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Rating of acoustic performance levels of NBR 15575 (2013) based on user perception: A case study in the Brazilian Amazon

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Abstract

The new Brazilian building performance standard is a landmark in terms of housing regulation in Brazil. Nevertheless, due to the standard recent release, it becomes essential to make its requirements compatible with users' needs. This work has the objective to evaluate the acoustic performance requirements of buildings based on the users' perceptions of acoustic comfort. In order to do this, field tests were performed and surveys were applied to the users. The results demonstrate that the requirements defined by the Brazilian norm are unsuitable to meet the users' necessities. The correlation analysed shows a clear perception of the habitants in relation to the transmitted noise through the slabs and walls. These unsatisfactory results concern the acoustic performance of impact noise between slabs, as well as internal and external walls, showing that construction companies must implement new solutions that can provide greater acoustic performance to achieve acoustic comfort to the users.

Keywords

Buildings performance, acoustic performance, NBR 15575, acoustic comfort, single number ratings

Introduction

Different from most European countries, acoustic performance of Brazilian residential buildings has been ignored for a long time, and only a few measures were taken by the Brazilian public government concerning the acoustic performance before the first version of the NBR 15575[1] standard. These measures would usually focus on one public health problem at a time and were applied to a specific region or county. One example of that is the Law 8.106[2] dated from 30 August 1974, also known as "The Silence Law." On top of that, Federal measures were adopted in terms of standards, such as NBR 10151[3] and NBR 10152,[4] which established requirements to acoustics comfort. These early

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measures, however, were criticized by several studies in the field,[5–7] pointing to the necessity to establish better noise regulations. Baring,[7] for example, refers to the necessity of creating a standard that establishes clearer parameters concerning noise emission and are suitable to inspection and, thus, able to provide quality of life regarding the acoustic comfort in constructed environments.

After being released, the NBR 15575[1] standard became a vital tool to comply acoustic performance with consumer expectations. Nevertheless, even after being modified numerous times, many studies are still questioning some of the requirements presented at the standard.[8–10]

During the last decades, in Europe, countries have been updating their acoustic emission and control standards by making them more stringent and so providing increased comfort and life quality to the population. Rasmussen[11] compared requirements on normative minimum sound insulation standards for airborne and impact sound in 24 European countries and converted them to an equivalent estimated parameter to minimize the individual variations related to the dimensions of an environment, especially when those parameters adopt "low-frequency" spectrum adaptation terms (including C_{tr}, C_I, and $C_{I,50–2500}$). Comparing the results obtained by Rasmussen[11] to the NBR 15575,[1] it is possible to see that all 24 countries possess more stringent insulation requirements when compared to the minimum required by the Brazilian standard.

Neto and Bertoli[12] pointed out that comparing Brazilian noise standards to the requirements of cold countries can lead to erroneous results because, according to the authors, the necessity of providing good thermal insulation in cold countries leads to improved air partition that, together with the acoustic insulation, provides an improved acoustic performance. Thus, the authors compared the Brazilian insulation requirements to countries like Japan, New Zealand, France, South Africa, United States, and Brazil's neighbors such as Argentina and Chile, some of these countries with climate similar to Brazil. Their work showed through a quantitative comparison that the minimum noise requirements in the Brazilian standard are also well below the requirements established by the countries of comparison.

An important point for investigation concerns the single number rating adopted to describe performance in the Brazilian standard, which is based on the international standard ISO 717.[13,14] In this respect, studies have shown a low correlation with the perceived annoyance,[15,16] especially when "low-frequency" spectrum adaptation terms are not adopted, which is the case for the Brazilian standard. However, this seems to be a wise decision for the Brazilian standard, since these terms are better suited for lightweight than heavyweight partitions, the latter being the predominant model in the country.

The correlation between the single number rating and the perceived annoyance has been gaining attention over the years, being highlighted in the European Project COST Action TU0901,[17] a network for research cooperation carried out over 4 years that presented 90 experts from all over the world but especially from Europe.

The objective of this article is to assess the acoustic performance requirements for buildings regulated by the NBR 15575,[1] based on the acoustic comfort perception of the users. The results were obtained by means of field experiments and application of surveys to the residents of newly constructed buildings, which were then correlated to one another. Nevertheless, since the NBR 15575[1] was recently released, this article represents an introduction to the discussion about whether the standard is effective in fulfilling the users' needs and, in this sense, to stimulate similar papers so that a representative sample of the national scenario can be obtained.

Methods

Six distinct buildings localized at the Metropolitan Region of Belém were studied. The field experiments, on one hand, were performed during the end of the building process, just before to the residents move-in. The surveys, on the other hand, were delivered at a minimum of 2 months after the residents moving in, except from the building number 6 that had the field experiments and the survey applied after the move-in.

In order to reach the objectives of this article, the research was separated into two steps:

(a) Acoustic insulation experiments, executed in the field to identify the acoustic performance of various residential buildings;
(b) Surveys with the residents, applied to verify the acoustic comfort provided by the buildings.

Partition description

Chart 1 depicts the assessed partitions, which can be identified by their abbreviations and numbers and grouped by the building number identification. In Chart 1, it is possible to compare the constructive typologies to the results presented in Table 2. It is important to notice that external and internal walls from building number 1 and the horizontal partition from building number 6 were not able to be assessed due to operational limitations.

The analysis was restrained to the most common typologies utilized in residential buildings of multiple stores that are localized in the city of Belém. In addition, the buildings are located around regions without excessive traffic and distant to airports, not interfering the experiments.

Most of the buildings under assessment utilize ceramic partition blocks; therefore, three internal walls made from ceramic hollow bricks of 9 × 19 × 19 cm^3, one wall of concrete block of 14 × 29 × 19 cm^3, one wall of reinforced concrete, and one wall of gypsum board fixed by steel frame with empty cavity were studied. All walls were covered by gypsum or mortar of variable thickness. A detailed description of the partition blocks is presented in Figure 1.

For the external walls showed in Figure 2, the same typologies as the internal ones were used, except from the gypsum board type, which is not utilized as an external block in Belém county due to its low adaptability to the extreme rainy regime of this region. Another characteristic of external partitions is the adoption of thicker coats of plaster in the external face to prepare the surface to the ceramic tile. As one can observe in Figure 2, VVE1 is 8 cm thick from the outer plaster. This constructive characteristic was adopted to correct alignment deviations from the structure.

To better represent the different scenarios encountered in the construction of residential buildings in the region, four solid and one ribbed slabs were studied. The slabs were constructed of different thicknesses of mortar screed and adopted a common type A ceramic of 50 × 50 cm^2 or porcelain tile of also 50 × 50 cm^2. Figure 3 depicts the representation of the different slab constructions.

Chart 1. Partition constructive typologies analyzed, grouped by building.

Building	Walls		Slabs
	Internal	External	
1	–	–	VH 4
2	VVI 1	VVE 1	VH 1
3	VVI 1 and VVI 5	VVE 1	VH 3
4	VVI 2	VVE 2	VH 5
5	VVI 3	VVE 3	VH 2
6	VVI 4	VVE 4	–

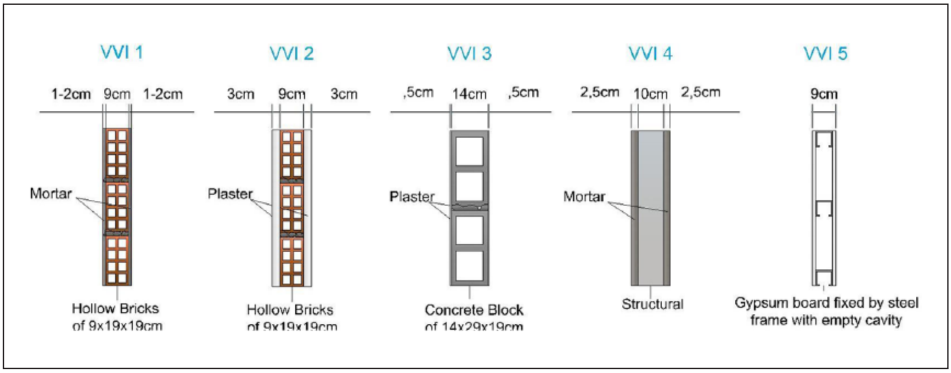

Figure 1. Constructive internal walls typologies analyzed (VVI).

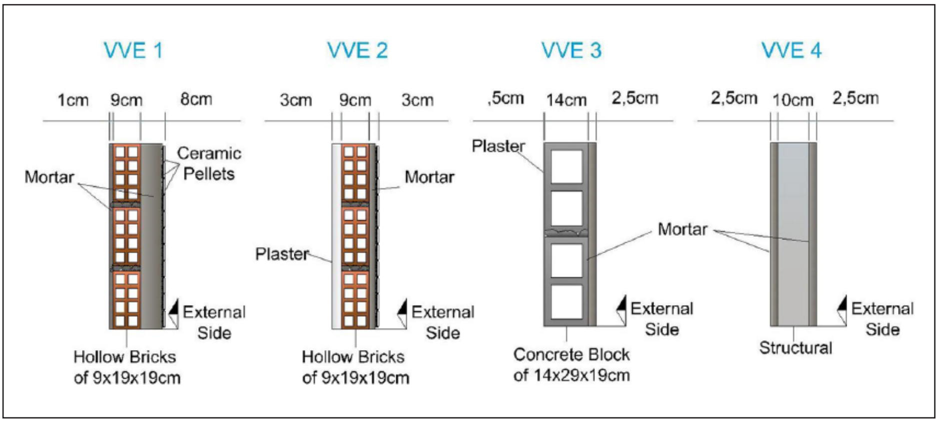

Figure 2. Constructive façade typologies analyzed (VVE).

Evaluation criteria

The first part of the NBR 15575[1] specifies that residential buildings must comply with suitable acoustics insulation in the construction of external partitions, to reduce the transmission from exterior airborne sound and common privative areas. In Table 1, the first column shows the performance requirements described in the standards for comparison. The minimum level (M) establishes the normative minimum requirements for the building according to the acoustic performance requested in the standard. Furthermore, intermediate (I) and superior (S) performance requirements are provided to give room to possible quality improvements considering a cost–benefit ratio. The NBR 15575[1] also specifies more stringent requirements. One that occurs more often in constructed environments and is related to the case of semi-detached walls where at least one of the environments enclosed by the wall is a bedroom; in such cases, the standard recommends the requirements presented in Table 1, the second column. In Table 1, the third column represents the results obtained by Rasmussen,[11] so the field experimental data can be compared to international requirements provided by the author.

Table 1. Standardized acoustic performance requirements.

Element	Least stringent situations[a] (dB)			Most stringent situations[b] (dB)	European[c] (dB)
	M	I	S	M	M
Acoustic performance of a floor to impact noise—$L'_{nT,w}$	80–66	65–56	<55	80–66	<50
Acoustic performance of a floor to airborne sound—$D_{nT,w}$	40–44	45–49	≥50	45–49	≥55
Acoustic performance of a wall to airborne sound—$D_{nT,w}$	40–44	45–49	≥50	45–49	≥55
Acoustic performance of an external wall to airborne sound—$D_{2m,nT,w}$	≥25	≥30	≥35	≥25	

M: minimum levels; I: intermediate; S: superior.
[a]Partition separating a single residence unit and common areas, such as corridors and stairways.[18,19]
[b]Semi-detached partition where at least one of the environments enclosed by the wall is a bedroom.[18,19]
[c]Minimum requirements of acoustic performance proposed by Rasmussen.[11]

Field experiments

Measurement procedure

In this research, every partition whose NBR 15575[1] classifies as mandatory in terms of acoustics performance was analyzed. Therefore, the field experiments were performed for floors and internal and external walls considering their acoustic performance to airborne sound and impact noise.

The experiment procedure is defined in the ISO 16283,[20–22] recommended by the Brazilian national standard. The reverberation time was obtained following the procedure described in ISO 3382-2[23] standard, while the background noise followed the ISO 16283[20–22] standard. For the evaluation of the partition acoustic insulation, a single number rating was used to be compared to the performance standards; for such cases, the 717-1[13] standard was followed for the airborne sound and the 717-2[14] standard for the impact noise measurements.

The experiments were carried out in partnership with the Acoustic and Vibration Group (GVA) from the Federal University of Pará (UFPA), responsible for providing the equipment used, which are listed here: omnidirectional loudspeaker, signal preamplifier, ½-in microphone, two channels sound intensity system, and a tapping machine.

The windows are made of aluminum and a monolithic tempered glass (6 mm) with two sliding doors, and in the balconies, there are monolithic tempered glass opening doors (8 mm) with two movable sliding leaves.

Field experiment results

In Figure 4, it is possible to see a large difference between the results of VVI1 for buildings 2 and 3. Although there is no significant variation of the areas and volumes of the rooms tested in the two buildings, the low performance of VVI1 in building 2 may have occurred due to the influence of a kitchen which presents a gap of 80 cm wide joining the environments. This detail can affect the variation in resonant time of the emitter environment. Another explanation comes from the impossibility of asserting at the time of the tests the quality or even the type of materials used in the evaluated partitions, since these

Table 2. Acoustic performance of the partitions according to the least stringent standard requirements.

Edificação	Vertical partition (Wall)		Horizontal partition (Slab)	
	Internal	External	Impact noise	Airborne sound
	$D_{nT,w}$ (dB)	$D_{ls,2m,nT,w}$ (dB)	$L'_{nT,w}$ (dB)	$D_{nT,w}$ (dB)
1			64[a]	
2	27[b] 28[b]	24[b]	70[c]	40[c]
3	42[c] 26[b] (VVI 5)	25[c]	66[c]	46[a]
4	38[b] 33[b]	24[b]	66[c]	48[a]
5	45[a]	26[c] 25[c]	69[c]	48[a]
6	21[b] 27[b]	26[c]		

[a]Meets the intermediate requirements in the NBR 15575[18,19] standard.
[b]Do not meet the NBR 15575[18,19] standard.
[c]Meets the minimum requirements in the NBR 15575[18,19] standard.

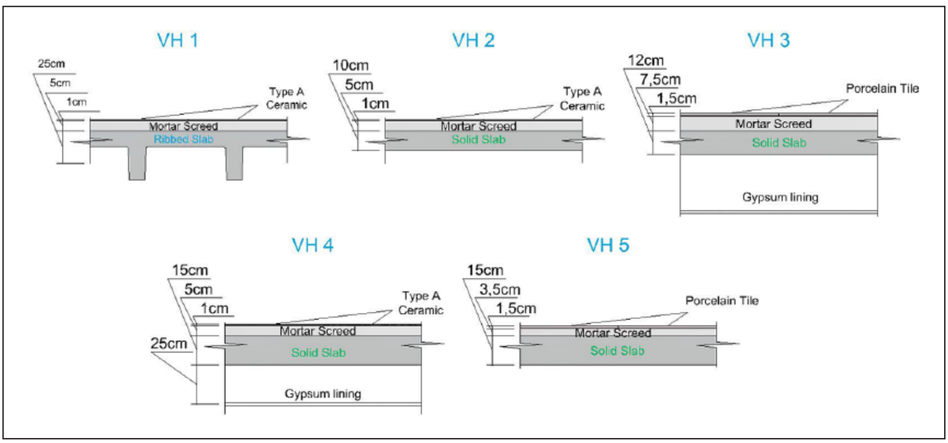

Figure 3. Constructive slab typologies analyzed (VH).

buildings were finished within a few days of delivery, being the responsibility of the researchers only to measure the thickness of these partitions and rely on the engineers responsible for the materials used.

Analyzing the results for the acoustic performance experiments for each partition typology (Table 2), it is clearly seen that the worst results are related to the walls, especially the internal ones, of which 78% do not meet the standard.

As for the low acoustic performance results of the ceramic blocks, it is suggested to study the influence of the constructive procedure, that is, the placement of mortar on the partition blocks, which are often poorly executed or deliberately omitted. These poor performance results for the case of using hollow bricks (Figure 5) can be explained due to the presence of air cavities that

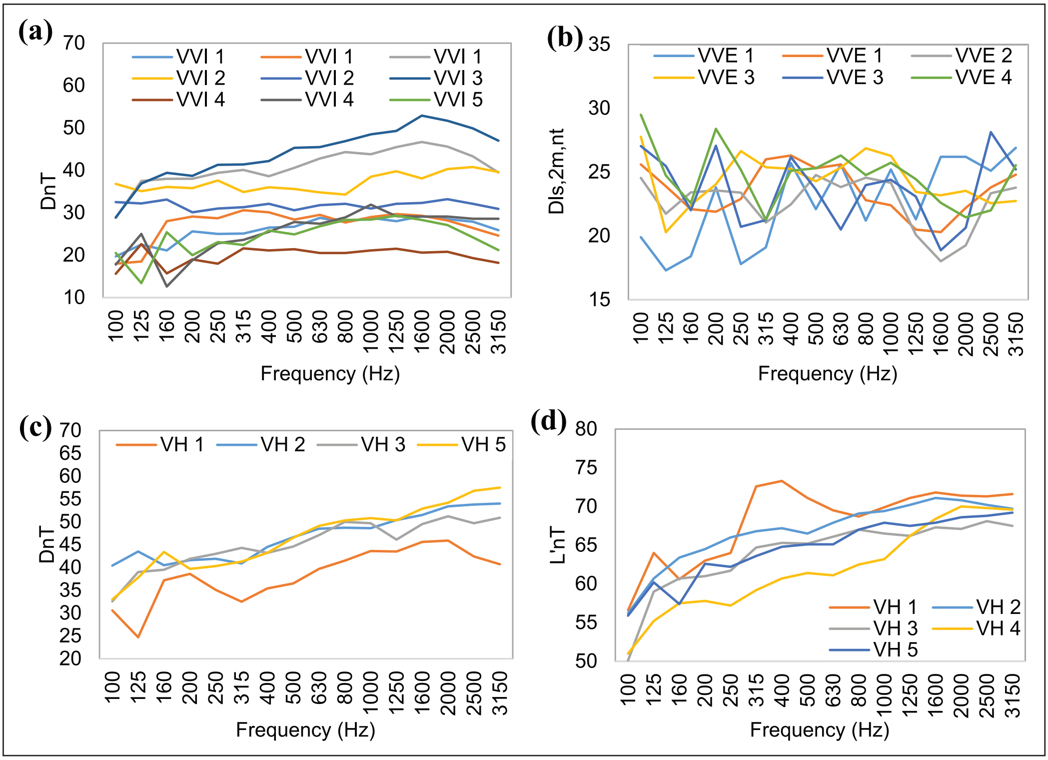

Figure 4. Measurement results by frequency band: (a) D_{nt} for the walls, (b) $D_{ls,2m,nt}$, (c) D_{nt} for the slabs, and (d) L'_{nT}.

facilitate the sound propagation. Since it is known that the correct placement of the mortar in the vertical and horizontal joints also contributes to the final acoustic performance of a wall.[24,25]

Regarding the external walls, although 66% of the partitions achieved the minimum required performance, it was not observed a great variation of the results (±1 dB) independent of the material or coating, demonstrating the need to adopt techniques or materials that can improve the performance, so the standard can be met more easily. As for the slabs, two typologies of the most used in the country were studied, the ribbed and the solid ones. In these cases, all buildings meet at least the minimum acoustic insulation performance requirements in the two field experiments performed.

Among the two field experiments carried out on slabs, acoustic insulation to airborne sound had better results, in which three of the four partitions achieved the intermediate performance. These results agree to the work done by Litwinczik,[26] were the author concludes that horizontal partition such as floors present higher acoustic performance due to their reinforced concrete construction, with a layer of mortar, commonly used in Brazil.

Even though more repetitions of the experiments need to be addressed in similar typologies to assure the consistency of results, it can be observed in Table 2 that the typologies adopted in buildings 3 and 5 represent the best construction recommendation, especially the concrete block walls with plaster and solid slabs with thickness of 12 cm or more, floating floor, and ceramic coating. The plaster or porcelain liner recommendations, however, can be found and are further discussed in the works developed by Pereyron et al.[27] and Silva and Silva.[28]

Figure 5. Example of air channels of a ceramic sealing brick.

Standardized requirements

Figure 6(a) presents the generalized results achieved in this work. Even though the Brazilian standard establishes low acoustic performance requirements, only 63% of the buildings studied could meet these requirements and 42% of these meet the minimum requirements.

Moreover, in the case of partition where a higher acoustic performance is required, for situations in which at least one of the rooms is a dormitory or area of collective use (Figure 6(b)), an even lower number of partitions were unable to meet the requirements (46%) and only one of them meets the intermediate requirements. Figure 6(c) regards the fulfillment of international requirements, where it is possible to observe an even worse scenario since none of the partitions could reach the requirements proposed by Rasmussen.[11]

This shows that although the Brazilian standard adopts lower requirements when compared to other countries, it is still stringent facing the construction technologies currently adopted in the Brazil and pointing to the necessity to change the existing constructive model. We can use as an example Italy, which historically uses heavyweight materials[29] as in Brazil and which, however, has been adopting new technologies that have allowed us to improve the acoustic performance of the building partitions along with increasing regulatory rigor.[25]

Subjective perception from users

Survey elaboration

With 15 questions, the survey model was adapted from the one proposed by the Acoustical Society of Japan (ASJ).[30] In the survey, a brief characterization of the interviewee is made by its age and sex. The questions follow a structured model and are subdivided into three groups: group 1, consisting of four introductory questions which reveal the residents' satisfaction with the location of the property; group 2, formed by six questions, seeks to identify which sound source is the most disturbing and how the resident behaves in respect to it; and group 3, consisting of five questions, is responsible for defining the level of acoustic comfort provided by the construction system.

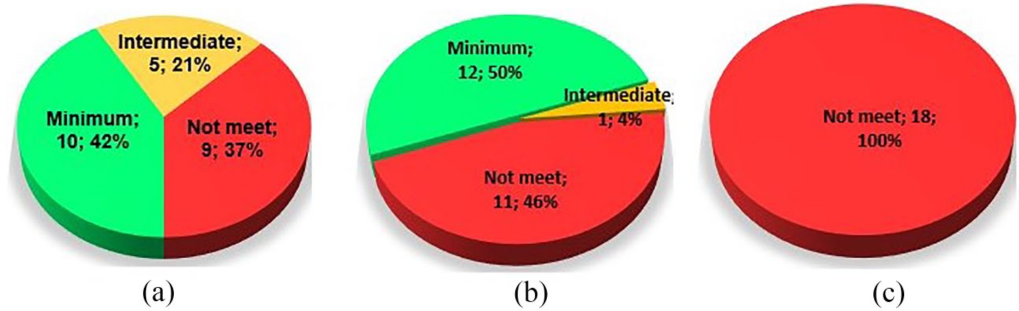

Figure 6. General field measurement results: (a) adopting less stringent requirements of NBR 15575,[1] (b) for situations in which at least one of the rooms is a dormitory or area of collective use, according to NBR 15575,[1] and (c) adopting international requirements of Rasmussen.[11]

In order to facilitate its application, speed up the process, and standardize the answers, the method chosen for the elaboration of the survey was the closed-question type, in which some alternatives of responses are offered. The question types were the five-level linear answer model, used with mastery in the works of Zhang et al.[31] and Meng et al.,[32] where in addition to the traditional "yes" and "no" answers, a neutral option and two intermediate options are offered, although other models have been used to a lesser extent, for example, multiple choice and binary questions.[33]

As for the method of application, at first, it was thought about the self-application, however, in detriment of the low amount of answers obtained, it was opted a face-to-face interview because it increases the number of answers obtained and give a general higher confidence in the answers, since the interviewer is capable of explaining the questions in depth.

Even though the survey was validated in its country of origin, due to the translation into Portuguese and the insertion of the questions related to group 1, a new validation was carried out through three rounds of interviews with residents of one of the evaluated buildings. The first one interviewed one person and then corrections were made; in the second, three residents were interviewed and corrections were made again; and finally, the third interviewed another five residents, and the authors accepted the final version of the model.

The surveys were applied in four of the six studied buildings. With the self-application method, the percentage of responses was very low, approximately 10%, in this way, and only after obtaining the authorization of the building syndics, the face-to-face interviews had begun. This was done asking the residents to descend to the entrance floor or knocking on the door of their apartments. With this method, a percentage of answers of about 40% from the occupied apartment population was achieved, totaling 78 applied surveys.

Results

Regarding the residents who answered the survey, 40 are women and 38 are men, whose age averages are 43 and 37 years, respectively.

In terms of what the interviewees think about the quality of life in Belém, from "very good" to "very poor," the mean (2.82) and the coefficient of variation (34%) suggest that they consider it between "Regular" and "Good." The satisfaction of the residents with the quality of life in the city indicates that they are less susceptible to any other annoyance that influences their perception of the acoustic comfort. Another fact is that 23% of respondents lived in the same neighborhood before buying their apartment in one of the analyzed buildings.

In the second step, interviewees were asked about 26 of the most common types of noise, and if they hear those noises inside their homes with the windows and doors closed, feel uncomfortable with those noises or do not hear them at all.

Among the types of the most disturbing selected noise, the noise of house works/reforms stands out with 21%, generating problems of sleep (56%); discomfort when performing their normal activities (38%); or in an even more serious way, health damage.

It is important to highlight the difficulty in reducing noise from house works/reforms, since among the structural ad airborne transmission media, the one that stands out the most is generated through impact, for example, noise from drills, hammers, and sawing machines, which propagates both through the slab and the wall, hence two questions arise:

- The performance standard, to the example of international standards, does not contemplates the impact noise transmitted by the wall.
- Knowing that the buildings studied are in accordance with the minimum level of impact noise tolerated in floor systems, the insulation provided is not enough to avoid this type of noise.

Although, due to the low occurrence of this type of noise, this result alone may not be able to justify the need for the Brazilian standard to predict acoustic performance requirements for impact noise in walls, this result is important for the discussion of the need for its regulation and could even guide more researches in that respect.

Regarding the perception of acoustic comfort of the user, in Figure 7, it can be seen that the building partitions that give the most perception of not having acoustic insulation are those of the external environment, the common area of use and the upper and lower floors, according to approximately 30% of respondents.

The low perception of the acoustic insulation in the external forms and the areas of common use confirms the results of the field experiments, evidencing the low acoustic performance of walls. Especially, about the façade, it corroborates with the conclusion that 53% of the respondents declared that the most perceived noise source in their residence is coming from outside the building (Figure 8).

In relation to the acoustic performance of the slabs, the situation is somewhat different. Despite the good results obtained in the field tests, it is verified that the minimum criterion of acoustic performance of the slabs in the impact noise is below the necessary according to the perception of acoustic comfort from the users, since 33% of the respondents stated that their residence does not isolate the noise generated in the upper or lower floors, and 38% claimed that it isolates only partially (Figure 7), making the impact noise between slabs the second most perceived noise source according to 32% of the respondents (Figure 8).

Another interesting information presented in Figure 7 is the deficiency of the insulation of the hydro sanitary equipment, perceived by a significant percentage of the interviewees, total (20%) or partially (25%), which is, nevertheless, mentioned in a nonmandatory nature in NBR 15575-6.[34] These results do not disqualify the decision taken by the standard; since only 1% of the interviewees are significantly disturbed by this noise, this result must in fact be attributed to the low acoustic performance of the internal walls, which constitute its main transmission. In this sense, its solution depends on the improvement of the acoustic performance of these walls.

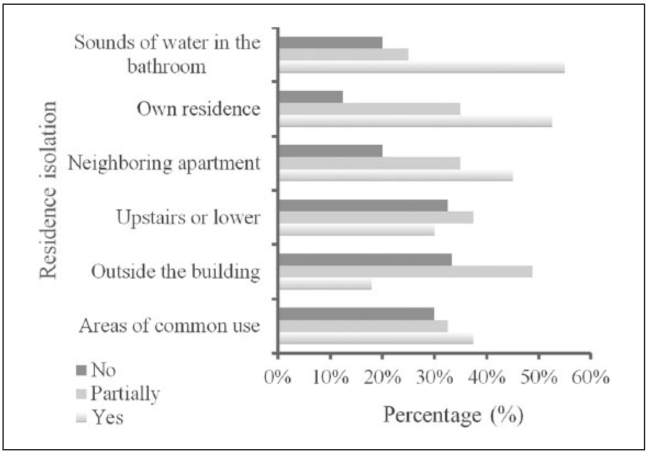

Figure 7. Residence insulation from noises generated in diverse places according to the users' opinions.

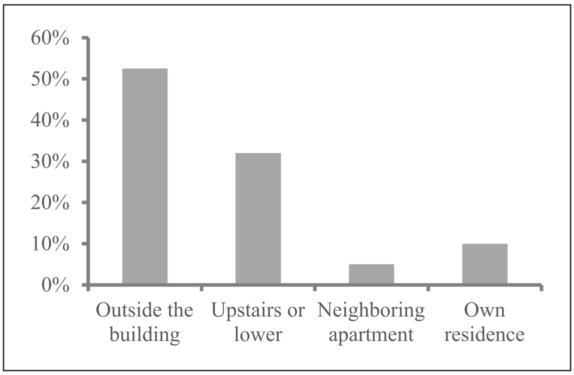

Figure 8. Main noise source directions according to users.

Finally, questions were raised regarding speech intelligibility in some environments in order to identify the acoustic privacy provided by the studied partitions. The result, shown in Figure 9, shows alarmingly the deficiency of the walls performance, especially of the internal walls, since it removes the right of privacy in their own home when it allows that conversations among the environments are heard by 60% of the interviewees, and even worst is the fact that in 5% of cases, they can be easily understood.

Comparison of results

In this work were presented results of the acoustic performance obtained with objective measurements in the field as well as results of the acoustic comfort perception from the point of view of the users, the latter obtained with subjective evaluations through the application of surveys. These results are summarized in Chart 2.

From the requirements of NBR 15575[1] regarding the acoustic performance of the partitions, the walls were more deficient, especially the internal ones, presenting a performance below the

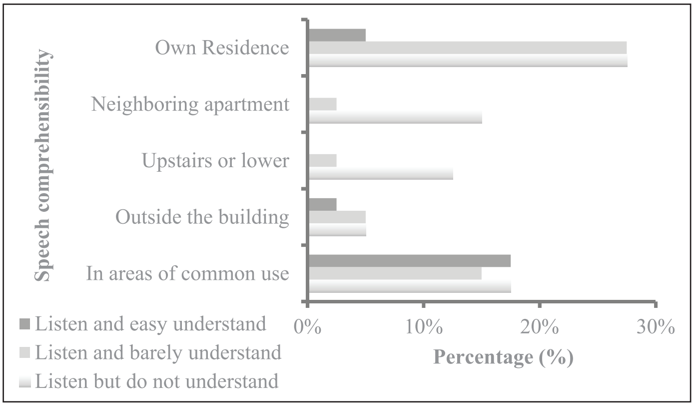

Figure 9. Speech intelligibility in the residence environments according to the interviewed opinions.

Chart 2. Comparison between the results from the measurements and the questionnaires.

Partition evaluated	Type of measurement	Field test evaluations	Most representative subjective analysis from the residents
Internal walls	Airborne sound	Insufficient acoustic performance	62% declared to not notice total or partially the isolation
			61% declared to hear conversations coming from their own residence
			18% declared to clearly hear conversations coming from common use areas
External walls	Airborne sound	Minimum acoustic performance	82% declared to not notice total or partially the isolation
			56% declared that the most noticed noise source was coming from outside the building
Slabs	Impact noise	Intermediate acoustic performance	21% declared it to be one of the types of noise which most generates annoyance (house work and renovations)
			70% declared to not notice total or partially the isolation
	Airborne sound	Minimum acoustic performance	32% declared that the most noticed noise source was from a superior or inferior floor
			33% declared it to be one of the types of noise which most generates annoyance (traffic of planes and cars, air conditioner, etc.)

normative minimum, a fact that was also perceived by the users through the low privacy perception of the insulation provided by the partition.

The external walls, however, obtained the minimum normative performance, although in a not very effective way, since it is just 2 dB better than the normative minimum, and nevertheless, the great majority of the interviewed users declared the perception of a low acoustic insulation and more than half emphasized the noise coming from outside the building as the most noticed, showing the low normative rigor with regard to these partitions. As a palliative, it is suggested that despite the subjectivity in the choice of the noise class from the acoustic performance of the façade,

Table 3. Linear regression y = a + bx, where y is the annoyance and x are the measured parameters.

Parameters	ny[a]	nx[b]	r	R^2	p-values	a	b	95% Confidence interval (b)
$D_{nT,w}$ (walls)	26	3	0.582	0.339	0.002	3.048	−0.035	[−0.055, −0.014]
$D_{2m,nT,w}$	44	3	0.551	0.304	0.000	−25.121	1.091	[0.577, 1.605]
$D_{nT,w}$ (slabs)	32	2	0.763	0.582	0.000	−8.649	0.248	[0.170, 0.327]
$L'_{nT,w}$	32	2	0.763	0.582	0.000	140.377	−1.987	[−2.615, −1.359]

[a]Number of samples from the valid surveys.
[b]Number of samples from the measurements.

it should be assumed that all buildings located in urban surroundings fall into class III, requiring, in this way, more from the constructors, although it cannot be said that this measure would in fact provide the acoustic comfort necessary to the users quality of life.

As far as slabs are concerned, it is clear that the regulatory requirements are not very strict when it comes to acoustic comfort. Despite the good acoustic performance obtained, most of the interviewed users declared not to notice the acoustic insulation, and above all, a representative part of them is disturbed by the noise coming from those partitions.

Correlation between field results and surveys

This work enabled us to perform a statistical analysis fitting a linear regression between the field results and the answers of the surveys. Both the Pearson correlation coefficient (Pearson-r) and the coefficient of determination (R^2) were calculated in association with their p-values in the correlation analysis.

Table 3 presents the results of the linear regressions for each of the four carried out tests, where the coefficients of the linear equation (y = a + bx) can be extracted, the dependent variable y being the annoyance with the noise and the independent variables x being the measured parameters.

The results obtained for the R and R^2 of the parameters $D_{nT,w}$ (slabs) and $L'_{nT,w}$ are the same because the answers of the surveys (y) are the same. The low coefficient of determination obtained by the $D_{nT,w}$ (walls) and $D_{2m,nT,w}$ was expected.[15,16,35]

The higher correlation coefficient obtained for the $D_{nT,w}$ (slabs) and $L'_{nT,w}$ may suggest that in concrete slabs, the users' annoyance regarding noise from this type of partition is more noticeable than in the others. In fact, the correlation shows a clear perception of the users regarding this annoyance, which demonstrates a fragile point in the criteria established by the norm in relation to the acoustic comfort coming from this structural element. It was considered that a coefficient of determination value greater than 0.50 was significant because the mathematical model explains over half of the variability in the variable response.

Jagniatinskis et al.[36] analyzed the results of approximately 2000 measurements, and although the authors had only analyzed the favored data, of occupant which evaluated their acoustic comfort level as poor, they found a good correlation for $L'_{nT,w}$ (0.93). Some studies obtained a low correlation for noise impact on slabs;[16,35,37] however, these values have been improved by adopting the "low-frequency" spectrum adaptation terms, especially $C_{I;20\text{–}2500}$ when dealing with systems composed mostly of lightweight partitions. Although it was not the goal to analyze the correlation between the descriptors and the subjective perception, Monteiro et al.[15] demonstrated by investigating lightweight and heavyweight partitions that their results indicate a low correlation of $R_{A,50\text{–}5000}$, and the authors suggest that one should disregard the frequencies below 100 Hz and focus exclusively on the frequency range 100–3150 Hz. Based on these authors, we can conclude that the good correlation obtained for the slabs in this article is in agreement with what has been found in the literature, although a more thorough research is still necessary. It should be emphasized that due to the results found in the literature, which concerns the good correlation obtained, probably the Brazilian norm is correct in not requiring "low-frequency" spectrum adaptation terms for buildings with heavyweight partitions.

Conclusion

NBR 15575[1] represents a very important milestone in the sense of improving the quality of the habitation offered to the consumer, and yet, almost 4 years after its publication, this work shows that much still needs to be done in order to fulfill all its requirements.

It should be noted that the recent Brazilian standard establishes acoustic performance levels which are inferior than most international standards. However, as this work has shown, the analyzed buildings do not meet the criteria stipulated by the Brazilian standard, thus it is meaningless to think of performing an analysis of the acoustic performance of Brazilian buildings using the international standards, which are more stringent.

Although this work does not present a conclusive character, since it would be necessary to obtain a larger number of samples for a national representativeness, this research allows one to obtain an indicative of actions that could improve the acoustic performance of buildings, aiming mainly at the comfort of its users.

Despite the low correlations found for the internal and external walls (0.399 and 0.304), some users claimed to fell discomfort due to noise transmitted through these structures. However, the high correlation levels of the slabs (0.582) show a clear perception of the building habitants in relation to the transmitted noise. Therefore, the data demonstrate the need to adapt the standard to meet the needs of the users.

In this sense, some possible suggestions for implementation by the agents involved in the process are suggested: on the part of the builders, they should improve the acoustic performance of the internal and external walls to be more confident to meet the normative criteria and to improve the acoustic comfort to external noises. In relation to NBR 15575,[1] it is suggested that the latter may adopt more stringent minimum values regarding the impact noise performance of slabs, using, for example, international values as suggested by Rasmussen.[11]

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References

1. Brazilian Association for Technical Standards (ABNT). NBR 15575-1:2013: residential buildings—performance part 1: general requirements.
2. SÃO PAULO Law no. 8.106, of 08/30/1974. Rules on urban sounds, levels and hours in that will be allowed the emission of sounds in the different areas of use and activities, and other provisions. São Paulo, SP, 1974, http://cmspbdoc.inf.br/iah/fulltext/leis/L8106.pdf (accessed 18 May 2016).
3. Brazilian Association for Technical Standards (ABNT). NBR 10151:2003: acoustics–evaluation of noise in inhabited areas, aiming the comfort of the community–procedure.

4. Brazilian Association for Technical Standards (ABNT). NBR 10152:1987: noise levels for acoustic comfort–procedure.
5. Institute of Technological Research of the State of São Paulo (IPT). *Formulation of criteria for performance evaluation of housing*. Report no. 16.277, 1981. São Paulo: IPT.
6. Mitidieri Filho C. *Performance evaluation of innovative components and constructive elements for housing: specific proposals for the evaluation of structural performance*. PhD Thesis, Polytechnic School of the University of São Paulo (USP), São Paulo, 1998.
7. Baring J. Sustainability and acoustic control of the environment. *Acoust Vib* 2007; 38: 3–8.
8. Silva A, Sorgato M, Mazzaferro A, et al. Uncertainty of the NBR 15575–1 simulation method in assessing the thermal performance of dwellings. *Ambiente Construído* 2014; 14(4): 103–117.
9. Almeida Y and Reinaldo R. Thermal performance analysis of buildings: a case study in Palmas-TO. *Desafios* 2016; 3(2): 14–25.
10. Ferreira C, Souza H and Assis E. Discussion of the limits of the thermal properties of building envelopes according to Brazilian thermal performance standards. *Ambiente Construído* 2017; 17(1): 183–200.
11. Rasmussen B. Sound insulation between dwellings—requirements in building regulations in Europe. *Appl Acoust* 2010; 71(4): 373–385, http://dx.doi.org/10.1016/j.apacoust.2009.08.011
12. Neto M and Bertoli S. Acoustic performance criteria in residential buildings. *Acústica E Vibrações* 2011; 43: 19–29.
13. ISO 717-1:2013. Acoustics—rating of sound insulation in buildings and of building elements—part 1: airborne sound insulation.
14. ISO 717-2:2013. Acoustics—rating of sound insulation in buildings and of building elements—part 1: impact sound insulation.
15. Monteiro C, Machimbarrena M, Prida D, et al. Subjective and objective acoustic performance ranking of heavy and light weight walls. *Appl Acoust* 2016; 110: 268–279.
16. Ljunggren F, Simmons C and Öqvist R. Correlation between sound insulation and occupants' perception—proposal of alternative single number rating of impact sound, part II. *Appl Acoust* 2017; 123: 143–151.
17. COST Action TU0901: integrating and harmonizing sound insulation aspects in sustainable Urban housing constructions, 2013, http://www.costtu0901.eu/
18. Brazilian Association for Technical Standards (ABNT). NBR 15575-3:2013: residential buildings—performance part 3: requirements for floor systems.
19. Brazilian Association for Technical Standards (ABNT). NBR 15575-4:2013: residential buildings—performance part 4: requirements for internal and external wall systems.
20. ISO 16283-1:2014. Acoustics—field measurement of sound insulation in buildings and of building elements—part 1: airborne sound insulation.
21. ISO 16283-2:2015. Acoustics—field measurement of sound insulation in buildings and of building elements—part 2: impact sound insulation.
22. ISO 16283-3:2016. Acoustics—field measurement of sound insulation in buildings and of building elements—part 3: Façade sound insulation.
23. ISO 3382-2:2008. Acoustics—measurement of room acoustic parameters—part 2: reverberation time in ordinary rooms.
24. Fringuellino M and Smith R. Sound transmission trough hollow brick walls. *Build Acoust* 1999; 6(3): 211–224.
25. Nannipieri E and Secchi S. The evolution of acoustic comfort in Italian houses. *Build Acoust* 2012; 19(2): 99–118.
26. Litwinczik V. *Acoustics of buildings: floors acoustic performance*. Florianópolis: Animacustica, 2012, p. 19.
27. Pereyron D, Santos J and Pizzutti J. Ribbed slab: acoustic performance analysis for impact noise. In: *IX national meeting on comfort in the built ambient (ANTAC 2007)*, Ouro Preto, 8-10 August 2007.
28. Silva O, Jr and Silva A. Acoustic scenery behavior in buildings in northeastern Brazil—results of case studies. In: *Symposium of mortars and coating thermal solutions*, Coimbra, 5-6 June 2014.

29. Secchi S, Fausti P, Garcia T, et al. How building technology in Italy and Spain can be improved after the experience of COST Action TU0901 and the discussion on going on the new descriptors. In: *Forum Acusticum*, Krakow, 7–12 September 2014.
30. Namba S, Kuwano S, Kaku J, et al. Proposal of fundamental items for social survey on noise problems. *Acoust Sci Tech* 2010; 31(2): 124–128.
31. Zhang M, Kang J and Jiao F. A social survey on the noise impact in open-plan working environments in China. *Sci Total Environ* 2012; 438: 517–526.
32. Meng Q, Kang J and Jin H. Field study on the influence of spatial and environmental characteristics on the evaluation of subjective loudness and acoustic comfort in underground shopping streets. *Appl Acoust* 2013; 74: 1001–1009.
33. Vieira S. *Como elaborar questionários*. São Paulo: Atlas, 2009.
34. Brazilian Association for Technical Standards (ABNT). NBR 15575-6:2013: residential buildings—performance part 6: requirements for hydrosanitary systems.
35. Ljunggren F, Simmons C and Hagberg K. Correlation between sound insulation and occupants' perception—proposal of alternative single number rating of impact sound. *Appl Acoust* 2014; 85: 57–68.
36. Jagniatinskis A, Boris F, Mickaitis M, et al. Features of sound classification scheme designated to label buildings in Lithuania. *J Civ Eng Manag* 2017; 23(3): 409–420.
37. Späh M, Hagberg K, Bartlomé O, et al. Subjective and objective evaluation of impact noise sources in wooden buildings. *Build Acoust* 2013; 20(4): 193–214.