitudinal web versions provided a U-value below the 1.40 W/m^2.K reference value (Portugal, 2006). Also, in both versions, the unit raw material quantity was below the existing averages. The 6 longitudinal webs unit was considered the basic unit of the system, due to its greater mass and, theoretically, greater mechanical strength. Table 1 shows the comparison between existing 300 mm thick blocks and the proposed 300 mm thick unit with 6 longitudinal webs.

Figure 8. *The 250 (top row) and 300 mm (bottom row) thick blocks with 4 and 6 longitudinal webs variants, axonometric and transversal sections*

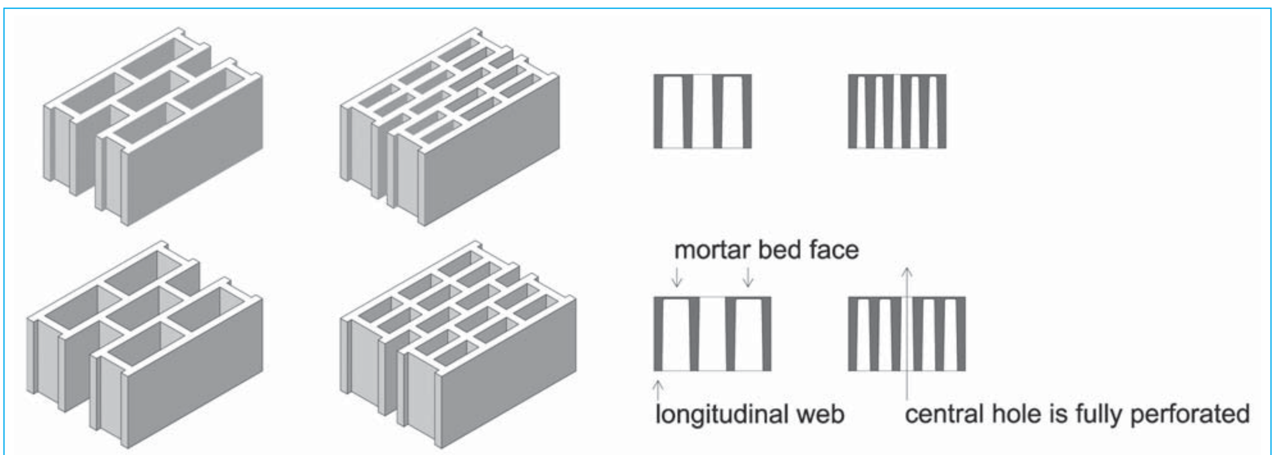


Table 1. *Comparison between the 300mm thick existing blocks (average value of the blocks presented under reference [13]) and the unit proposed*

	Perforation (%)	Weight (kg)	U-value (W/m2K) Considering interior and exterior plaster
Existing Blocks	28,4	26,6	1,44
Proposed unit	49,5	18,0	1,00

In the 250 and 300 mm thick units, intended for exterior and bearing walls, the laying mortar covers more than 40% of the block thickness and the vertical joints consist of pockets formed by horizontally laid blocks (Figure 9), as requested by EN Standards (CEN, 2005; CEN 2003). In order to avoid preferential pathways to water seepage and to form a capillary and thermal barrier, it was envisaged the mismatch of the transverse web, associated to the discontinuity of mortar joints. Therefore, the webs form an odd number of alveolar layers (hole rows perpendicular to the heat flow) in order to force discontinuity in laying mortar in the vertical and horizontal joints. This discontinuity, associated with a central perforated buffer zone, establishes a layer of air not vented along the wall. Thereby, the vertical joint is formed by two independent pockets and the horizontal joint by two mortar bed face areas (Figure 9). In the other units, of 100, 150 and 200 mm thickness, horizontal and vertical joints are entirely mortared, since they are not intended for single leaf exterior walls.

Figure 9. *Horizontal and vertical mortar joints execution*

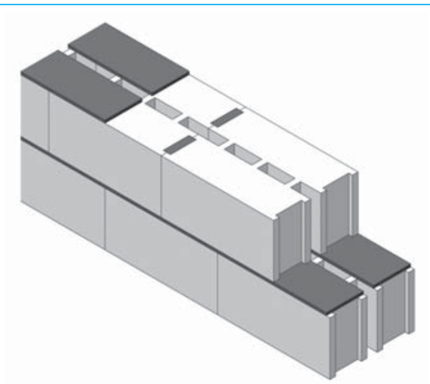


Figure 10 represents the theoretical model of the masonry system. The base unit is associated with row "XXX.N" (where "XXX" is the thickness of the unit) and column "01". Accessory units follow on lower down the column "01" and the remaining columns show the respective variations.

4.2. Accessory units and variations

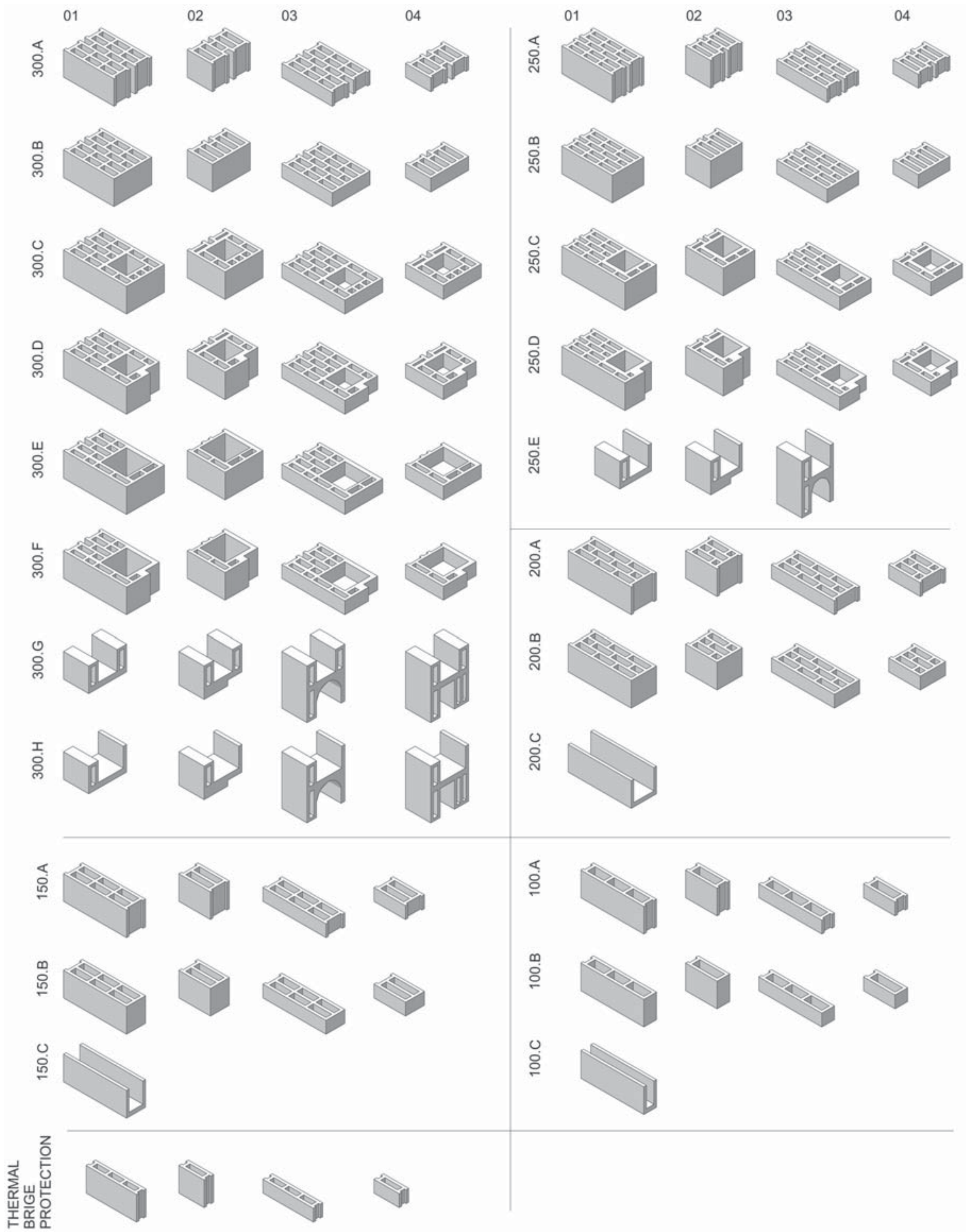
The accessory units apply to distinct situations in the construction of common small and medium-sized buildings, such as the execution of concrete confinements (or supporting the execution of structural elements in concrete), of openings (window frames and perimeter reinforcement), the installation of blinds and thermal bridge protection.

The units intended for the execution of vertical confinements –rows 300.C, 300.D, 300.E, 300.F, 250.C and 250.D– (for angle, intersection of walls, jambs and wall confinement situations) and horizontal confinements –rows 300.G, 300.H and 250.E– (for beams, confinements along the height of the wall, lintels and sills situations) provide minimum sections in accordance with the code requirements for confined masonry (CEN, 2005; CEN 2003), in this case allowing 200x200 mm and 150x150 mm sections in the 300 mm thickness and 150x150 mm sections in the 250 mm thickness. The confinement units provide the continuity of concrete elements and the combination of sections, satisfying the thermal bridge protection of concrete elements in a way that minimizes heterogeneity.

The accessory units for fixing and sealing exterior window frames (rows 300.D, 300.F and units 300.G.02, 300.H.02 and 250.E.02) provide a ledge for the application and sealing of the frame and also allow the confinement reinforcement of the opening; the same principle can be used in interior openings and wall tops. The units intended for the installation of blinds (300.G.03, 300.G.04, 300.H.03, 300.H.04 and 250.E.03) are compatible with the other confinement units, as well as the thermal bridge protection units.

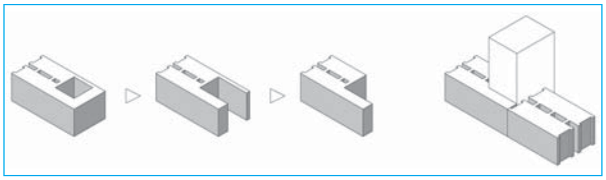
The 100, 150 and 200 mm thick units are limited to the base unit and two accessory units, one having a plain top (all XXX.B rows in those thicknesses), and one intended for use as a lintel (all XXX.C rows in those thicknesses). The vertical confinement of these walls is assured by concrete elements of the same thickness as the wall, for they are intended for partition walls, which are considered secondary seismic elements, or double-leaf exterior walls, which require other constructional conditions and arrangements.

Figure 10. *The masonry system*



All base and accessory units have variations in half length and height (except those for horizontal confinement) and with one top with a flat face (except those for horizontal confinement and thermal bridge protection). Accessory units can also be processed by mechanical cut, covering more interaction possibilities with diverse concrete sections, as shown in Figure 11.

Figure 11. *Accessory unit's interaction with larger concrete sections*

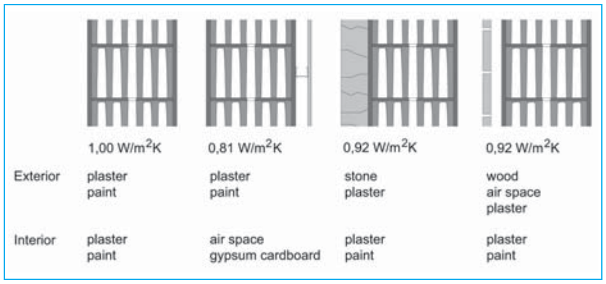


5. Analyses and discussion

5.1. Thermal performance of 250 and 300 mm base units

Through the geometric changes and its impact in the thermal properties of the base unit, both 4 and 6 longitudinal web versions provided a U-value below the 1.40 $W/m^2.K$ reference value (Portugal, 2006). This confirmed that just by modifying the geometry, thermal performance can be improved. Additionally, in both versions tested, the unit raw material quantity was below the existing averages, which implies a reduction of the raw material cost and of the unit weight. Exterior wall types were defined based on the 6 longitudinal web version, according to their thermal quality (U-value), representing some single-leaf solutions used in the Azores (Figure 12). There is still further improving possibilities, the modification of properties, such as the mortar's thermal conductivity, or the units inclusion of more alveolar layers, can still positively influence the wall final thermal behavior

Figure 12. *U-value of some single-leaf wall solutions, considering the new unit configuration (300 mm)*



5.2. Masonry system

The envisaged masonry system enhances the fulfillment of stability (CEN, 2005; CEN 2003) parameters by the shape and modular interconnection of the units that favor masonry confinement or reinforcement in particular areas subject to high stresses such as openings, corners and walls of excessive length or height. Modularity defines the construction dimensions avoiding unit cuts and maintaining a geometric regularity within the masonry heterogeneity, thus enhancing

Table 2. *Wall thickness and functional requirements*

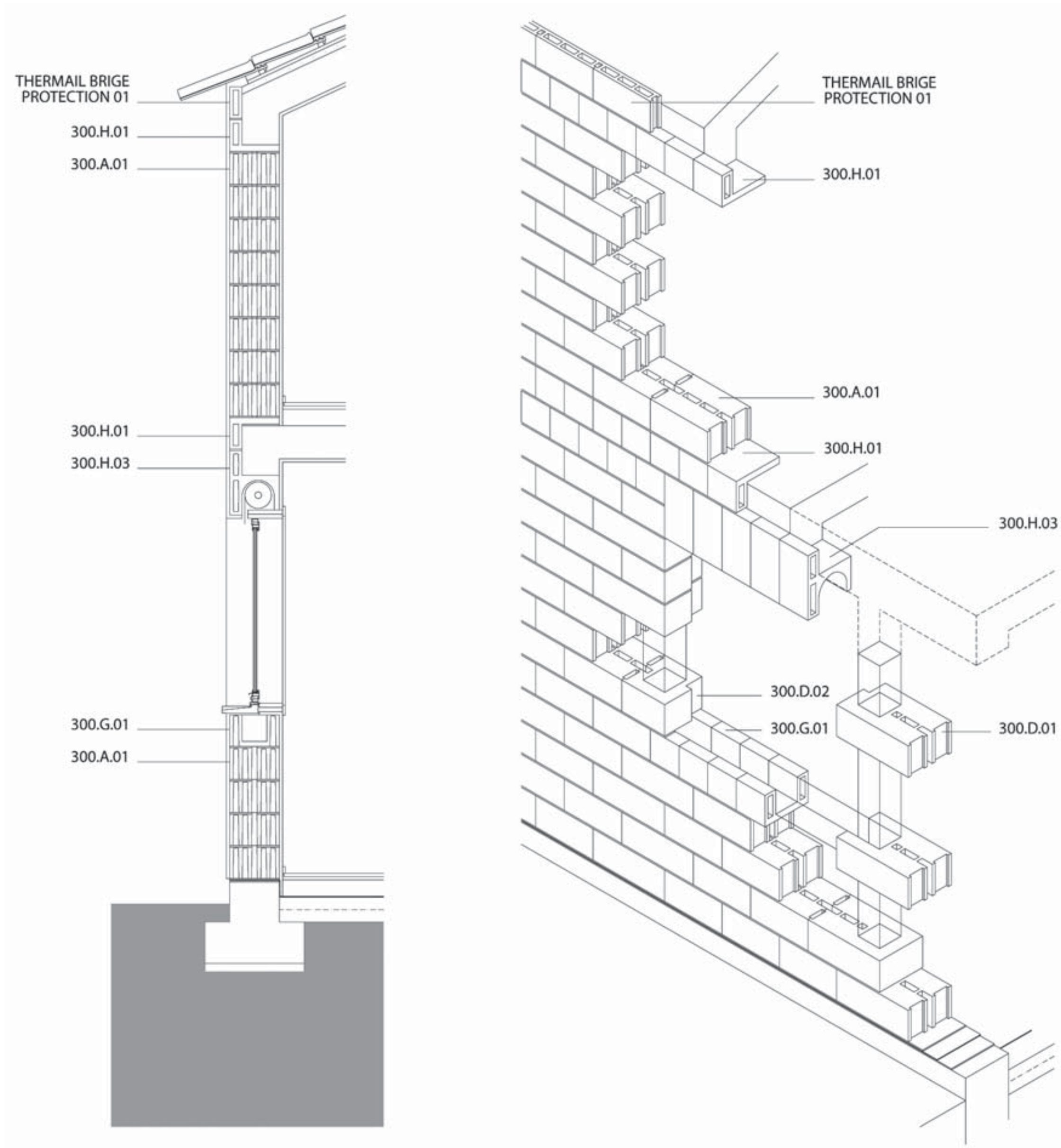
Wall thickness (mm)	stability		U-value	watertightness (according to British and French codes)
	structural	Non structural		
Thermal bridge protection	_	ok	2,21	_
100	_	ok	2,57	
150	_	ok	1,89	ok, with watertight finish
200	_	ok	1,51	
250	ok	ok	1,10	ok, except non sheltered walls in isolated construction in sea cost
300	ok	ok	1,02	ok, in non sheltered walls in isolated construction in sea cost, until 6m high

compliance with various code requirement aspects such as confinement execution. Also, the filling of joints covers more than 40% of the unit thickness and vertical joints are filled through pockets.

Summarizing all the information above, the key parameters in selecting a wall type according to its performance are set out in Table 2.

Figure 13 shows a façade example of a single-leaf wall, while displaying current situations in the local building practice. It highlights the distinct features that the development of a vertical wall manifests in a small building, showing the interaction of the system units.

Figure 13. *A façade example showing the interaction of the system units*



The proposed system involves a number of units, all of which may not be essential in a transposition from a construction process based on non-structural masonry with limited options, to a complex masonry system. A minimal system involving fewer unit types was developed, with the different functions being ensured by means of mechanical cut. The disadvantage is the cutting process, due to the damage that the units may sustain, although it is quantitatively similar to the current production of masonry units (Figure 144).

6. Conclusion

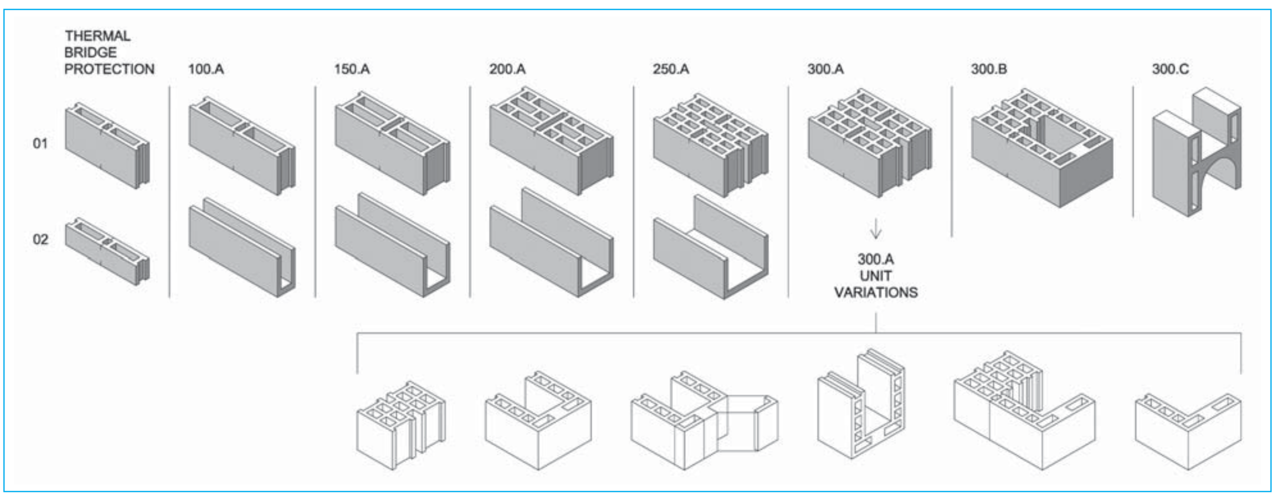
The proposed system has an improved performance compared to the existing masonry, achieved by altering the unit's geometry, the way units are laid and increasing the range of accessory units. With less quantity of raw material, in the case of the base unit, building efficiency is environmentally and functionally improved (for example, in a single leaf exterior wall, extra wall thermal insulation products are unnecessary), providing not only a higher level of comfort and cost reduction, but also achieving higher sustainability. Changes to current production to achieve this are not significant and would open the possibility of returning to single-leaf envelopes and to a minor complexity of building processes.

Nevertheless, the *bagacina* concrete blocks are an open field of study. Further research should determine the optimized geometric configuration for the base unit under other performance requirements, such as stability or acoustics. Also, future developments in production improvement can still be achieved, through aggregate control (size, type and moisture), through the *bagacina* concrete composition characterization and adjustment, and through an adequate curing process. In the wall construction, mortar properties, such as thermal conductivity, can also be improved. Changes to these parameters can still positively influence the wall's final behavior.

Another thing worth considering is that structural masonry may offer a viable building system. However, it depends on the units' mechanical behavior stabilization in order to meet Eurocode standards. A structural alternative to the concrete frame structure would allow a reduction of costs through a higher work rate and less dependence on imported materials such as cement and steel. Also, the execution of *bagacina* concrete confinements would provide a more homogeneous construction, though this is an option that requires adequate characterization.

In sum, the viability of a masonry system, designed for the construction in the Azores, based on the need for a high-quality system, of simple procedure and complexity, for small and medium-sized buildings, can be achieved.

Figure 14. *The minimum system version*



References

Bastos, A. M., Sousa, H., Melo, A. F. (2005). Methodology for the Design of Lightweight Concrete with Expanded Clay Aggregates. The Masonry Society Journal; Vol.23 nº 1: 73-84.

BSI (2005). BS *5628-3, Code of practise for the use of masonry, part 3, materials and components, design and workmanship*. BSI, London.

Caetano, S. (2007). Prospecção de recursos minerais nos Açores, Modelo integrador de valores ambientais e de ordenamento do território. Master thesis, Departamento de Biologia da Universidade dos Açores, Ponta Delgada.

CEN (2003). EN 1998-1, Eurocode 8, Design of structures for earthquake resistance, Part 1, General rules, seismic actions and rules for buildings. European Committee for Standardization, Brussels.

CEN (2005). EN 1996-1-1, Eurocode 6, Design masonry structures, Part 1-1, General rules for reinforced and unreinforced masonry structures. European Committee for Standardization, Brussels.

CSTB (1994). DTU 20.1, Parois et murs en maçonnerie de petits éléments, Document technique unifié, Cahier des clauses techniques. Centre Scientifique et Technique du Bâtiment, Paris.

Fraga, C. (1988). Caracterização geotécnica de escórias vulcânicas. Master Thesis, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, Lisboa.

IPQ (2007). NP EN 771-3. Especificações para blocos de alvenaria, Parte 3, Blocos de betão de agregados (agregados correntes e leves*)*. Instituto Português da Qualidade, Lisboa.

ISO (1996). EN ISO 6946, Building components and building elements, thermal resistance and thermal transmittance, calculation method. International Organization for Standardization, Genève, Switzerland.

Leite, L. (2008). Concepção de um sistema de alvenaria à base de blocos de betão com bagacina vocacionado para a construção nos Açores. Master Thesis, Faculdade de Engenharia da Universidade do Porto, Porto.

LNEC (1998). Caracterização térmica de paredes de alvenaria de blocos de betão de bagacina, Relatório 303/98. Laboratório Nacional de Engenharia Civil, Lisboa.

MIT Portugal (2011). Sustainable Energy Systems: Research Projects. Retrived August 1, 2011, from http://www.mitportugal.org/sustainable-energy-systems/research-green-islands.html#h0-1-project-description

Parlamento Europeu, Conselho (2003). Desempenho energético dos edifícios. Directiva 2002/91/CE. Jornal Oficial da União Europeia. L1 de 4 de Março de 2003.

Portugal, Leis, Decretos, etc. (1980). Despacho normativo nº. 38/80. Jornal Oficial. Região Autónoma dos Açores. I série. Numero 18. (27-05-1980).

Portugal, Leis, Decretos, etc. (1990). Regulamento das características de comportamento térmico dos edifícios. Decreto-Lei nº. 40/1990. D.R. I Série A. Número 31 (06-02-1990).

Portugal, Leis, Decretos, etc. (2006). Regulamento das características de comportamento térmico dos edifícios. Decreto-Lei nº. 80/2006. D.R. I Série A. Número 67 (04-04-2006).

Sousa, L. C., Castro C. F., António C. C., Sousa H. (2011). Topology optimisation of masonry units from the thermal point of view using a genetic algorithm. Construction and Building Materials; Vol.25 nº 5: 2254-2262.

Sousa, H. (1996). Melhoria do comportamento térmico e mecânico das alvenarias por actuação na geometria dos elementos. Aplicação a blocos de betão de argila expandida. Phd Thesis, Faculdade de Engenharia da Universidade do Porto, Porto.

SRES, LREC (1986). Os ensaios foram efectuados... [Characterization report, confidential title]. Laboratório Regional de Engenharia Civil, Ponta Delgada.

Tourtellot, J. B. (2007). 111 Islands. National Geographic Traveler. Nov./Dec.; 108-127.