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Comparative study of fire resistance and acoustic performance of ceramic brick walls in concern to NBR 15575 in residential buildings in Brazil

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Abstract
After the publication of NBR 15575 (ABNT, 2013) standard, it became necessary that the constructive systems used in residential buildings go through verification processes concerning the performance requirements. Considering the security requirements, it is necessary to evaluate the fire resistance of vertical sealing systems. Within the scope of habitability, the standard specifies that these systems must have an adequate acoustic performance. Regarding this scenario, this study has the purpose of evaluate the performance of two non-structural vertical sealing systems in ceramic bricks by comparing two different layouts of horizontal air gaps. Therefore, laboratory tests were performed, following the prescriptions of NBR 10636 (ABNT, 1989) and ISO 10140-2 (ISO, 2010). It was verified that the system with higher air gaps number had a better performance on fire resistance, and that the acoustic performance was very similar between the two systems.

Keywords: laboratory test; vertical sealing systems; acoustic performance; fire resistance; ABNT NBR 15575-4:2014.

Estudio comparativo de resistencia al fuego y desempeño acústico de paredes en bloques cerámicos en cuestión de NBR 15575 en edificios residenciales de Brasil

Resumen
Con la publicación de la norma NBR 15575 (ABNT, 2013), ha sido necesario que los sistemas constructivos utilizados en edificios residenciales se sometiesen a ensayos para el cumplimiento de los requisitos de desempeño. En el ámbito de los requisitos de seguridad solicitados por la norma, existe la necesidad de la evaluación de la resistencia al fuego de los sistemas de aislamiento vertical. Dentro de la habitabilidad, la norma recomienda que estos sistemas tienen un desempeño acústico adecuado. Dentro de este escenario, el objetivo de este trabajo es evaluar el desempeño acústico de dos sistemas de pared compuestos por diferentes tipos de bloques cerámicos con agujeros horizontales. Para este análisis, fueron realizados ensayos de laboratorio de acuerdo con las normas NBR 10636 (ABNT, 1989) y ISO 10140-2 (ISO, 2010). Se verificó que el sistema con mayor densidad presentó desempeño sensiblemente mejor acerca la resistencia al fuego, con desempeño prácticamente idéntico en el análisis del aislamiento acústico.

Palabras clave: ensayos de laboratorio; sistema de aislamiento vertical; desempeño acústico; resistencia al fuego; ABNT NBR 15575-4:2014.

1. Introduction

The national methodologies of evaluation and classification of the performance in residential buildings systems in Brazil are prescribed by NBR 15575 (ABNT, 2013), that is the first national standard that concern the performance as an obligatory requirement. The standard describes criteria to promote the classification of all systems that compose a residential building, attributing minimum performance to the systems during their normal use

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conditions. Also, the standard classifies the performance of the buildings in three different classes, minimum, intermediate and superior, among the security, habitability and durability areas. In this way, the standard has increased the concern in the use of adequate systems, adding quality, security, sustainability and comfort for the users (MOURA; SANTOS; PINHEIRO, 2016).

In the country, since the standard reveals the necessity of fulfill requirements that were ignored and has, relatively, been published recently, the systems until then used had to be tested and, if necessary, remodeled to comply with, at least, the minimum performance classification. Demanding the material manufacturers and construction companies to adequate their systems to the standard requirements, causing a revolution in the way buildings were made until then (SILVA *et al.*, 2014).

As areas in the scope of the NBR 15575 (ABNT, 2013), concerning to the security and the habitability of a building, the fire resistance and sound insulation requirements of the wall systems are of interest on the design, material specification and use of a residential edification, justifying the significance of the research.

Into the fire resistance of the systems that compose a building, the main objective is to promote a secure way to the users to get out of the building in case of a sinister. For this, the wall sealing systems must limit and prevent the spreading of fire through the building. The walls promote an essential compartmentalization to the building, proportioning security in the evacuation route, depending directly on the performance of the bricks and the coating system. The coating system protects the bricks from the direct incidence of the fire, increasing the fire resistance of the system (BUCHANAN; MUNUKUTLA, 1991; BRETANO, 2004; ONO, 2007; NGUYEN; MEFTAH, 2012).

Some geometric characteristics of the system, like voids, spaces and internal dimensions, have a strong influence on the fire resistance of the wall, due to the interference on the predominant heat transfer between the vertical divisions inside the blocks (NGUYEN et al, 2009).

Considering mortar coatings, with high temperature exposure, there is a resistance of the mortar against the heat transfer when the temperatures reach 100°C. While there is intrinsic water, this temperature remains constant. When the liquid phase of the pores disappears, the heat transfer is indicated by an increase in the material temperature, becoming progressively linear. At these temperatures, the solid phases are responsible for the transmission of heat, and also for the hot air, or steam, that must be enclosed in then exists throughout the test (MACIÁ; ROLANDO, 2013).

Into the habitability, one of the concerns is the acoustic performance, because of the characteristics and the possible hazard caused by the sound. As it is omnipresent in our environments, bringing information about what is happening in the emission thus the transferring paths, being beneficent or malefic, as noise pollution. These noises can cause hearing loss or affect the comfort of the users, influencing in their physical and mental health, principally in residences, where the nuisance is amplified (HANSEN, 2005; FAHY, 2014; PARIS-NEWTON; PROKOFIEVA; HENRY, 2016).

Considering the acoustic comfort from the external and internal noises in a building, we have that it is promoted by the vertical sealing systems, which have their performance directly linked by their sound reduction capability, keeping comfortable sound pressure levels (GUILLEN et al., 2008; GÖSELE; SCHRÖDER, 2013).

The evaluation of the sound reduction capability is important to ceramic brick masonry walls because they have acoustic fragility related to their voids, who decrease their sound insulation capability by the internal resonances that occur when compared to solid bricks. The existing voids in the bricks affect their resonance frequency, modifying their comportment through the frequencies, causing dips in their sound reduction spectrum, generating fragilities and decreasing the punctual and overall sound insulation capability of the wall (FRINGUELLINO; SMITH, 1999).

In this way, this article has the aim to evaluate the fire resistance and acoustic sound insulation, among Brazilian standard NBR 15575 (ABNT, 2013), of two non-structural systems composed by different ceramic bricks composition, in weight and geometry, both with horizontal voids, commonly used in the country construction market.

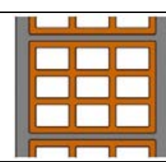
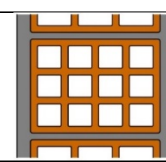
2. Methodology

The samples are composed by non-structural ceramic bricks with mortar coat in both sides with 2 cm thick and were tested in the itt Performance/Unisinos facility in São Leopoldo, Brazil. The Table 1 shows the information regarding the dimensions, configuration and mechanical resistance of the brick samples, as well as the superficial density and the thickness of the coat applied in the systems, denominated A1 and A2.

2.1. Sound insulation

The determination of the sound reduction index of the samples were made into a laboratorial environment, testing both the aforementioned systems, that were constructed inside a movable reinforced concrete portico and installed between two reverberant rooms (Fig. 1) that follows the requirements of ISO 10140-5 (ISO, 2010), with a sample area of 10.8 m².

Table 1.
Tested samples

System	A1	A2
Brick dimensions (cm)	14x19x29	14x19x24
Mechanical resistance (MPa)	1,5	1,5
Superficial density (kg/m²)	270	230
Brick configuration	9 voids	12 voids
Liquid area / Gross area	0,30	0,35
Graphic representation		
Coating	Mortar with 2 cm thick in both sides	

Source: The authors.

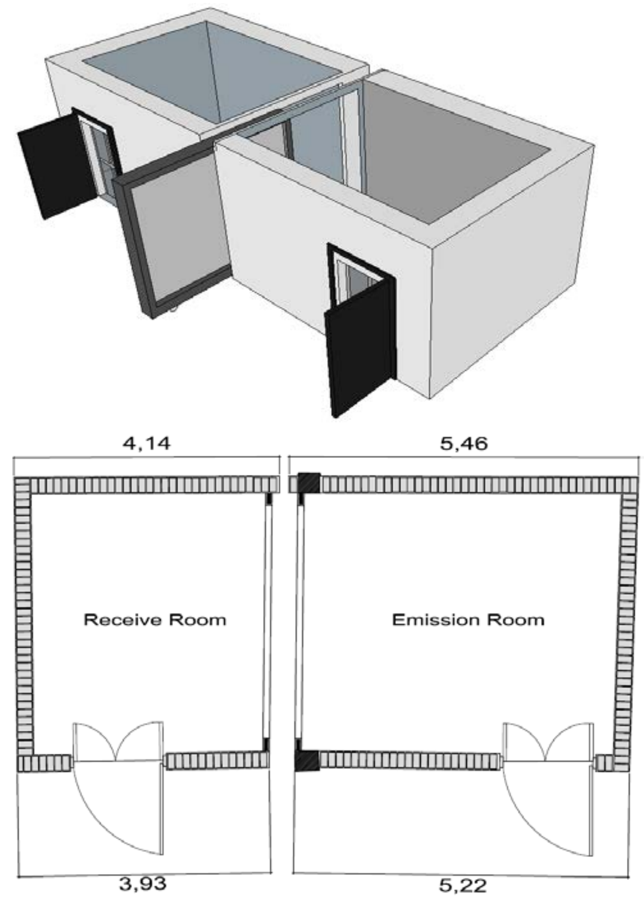


Figure 1. Test facility.
Source: The authors.

The test procedures used to the determination of the sound reduction index were described by ISO 10140-2 e ISO 10140-4 (ISO, 2010), making the measurements with the adequate and calibrated equipments, measuring the sound pressure levels in 10 distinct positions for each parameter, and in one-octave bands from 100 to 5000 Hz. The reverberation time was obtained by the interrupted method, with three decays per position, in twelve distinct positions. All the equipment's are from Brüel & Kjäer, being them: sound analyzer Type 2270, sound source Omnipower 4292-L, sound calibrator Type 4231 e power amplifier Type 2734.

The measurements were made and then the sound reduction index was obtained by eq. 1 for each of the frequency band measured, present in ISO 10140-2 (ISO, 2010). For this, the sound pressure level in the emission room is subtracted by the one in the reception room, plus the relation between the sample area and the equivalent sound absorption area of the reception room.

$$R = L1 - L2 + 10 \log\left(\frac{S}{\frac{0,16V}{T}}\right) \quad (1)$$

Considering: L1 is the sound pressure level in the emission room [dB]; L2 is the sound pressure level in the reception room [dB]; S is the sample area [m²]; V is the volume of the reception room [m³]; T is the reverberation time of the emission room [s].

With the calculated sound reduction index for each frequency band, by the calculation processes present in ISO 717-1 (ISO, 2013), the sound reduction index was obtained for each sample. Then, their performance could be compared with the requirements and classification present in NBR 15575-4 (ABNT, 2013), that classifies the performance in minimum, intermediate and superior classes, with the requirements varying as a function of the boundary conditions of the system under use.

2.2. Fire resistance

In order to verify the compliment of the systems in their fire resistance requirements, real scale specimen were made by the same processes as the sound insulation tests but with a steel portico and a sample area of 9 m² that is fixed into a vertical furnace (Fig. 2). The tests were taken by the prescriptions of the NBR 10636 (ABNT, 1989), the Brazilian standard for evaluation of non-structural sealing systems. The samples were exposed to the fire by the standardized temperatures of ISO 834 (ISO, 1999). According to this standard, the samples were classified as fire blocking (FIB) by the period that they complied with the requirements of structural stability, airtightness and thermal insulation, and also classified as flame blocking (FLB) when they doesn't comply only with the thermal insulation requirements. In this two classifications the prefix FB or FLB are succeeded by the time, in minutes, that the sample resisted to each parameter. For both samples, the test time was 360 minutes and the exposure conditions were the same.


Figure 2. Vertical furnace used to determine the fire resistance of vertical sealing walls.
Source: The authors.

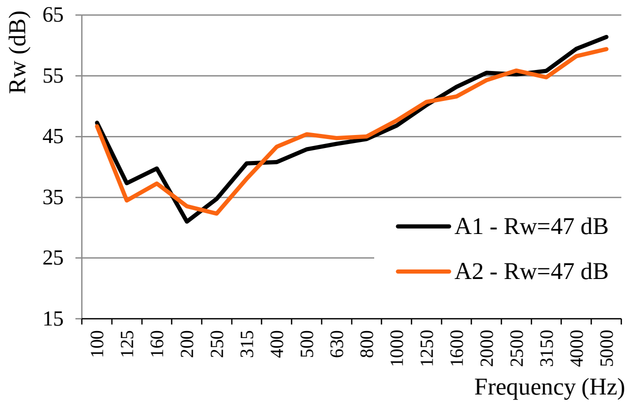


Figure 3. Sound reduction index of the samples.
Source: The authors.

During the test period and by the recommendations of NBR 10636 (ABNT, 1989), mechanical resistance, airtightness and thermal insulation were verified in both samples. On mechanical resistance, we have the structural stability, where an impact of three steel spheres with 25 kg were projected by a pendular movement with an energy of 20J applied three minutes before the end of the test, and the deformation was measured by a laser ruler. In order to verify the airtightness failure, a cotton wad, previously dried in a stove, was positioned near the fissures, detected with the support of a thermographic camera, for a period of 10 seconds. If the cotton ignites the system loses its airtightness. Thermal insulation was analyzed by the temperatures registered by nine thermocouples placed in the non-exposed side of the wall. The arithmetic average of the temperatures of the main thermocouples (6 to 10) cannot pass the limit of 140 °C and/or one of the nine thermocouples (6 to 14) must not overpass 180 °C. For these two cases, the ambient temperature at the start of the test must be added.

3. Results

3.1. Sound insulation

On acoustic performance, the sound reduction index of the samples are expressed in Fig. 3, where it's possible to verify that both had a similar comportment of the transmission loss over the frequency bands analyzed.

It is possible to verify that both samples had an accentuate sound reduction index in 100 Hz provided by their stiffness, decreasing and differing in the others low frequency bands, characteristic of the coincidence valley commented by Fringuellino and Smith (1999), in the first resonance controlled zone, varying as a function of the damping mechanisms of each brick composition. The two samples resemble each other again in the mid frequency bands, in the mass controlled zone, differing only in the 400 to 630 Hz bands. At these points, sample A2 had a greater sound reduction index, contradicting the expected result if only the superficial mass of the systems were considered. Still, it also shows that with a greater liquid to gross area, even with less superficial mass, the sound reduction index of the sample can be greater in these bands. In the high frequencies, the comportment of the systems is also similar, differing only in the frequency where the coincidence effect occurs, in 2500 Hz band for sample A1 and 3150Hz on sample A2, where the relatively small cavities can't handle frequency modes in the mid and high bands, causing the resonance effect as referred to Hopkins (2012).

With the measured sound reduction index of the samples, they can be classified by NBR 15575-4 (ABNT, 2013) requirements. As both had the same measured sound reduction index (47 dB), they have the same performance classification. The two systems, according to terms of application by the standard, presents minimum performance classification when used as vertical sealing systems between units in situations where one of the rooms isn't a bedroom or living room, partitions between bedrooms and common use areas with eventual transit. In addition, the systems have superior performance when used as partitions between kitchens or living rooms and common use areas with eventual transit.

3.2. Fire resistance

The normative limits of the ISO 834 standard curve were respected throughout the test. The temperatures of each sample during the fire resistance test are shown on Fig. 4-6.

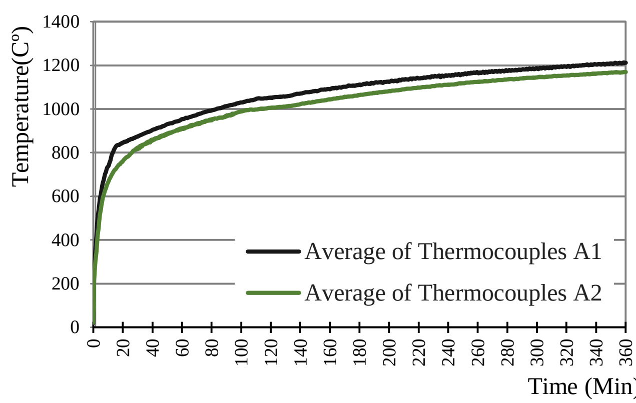


Figure 4. Average temperature of the exposed face of samples A1 and A2.
Source: The authors.

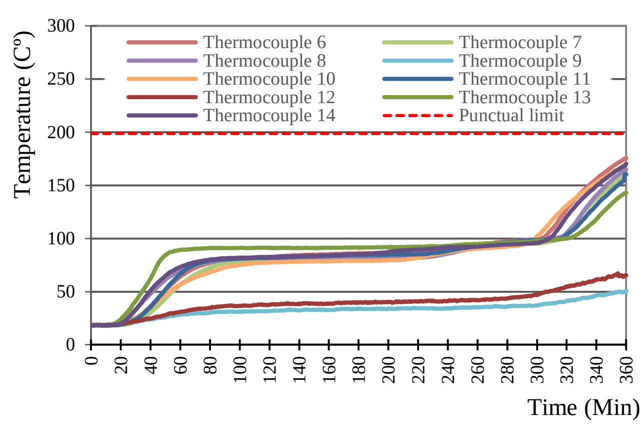


Figure 5. Average temperature of the non-exposed face of sample A1.
Source: The authors.

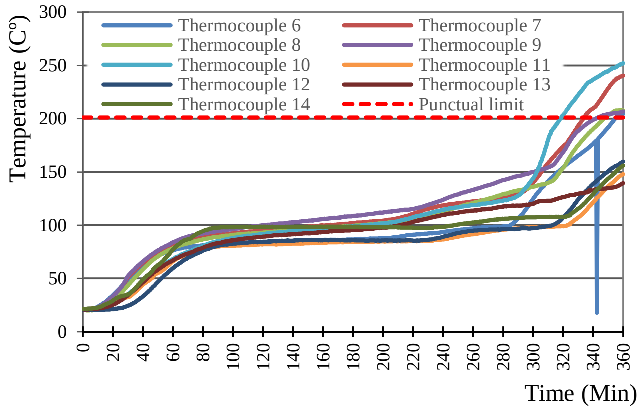


Figure 6. Average temperature of the non-exposed face of sample A2.
Source: The authors.

Sample A1 had a better performance when compared to A2, mainly in terms of the temperature elevation in the non-exposed side. At 319 minutes of the test of sample A2, the punctual temperature of the thermocouples 7 and 10, in the non-exposed side, overpassed 180 °C (added to the temperature in the beginning of the test, 21,1 °C), indicating the occurrence of a failure in the system, overpassing the limit according to NBR 10636 (ABNT, 1989).

After the exposure of the samples to high temperatures, sample A1 showed satisfactory structural stability, and the exposed side of the coating layer remained adhered to the substrate, showing only small fissures in this same side. On sample A2, there was spalling of the mortar coating approximately on 32 percent of the area of the face exposed to fire, in the mid-inferior partition. It is the most possible cause of the increase in the exterior temperature of the sample, as referenced by Nguyen and Meftah (2012). It is also observed that there was no stabilization of the temperature of the non-exposed face, referred to above and occurred in system A1, impairing the thermal insulation over time by failure of adhesion of the coating to the substrate. The final aspect and the projection of the position of the thermocouples in the non-exposed face of the two samples are shown in Fig. 7-8.

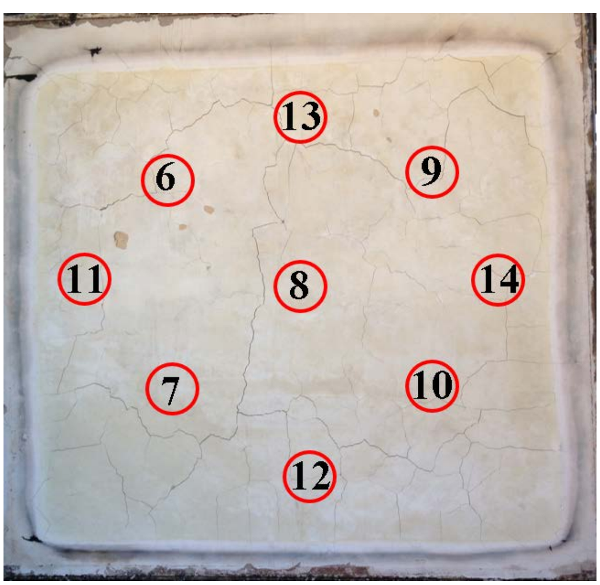


Figure 7. Final aspect of the exposed face of sample A1.
Source: The authors.

Figure 8. Final aspect of the exposed face of sample A2.
Source: The authors.

4. Conclusion

From the tests and posterior analysis of the obtained results, it is possible to visualize the influence of the geometry of the two bricks that composed the samples A1 and A2 in their acoustic sound reduction capability and their fire resistance, as well as their specific classifications for each case.

Regarding the acoustic performance, both samples showed similar partial results, differing only in some frequency bands by the internal damping, geometry (with their different liquid to gross relation) and mass of the bricks, varying as a function of their geometry, as well as the same measured sound reduction index (47 dB). As they have the same measured result, they have the same performance classification on the standards.

On fire resistance, the difference in the geometries of the bricks that composed the two samples promoted a higher discrepancy on their performance. There was the loss of thermal insulation in sample A2, with the spalling of the mortar coating at 319 minutes, making the comparison impossible from then. However, it was possible to observe the importance of the mortar coating for the heat transfer resistance. Thus, sample A1 had the classification as FB360 and FLB360, and A2 had FB240 and FLB360. In this way, sample A1 had a sensitive superior performance when compared to A2.

With the tests and analysis of each sample, it is possible to verify a relevance and validation of the obtained data. It is possible as well to evidence the necessity of the verification of the performance of the usually used systems in the country construction market with the relatively new standard requirements. This study allowed the visualization of the negative influence, at some points, of a ceramic brick wall with less density and more voids than the other analyzed system.

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