Acoustic Performance and Reverberation Time of Walls Partitions in Educational Institution Classrooms

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***Abstract*— This article aims to evaluate the walls partitions of educational institution classrooms in relation to acoustic performance and reverberation time, whose methodology includes data collection in 26 classrooms in three buildings, according to the specifications of ISO 16283-1 (ISO 2014) and ISO 717-1 (ISO 2013) and compiled using the software dBBati. The acoustic performance results were analyzed in relation to international references in Portugal, United Kingdom, USA and New Zealand and the reverberation times in relation to Brazilian standard. Besides that acoustic performance and reverberation time were analyzed in relation to size classrooms and dimensions of the windows. The results correspond to 46 measurements, 17 to internal walls partitions and 29 to façades. The values obtained ranged from 41 to 49 dB (internal) and 22 to 34 dB (external), corresponding to 41% approved internal walls partitions and 24% approved external walls partitions. Beyond the influence of the size rooms and the dimensions and the opening of frames were confirmed to acoustic performance and the reverberation time values obtained. These results indicate that a significant portion of the classroom walls partitions aren't approved in relation to acoustic performance, implicating the intelligibility of speech and the learning process of students.**

***Index Term*— acoustic performance, walls partitions, classrooms, reverberation time.**

I. Introduction

The results of deficient approach are present in buildings, including the noise and its power to interfere in the environment and health and quality of life of the population [19, 27].

The sound pollution can cause annoyance, sleep disorders, cardiovascular diseases, loss of cognitive performance in children and the hearing loss. About 56 million people - approximately 54% - of the population living in cities of up to 250,000 people are exposed to air noise exceeding 55 dB in Europe [10, 17].

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The reference [6] state that noise can interfere in school activities carried out by the student, especially in school performance and understanding of the program content. Also, they complements saying that the occurrence of complaints of teachers in relation to the voice rise to compensate the internal and external noise (corridors), causing irritability, fatigue, difficulty concentrating, headaches and tinnitus.

The World Health Organization (WHO) establishes human exposure limits, which subsidized admissibility limits in many countries, including Brazil [28].

The references [29] and [30] present, respectively, the procedure for evaluation and the acceptable noise levels for the acoustic comfort of some constructions, including schools.

The auditory comfort of the individuals in a building is what allows the quality of the activities. The construction systems and materials must have adequate acoustic performance to meet this need [31]

The background noise and sound insulation are also relevant for privacy of speech evaluation, an important requirement for some users, which can be controlled in the acoustic design of rooms. [14]

Within this context, this work describes the experimental evaluation 26 classrooms of 3 buildings in the northeast Brazilian education institution, analyzing the acoustic performance of external and internal walls partitions.

II. The Acoustics in Buildings

A. *The acoustic performance in educational institutions*

The architectural acoustics aims at the minimum isolation, involving a correct planning to control the noise tolerable inside the buildings [27, 32].

The ambient noise or air is transmitted through the air by successive waves of pressure generated by speech or loudspeakers [8].

The walls partitions are relevant for airborne noise control, whose constitution and installation determine the insulation in the built environment [20, 23].

The sound insulation of walls partitions can reduce the external noise at the classroom. The characteristics of classrooms influence the acoustics of these environments [12, 20, 26].

B. *Acoustic performance variables*

The constitution and the installation of walls partitions and floors determine, largely, acoustic performance in the built environment [23].

The reference [21] complements saying that the reduction in density of the wall partition can promote a reduction in insulation due to the law of mass.

The window frames also have an influence on acoustic performance. The use only of thicker glass, not constitute such a significant contribution due to behavior of the components system [8, 9]. Furthermore, the type of opening can contribute to isolating or not too [20].

Another important variable is the form of the environment that includes a sense of bulk, having properties such as shape, size and texture [13].

The format refers to the characteristic contour of a particular shape. The size relates to the three measures, length, height and width. Finally, the texture is the tactile and visual quality of the surfaces and are associated with the absorption of sound waves [1, 12, 13].

C. Acoustic performance parameters

The experimet can be performed in the field or in the laboratory with specific parameters [16].

The acoustic performance evaluate of walls partitions in relation to airborne noise in the building has as parameters the weighted standardized level difference (Dnt,w) and the weighted standardized level difference at 2 m (D2M,nT,w), respectively, for internal and external walls partitions [16].

The Weighted Sound Reduction Index (Rw) is parameter for the laboratory evaluation [16].

The field experiments have the objective of verifying the sound insulation in buildings already completed; while laboratory experiments aim to predict the behavior of the system with more accurate and with superior results at field results [9, 27].

The field evaluation may present variables that contribute to the unsatisfactory result, since as laboratory conditions are better controlled [24, 27, 33].

In the case of residential buildings, the Brazilian standard [3] establishes the evaluation criteria of these parameters. However, in other types of buildings, for example the educational institutions, there isn't Brazilian standards, requiring the search for international references.

D. The field parameters

The field parameters depend on the sound pressure levels in the reception and emission environments, background noise and reverberation time [24].

The reference [15] presents the Equation (1) for the field parameters ($D_{nt,w}$ or $D_{2m,nt,w}$) that are obtained through difference in sound pressure levels between the source and receiving rooms (D) and the reverberation time in the receiving room (T) and the reference reverberation time for dwellings (T_0).

$$DnT = D \ + 10log\,(T/T0)\ (1)$$

The background noise, according to the reference [15], is the sound pressure level in the privation of noise generated by the loudspeakers, and must be at least 6 dB (or preferably 10 dB) below the source noise and background combined, considering all frequencies.

The reference [15] defines the reverberation time (RT) as the time required for the sound pressure level falls to 60 dB after the source has ceased.

The reference [12] complements that each room has a great reverberation time, which varies depending on use and size room.

For classrooms, the standard [4] recommends great times reverberation below 0.5 s.

The reverberation excess hinders communication between teacher and students, affecting the learning process [18].

Reverberations long time compared to the great time generate overlapping sounds; while short tend to disappear. They are responsible for good or bad acoustics of a rooms and associated with understanding or speech intelligibility. The speech intelligibility is the ability to recognize the acoustic signal issued by the speaker [5, 12, 25].

III. Methodology

A. Characteristics of case study

This experimental study aimed acoustic performance evaluate and reverberation time carried out in 1 educational institution located in the Metropolitan Region of Recife (RMR), a city in northeastern Brazil, thereabout 2 km from the city center.

The choice of this institution considered the accessibility of the site due to proximity to the city center as well as the interest of the directors who authorized the tests. The buildings selected were B, I and K, because they have high frequency of use, as shown in Figure 1.

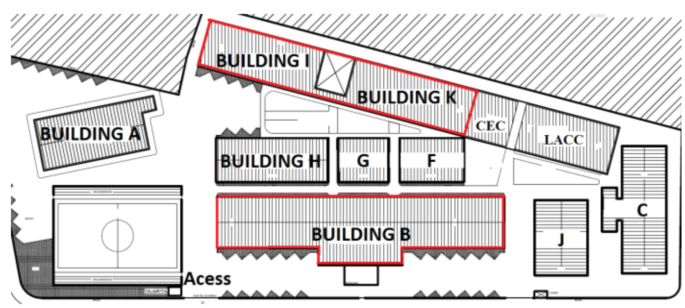

Fig. 1. Buildings analyzed

The building B has 2 floors, 1 downstairs and 1 upstairs (Figure 2), with classrooms with ceiling height of 3.65 m.

Fig. 2. The building B

This building is located the administrative sector, copiers and Academic Directory (AD). The layout of downstairs is shown in Figure 3.

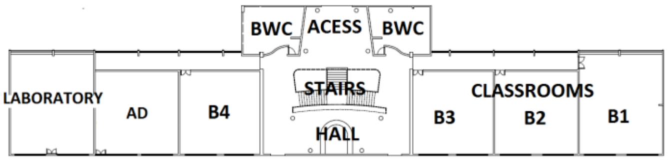

Fig. 3. The layout of building B

The buildings I and K are interconnected buildings with 4 floors, 1 downstairs and 3 upstairs (Figure 4), the same construction standards and the same architectural layout.

Fig. 4. The layout of buildings I and K

This building has a main circulation giving access to classrooms, shown in Figure 5.

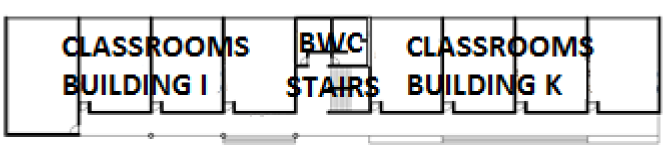

Fig. 5. The layout of buildings I and K

The classrooms analyzed buildings totaling 26 units and are in traditional masonry of ceramic block with mortar.

The walls are all coated with mortar and paint, but the rooms of the buildings I and K still have ceramic coating to 1.20 m.

The laboratories weren't considered, which restricted the testing only classrooms.

The characteristics of frames window were monitored frames per building in Table I.

TABLE I
CHARACTERISTICS OF WINDOW AND DOOR FRAMES OF BUILDINGS

Building	CLASSROOMS	Characteristics
B	B1	2 fixed windows (2,90 x 1,55 m) 1 wood door with 2 frames (2,25 x 1,17 m)
B	B2, B3, B4	2 fixed windows (2,90 x 1,55 m) 1 wood door with 2 frames (2,25 x 0,98 m)
I e K	All	1 sliding window with 6 frames (6,60 x 1,60 m) 8 window maxim-ar (0,40 x 0,40 m) 1 wood door with 1 frames (2,10 x 0,90 m)

B. The measuring equipment

The measuring equipment used in tests was made available by the laboratory of the educational institution, shown in Figure 6, which presents the following components, as shown in Table II.

Fig. 6. The measuring equipament

TABLE II
THE MEASURING EQUIPAMENT

COMPONENTS	Characteristics
1 Microphone	Collect noise emission and reception and reverberation time for further analysis and compilation with dBBati software.
1 Calibrator	Verify calibration of the microphone, acoording to manufacturer's specifications.
1 Loudspeakers	Responsible for issuing white noise
Software dBBati 01 dB	Compilation of field data and generation of results.

C. The test procedure

The tests were performed according to the procedures of the references [15] and [16] in the afternoon - between 12 h and

16 h - except for the building B, which was conducted between 18h and 21h. The choice of the time considered the availability of rooms.

The reference [15] recommends the positions of the microphone during the test, well as the minimum distance is 0.5 m from any surface, 0.7 m between unaligned measurements and 1 m of loudspeaker.

The microphone positions were distributed within the maximum permitted space throughout central zone of room. No two microphone positions shall not be in a regular grid [15].

The software dBBati requires 1 emission spectrum, 1 reception spectrum; 1 reverberation time spectrum and background noise to calculate the parameters $D_{nt,w}$ and $D_{2m,nT,w}$, according to reference [15].

Therefore, in relation to the number of measurements per experiment: 1 source measurement; 4 receiving measurement and 4 background noise; plus 2 reverberation time for experiment the internal walls partition. The placement of microphones, for example, is present in Figure 7 for internal walls.

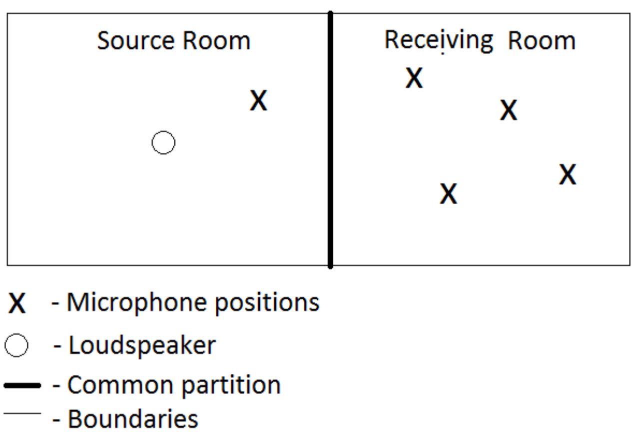

Fig. 7. Loudspeaker and microphone positions example for internal walls

As for the external walls partitions, only the receiving measurements and background noise were changed, which totaled 3 measurements per experiment (Figure 8).

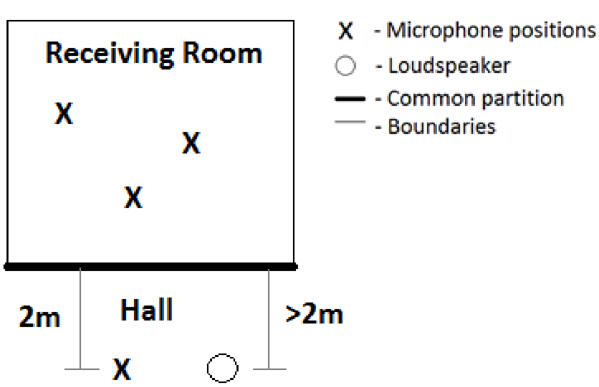

Fig. 8. Loudspeaker and microphone positions example for external walls

The number of receiving measurements equals the number of results per experiment. So it was obtained 4 results by each internal walls partitions; while the external walls partitions were obtained 3 results. Adopted the minimum value as a single value representative of the acoustic performance for each walls partitions, either internal or external.

Furthermore, dBBati software requires a minimum difference of 6 dB between background noise and reception noise, according to that standard specifications. Otherwise, the data can't compile and generate the results, as shown in Figure 9.

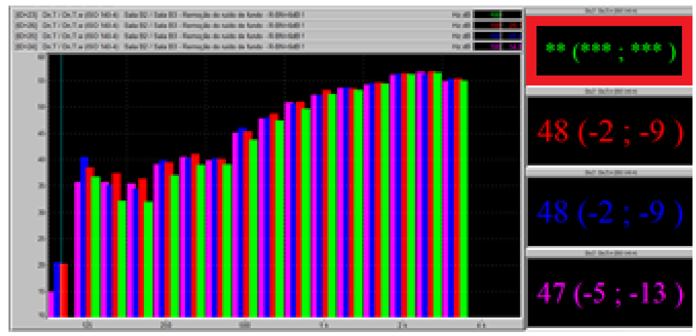

Fig. 9. The measuring equipament

D. The analysis of results

The results of acoustic performance were compared with the criteria established in international references, including: the Decree-Law 96/2008 of Portugal [22]; the reference guide for UK design schools [11] published in 2003; American Standard for school architecture [2]; the New Zealand standard [7].

TABLE III
CRITÉRIA ACCORDING TO INTERNATIONAL REFERENCES

PARAMETERS	Portugal	United Kingdom	USA	New Zealand
Dnt,w	45 dB	45 dB	48 dB	48 dB
D2m,nt,w	30 dB	45 dB	43 dB	-

Table III presents a summary of the above criteria.

In addition, the reverberation times were also obtained via software dBBati 01 dB, as shown in Figure 10.

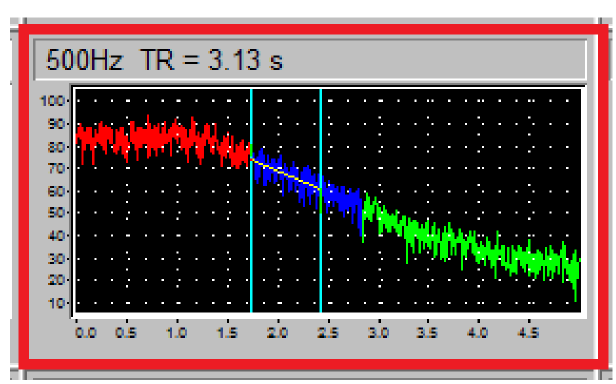

Fig. 10. Time reverberation to 500 Hz frequency

These reverberation times to 500 Hz frequency in receiving rooms of walls partitions analyzed were compared with the optimum reverberation time recommended in standard [4], which is 0.5 s, to ensure the speech intelligibility in these environments.

The results of acoustic performance and reverberation times were also analyzed for the following acoustic variables: room size and window frames.

IV. Results And Discussion

A. *Internal walls partitions*

In Table IV, the internal walls partitions with 4 acoustic performance results are identified for each of the 4 receiving measurement by experiment. For these results, the minimum value was identified (Dnt,w), featuring the wall partition, and the reverberation time obtained to 500 Hz.

TABLE IV
DNT,W AND REVERBERATION TIME OF INTERNAL WALLS PARTITIONS

Building	Wall partition	Value 1 (dB)	Value 2 (dB)	Value 3 (dB)	Value 4 (dB)	Minimum (dB)	RT (s)
B	I1	48	49	48	49	48	3,31
	I2	47	*	48	48	47	3,13
I	I3	45	47	47	45	45	1,67
	I4	45	47	48	45	45	1,81
	I5	45	46	47	46	45	2,56
	I6	46	47	47	47	46	2,95
	I7	48	47	48	47	47	3,42
	I8	44	45	45	45	44	1,65
	I9	42	43	41	43	41	0,51
K	I10	*	44	44	43	43	2,68
	I11	44	44	44	44	44	1,55
	I12	44	44	44	44	44	2,7
	I13	43	43	43	43	43	2,39
	I14	41	41	41	41	41	3,36
	I15	43	43	43	43	41	1,76
	I16	43	44	43	44	43	2,67
	I17	44	43	44	44	43	2,36

The walls partitions 2 and 10 have an asterisk, it means that the software failed to compile and generate the result. This is due to the difference between the background noise and receiver is less than 6 dB.

The minimum criteria required is 45 dB at [22] and [11], concluding that approximately 41% of internal walls partitions present comply results.

However, if the references are [2] and [7], the comply results tend to reduce this percentage to 6%, as the minimum criteria for the acoustic performance becomes 48 dB.

Analyzing the reverberation times obtained in the reception room at 500 Hz frequency, also shown in Table IV, none of the rooms had values less than 0.5 s recommended for classrooms, according to the standard [4].

The average results of Dnt,w and RT for the building were also analyzed in relation to the size of classrooms, as Table V. Note that the largest size of the building B classrooms may have contributed to the better results of acoustic performance.

TABLE V
SIZE OF CLASSROOMS

Building	Dnt,w (dB)	RT (s)	Size (m³)
B	47,5	3,22	279
I/K	43,8	2,27	154

However, larger environments also favor the reverberation times, impairing intelligibility of speech.

B. *External walls partitions*

In Table VI, the externa walls partitions with 3 acoustic performance results are identified for each of the 3 receiving measurement by experiment. For these results, the minimum

TABLE VI
D2M,NT,W AND REVERBERATION TIME OF EXTERNAL WALLS PARTITIONS

Wall partition	Value 1 (dB)	Value 2 (dB)	Value 3 (dB)	Minimum (dB)	RT (s)
E1	33	34	34	33	1,79
E2	30	32	32	30	3,20
E3	31	32	32	31	3,34
E4	30	31	32	30	2,50
E5	26	26	25	25	1,79
E6	28	28	28	28	3,20
E7	28	28	28	28	3,34
E8	22	22	22	22	2,50
E9	26	29	29	26	2,30
E10	30	27	29	27	1,45
E11	33	32	31	31	2,13
E12	31	31	32	31	2,20
E13	28	29	29	28	3,28
E14	28	30	30	28	3,22
E15	32	32	32	32	2,85
E16	26	26	26	26	1,80
E17	25	27	27	25	1,97
E18	25	26	26	25	2,29
E19	24	24	24	24	0,40
E20	26	26	26	26	1,82
E21	25	26	25	25	2,41
E22	25	24	25	24	2,11
E23	24	24	24	24	2,04
E24	24	24	23	23	2,50
E25	23	23	23	23	2,58
E26	26	26	26	26	2,53
E27	27	27	26	26	2,17
E28	23	23	23	23	2,71
E29	23	23	23	23	3,30

value was identified (D2m,nt,w), featuring the wall partition, and the reverberation time obtained to 500 Hz frequency.

The minimum criteria required is 30 dB per [22], it follows that approximately 24% of the external walls partitions are in accordance with the minimum criteria required acoustic performance.

However, if the references are the britanic guide [11], which criteria is 45 dB, and the US standard [2], which criteria is 43 dB, no wall partition comply the criteria.

Analyzing the reverberation times obtained in the reception room at 500 Hz frequency, also shown in Table VI, note that just wall partition 19 showed a value of less than 0.5 s recommended for classrooms, as the standard [4].

The average results of $D_{2m,nt,w}$ and RT for the building were also analyzed in relation to the window and door frames of classrooms, as Table VII.

TABLE VII
AREA OF WINDOW AND DOOR FRAMES IN RELATION TOTAL AREA (%)

BUILDING	D2m,nt,w (dB)	RT (s)	Total area (m²)	Frames area (m²)	Relation (%)
B	28,40	2,70	288	11,4	4
I/K	26	2,30	200,5	13,7	6,83

Note that the contribution of the frames in the total area of the receiving rooms of building I / K may have contributed to the worst results of acoustical performance, as well as lower reverberation times.

In addition, the window frames of this buildings are sliding windows; while the window frames of building B are fixed, which may have influenced the performance.

V. CONCLUSION

This paper presents an experimental study of the acoustic performance measurement in walls partitions (internal and external) of an educational institution. It was established that a significant portion of the walls partitions aren't in accordance with international criteria - the portuguese reference [22], the britanic guide [11], American standard [2] and New Zealand standard [7] - for educational institution classrooms.

It was found that the 17 internal walls partitions tested, 41% were in accordance with Portuguese reference [22] and the Britanic reference [11] - less demanding - and only 6% with the American standard [2] and NZ [7].

In relation to the 29 external walls partitions (facades) tested, 24% are in accordance with portuguese reference [22] - less demanding - and that no meets US standard [2] and Britanic reference [11].

It's important to note that the absence of Brazilian standard governing minimum criteria of acoustic performances for non-residential units favors the buildings without planning and projects in this area.

The reverberation times were high in relation to 0.5 s recommended, harming the intelligibility of speech.

There is the influence of window frames on acoustic performances of classrooms, particularly in relation to their size and the type of opening; well as the environmental geometry, favoring or not the reverberations that compromise the intelligibility of speech.

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