MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Classroom acoustics in large universities: the replication of standardized design and poor acoustical quality

Alves, Luciana[1]
Federal University of Rio Grande do Norte
1545 Jairo Tinoco St, Lagoa Nova, Natal, RN, Brazil

Araujo, Bianca[2]
Federal University of Rio Grande do Norte
1985 Antídio de Azevedo Street, apt. 801, Lagoa Nova, Natal, RN, Brazil

ABSTRACT

People use speech to establish communication, sharing information, knowledge and stories. But the act of speaking and listening is no guarantee of a clear understanding of what is being communicated. Schools are places of learning where speaking and listening are primary methods of communication. In Brazil, it is a common practice to design a standard classroom and replicate the same room throughout the school or university, even public or private. The objective of this study was to measure the acoustical quality of standardized classrooms in two federal universities in Natal, Rio Grande do Norte, Brazil, in order to investigate acoustical similarities or differences between standardized classrooms. To evaluate the acoustic quality of these classrooms, it was compared the reverberation time measured in similar rooms, according to measurement techniques, architecturally equal rooms and volume variation as a function of ceiling height. The methodology consisted of an architectural survey, impulsive response measurements (with MLS and pink noise in omnidirectional source and with balloon pop) and a comparative among the results obtained between the classrooms evaluated. The analyzed classrooms have low acoustic quality regarding the intelligibility parameters, presenting similar reverberation time in rooms with equivalent architectural characteristics. The changes in reverberation time were considered insignificant in similar rooms with different ceiling height and, consequently, different volumes between them. Regarding the measurement techniques used, the results were quite approximate, which demonstrates a validation of any of the techniques used to measure the impulse response.

Keywords: Classroom acoustics, measurements, acoustical quality.
I-INCE Classification of Subject Number: 70

1. INTRODUCTION

The communication is only established if a clear understanding of the speech is guaranteed and the architecture has a great influence on it. A speech produced in an enclosed space must be comprised by every person in the room, regardless of where they occupy it. When considering a classroom, this is a fundamental feature to achieve in the

[1] luciana_ralves@hotmail.com
[2] dantasbianca@gmail.com

room, for the sake of accomplishing the main function on this kind of room: the teaching-learning process. In Brazil, the lack of adequate acoustical conditions in scholar rooms is considered chronic [1]. Also, it is common the replication of the same classroom throughout the school or university during the design process of new buildings or extensions, repeating the poor acoustical quality. Thus, much more students are submitted to bad sound quality, what impair the learning process.

When the message is not clearly listened by the students, the comprehension of the speech is affected and, hence, the learning process is impaired [2], justifying why the voice intelligibility is so important in a classroom. Bad acoustical quality in these rooms are a barrier to the learning, as this injures the oral communication, fundamental in this ambience. In Brazil, in general, the acoustic quality is not consider in classrooms design.

The reverberation time is the parameter that most characterize a room and represent the time that the sound remains audible after the sound source mute [3]. Brazilian standards do not have recommendations of reverberation time for classrooms. The standards of United States of America suggest 0,6 second in 500, 1000 and 2000 Hz for rooms with a volume lesser than 283m³ [4]. [5] proposes a value between 0,4 and 0,8 second in general and [6] suggests 1 second or less to classrooms and lecture rooms, concluding that, for a better intelligibility, 0,8 second should be consider the ideal time.

Following [7] recommendations to find out the ideal reverberation time in each octave considering the frequency of 500 Hz, the values presented below were calculated as ideal reverberation times per frequency for the kind of classrooms analysed in this study, considering 0,6 second for 500 Hz.

Table 1 - Ideal reverberation time per octave for classrooms.

Frequency [Hz]	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Recommended RT [s]	0,9	0,7	0,6	0,6	0,6	0,5	0,5

As for the human voice, the most representative frequencies are from 80 to 500 Hz. Although the sound energy of the voice sounds is distributed between 100 and 10000 Hz, predominantly between 200 and 6000 Hz [7].

The objective of this study was to characterize acoustically the standard classrooms in two federal universities in Natal, Rio Grande do Norte, Brazil, through acoustic measurements. In order to evaluate the acoustic quality of these classrooms, it was compared the reverberation time measured in similar rooms, according to measurement techniques, architecturally equal rooms and volume variation as a function of ceiling height.

2. METHODOLOGY

2.1 Characterization of the universities

This study was applied in two federal and public universities in a way to analyse how the high taxes charged in Brazil return to the population who have access to universities. Both universities have many campuses throughout the state, but both campuses chosen for this study are based in Natal, the principal city of Rio Grande do Norte state, located in Brazilian northeast.

The first university analysed was the Federal Institute of Rio Grande do Norte (IFRN), which was founded in 1910 as a technical school and added higher education courses in 1999 in their scope. Nowadays, there are 21 campuses of IFRN among the state with 12 undergraduate and six postgraduate courses in the campus called Natal-Central, the focus of this study.

This campus is located in an important corner of the city and has a central building with one for with rooms used by the administration and two floors of architecturally standardized classrooms used by all the courses offered by the institution. Classrooms of these two floors were used in this study. This building is highlighted in the figure bellow.

Figure 1 - The subdivision of IFRN Natal-Central campus.

The other university studied in this paper was the Federal University of Rio Grande do Norte, created in 1958 and the first campus was installed in the current location ten years later. The central campus is divided in five academic centres, each of them gathering the undergraduate and postgraduate courses correlates with each study area. There are 84 undergraduate and 86 postgraduate courses in the whole university.

When this campus was built, each academic centre had a complex of buildings with classrooms, called "sectors". As the university grew, others sort of buildings were constructed and the origin sectors were expanded with new buildings reproducing the same kind of architecture, including materials and dimensions. Thus, the same architecturally standardized classrooms were replicated with no significant changes. In the figure bellow, the sectors with classrooms for theorical classes are highlighted. This study was applied in the Sector IV, which houses technological courses.

Figure 2 – The subdivision of UFRN Central campus.

2.2 Characterization of the standardized classrooms

The classrooms analysed were chosen according to dimensions, shape, proportion between width and length, volume, location in the building and representative quantity of this classroom throughout each university (considering, so, that this is a standardized classroom in the institute).

In IFRN, two sorts of classrooms were analysed, however one of them have more significantly repetitions. So, this is the only kind of classroom considered for this study. With square shape, this sort of classroom is repeated in both floors of the academic building. However, in the second floor (called “Floor B”, Figure 3) the height of the rooms is smaller than in the third floor (called “Floor C”, Figure 4).

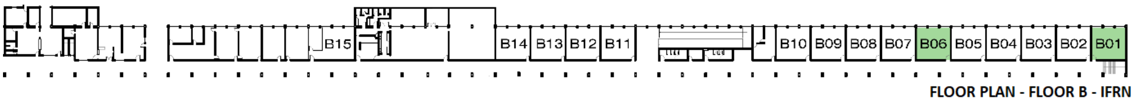

Figure 3 - Floor plan of "Floor B" with classrooms studied highlighted in light green.

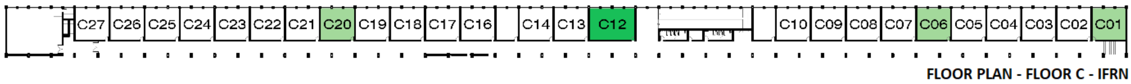

Figure 4 - Floor plan of "Floor C" with classrooms studied highlighted in light green.

The classrooms have a brick wall painted in the upper portion with ceramic coating in the lower part, student carts with polypropylene chair and wood table, canvas blinds covering glass windows and a glass chalkboard, as shown in Figure 5.

Figure 5 - Standardized classroom in IFRN.

In UFRN, the sectors have a modulate structure, that allows some kinds of standardized classrooms. The sector chosen presents classrooms with the same width and five different lengths (Figure 6), what occurs with among all sectors in UFRN. Three sorts of classrooms were studied: 2 modules (G03) and 3 modules, with (I02) and without (A03 and B02) absorbent ceiling. For this study, the rooms chosen were A03 and B02, both with same shape in floor plan, but different heights.

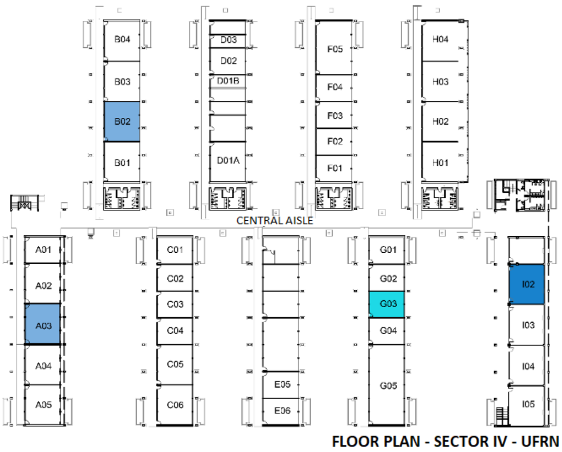

Figure 6 - Classrooms studied in UFRN.

The classrooms in UFRN have a brick wall painted, student carts with wood or polypropylene chair and wood table, glass windows and a glass or white board, as shown in Figure 7.

Figure 7 - Standardized classroom in UFRN.

2.3 Measurements method

The measurements occurred in a typical day, without rain or external noises, following the recommendations given by ISO 3382-2 [8]. For each classroom, one position of sound source was combined with four positions of receivers, according to Figure 8.

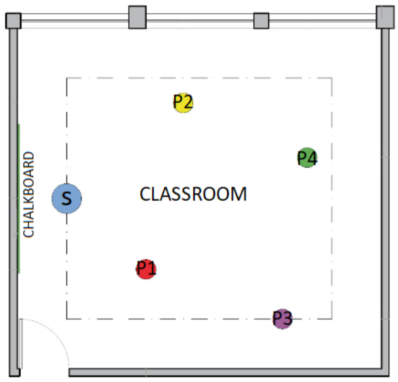

Figure 8 - Sound source and receivers' positions.

Three kind of measurements were made: with pink noise generated by the hand-held analyzer, with MLS signal generated by the software DIRAC version 6.0 from

Bruel&Kjaer and with a balloon pop. For each receiver position, three decays were analyzed in each sort of measurement.

3. RESULTS

The measurements were performed in 05 classrooms in IFRN and 04 classrooms in UFRN. For this study, the results presented consider classrooms B06 and C06 in IFRN or the average in all classrooms studied grouped by floor. In UFRN, only classrooms A03 and B02 were considered for this study in due to the similarity of the floor plan shape with IFRN classrooms.

3.1 Acoustical quality of the classrooms

As said before, the microphone (receiver) was positioned in four locations in each classroom and the average of three decays were considered as the result for each position. As an average for the classroom, all positions were contemplated. The graphs below represent the results in each receiver position, as well as the classroom average and the ideal values for the reverberation time in classrooms.

It is possible to see in the graphs below (Figure 9 until Figure 12) that none of the evaluated classrooms are in good condition when the reverberation time is the analysed parameter. The subtitle for the graphs colours is presented below them.

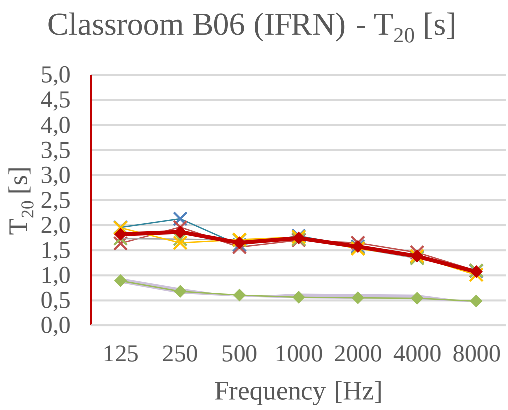

Figure 9 - Comparison between the ideal and the measured RT in classroom B06.

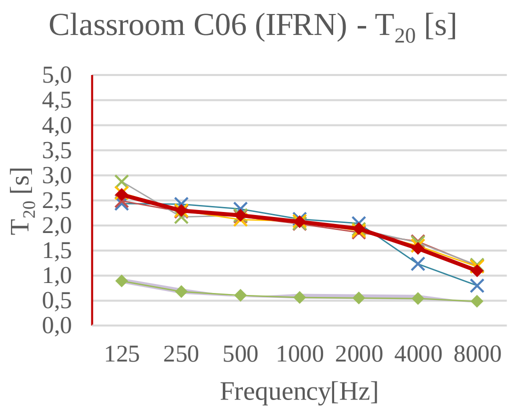

Figure 10 - Comparison between the ideal and the measured RT in classroom C06.

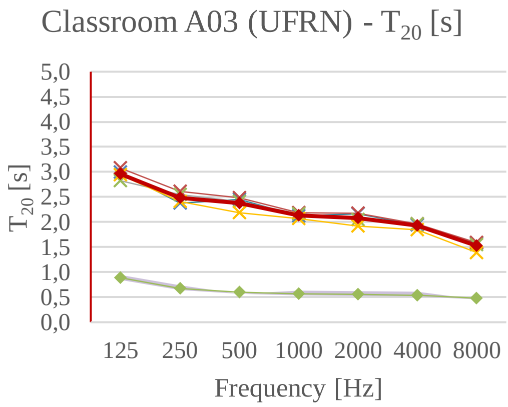

Figure 11 - Comparison between the ideal and the measured RT in classroom A03.

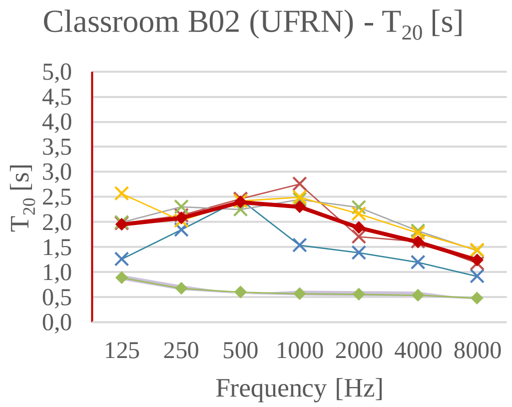

Figure 12 - Comparison between the ideal and the measured RT in classroom B02.

Receiver positions: P 01 P 02 P 03 P 04 Average

Recommended values: JND Ideal Reverberation Time

3.2 Comparison between measurements techniques

Due to a verification of the results, three techniques methods were used in the classrooms of IFRN. The aim was to validate the results provided by the software DIRAC using MLS signal, since it was not possible to use an e-sweep signal by reason of a small Impulse Response to Noise Ratio (INR) obtained during the measurements.

According to the graphs presented below (Figure 13 and Figure 14), the techniques evaluated suggest that the results of the measurement with MLS signal is reliable. So, it was possible to analyse other room acoustic parameters provided by DIRAC software.

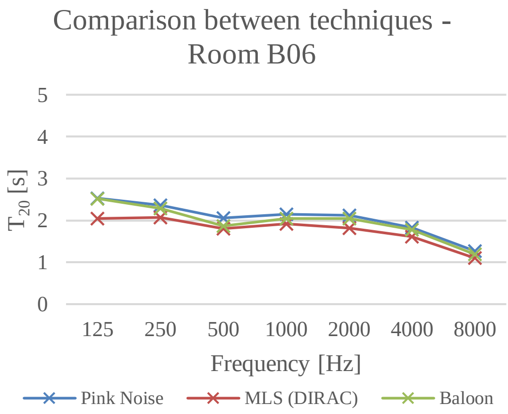

Figure 13 - Graph comparing the results measured with different techniques in Room B06, IFRN.

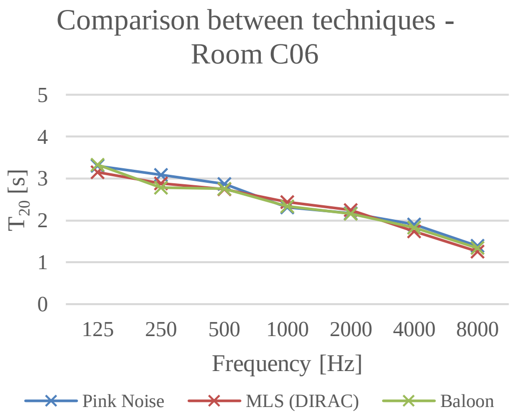

Figure 14 - Graph comparing the results measured with different techniques in Room C06, IFRN.

3.3 Comparison between architecturally equal rooms

In order to certify if it could be possible to measure the reverberation time in only one classroom and consider the same results for all classes with the same architectural features, the similar classrooms in IFRN, both in Floor B and Floor C, had the RT measured with MLS signal and compared accordingly to their group. The classrooms B01 and B06, located in the Floor B, had the T20 measured in each room compared between each other, as well as the classrooms C01, C06 and C20, in the Floor C.

The results, presented in Figure 15 and Figure 16, show the same tendency of behaviour in all frequencies measured, with quite similar results for the rooms on Floor B and with irrelevant differences for the rooms C01 and C06 on Floor C and most relevant in comparison to room C06, mainly in bass frequencies. These variations may occur due to the differences in some materials, as the type of ceramic and student charts, as well as the number of charts. The average line, however, presents the same behaviour among the frequencies.

Thus, small variations can be seen in rooms apparently identical with some differences mainly in low and medium frequencies, but, still, they are not so relevant. Hence, the acoustical quality results of one classroom can be used to describe all standardized classrooms with the same features.

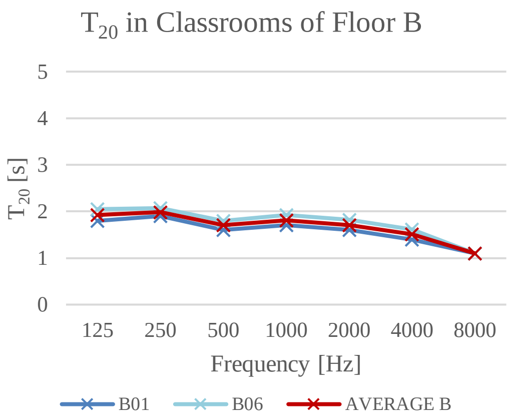

Figure 15 - Graph comparing the RT in standardized classrooms, type B.

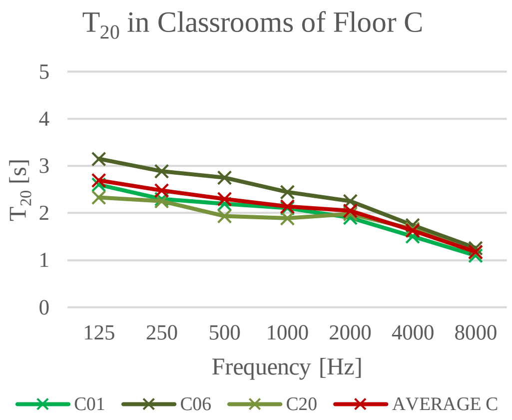

Figure 16 - Graph comparing the RT in standardized classrooms, type C.

3.4 Comparison between two classrooms with volume variation as a function of ceiling height

The classrooms located in Floor C in IFRN are 0,70m higher than that ones in Floor B. The same happens in UFRN, being the classroom A03 0,28m higher than B02. In both cases, due to the floor plan shape and measures, the volume variation is 35m³. With the aim of finding out if this volume variation represents a significative difference in the reverberation time, the T20 average of the B and C classrooms (IFRN) were compared, as well as the A03 and B02 classrooms (UFRN).

In IFRN classrooms (Figure 17), the most relevant difference occurs in low frequencies, mainly in 125 Hz, which varies 0,5 seconds. From 1000Hz, the difference is not significative, considering that the JND (Just Noticeable Difference) for T20 is 0,2 second. As the height alteration of 0,70m, only the frequencies with larger wave-length present audible differences. Since the prevalent sound in classrooms is the human voice, this discrepancy can be considered not relevant.

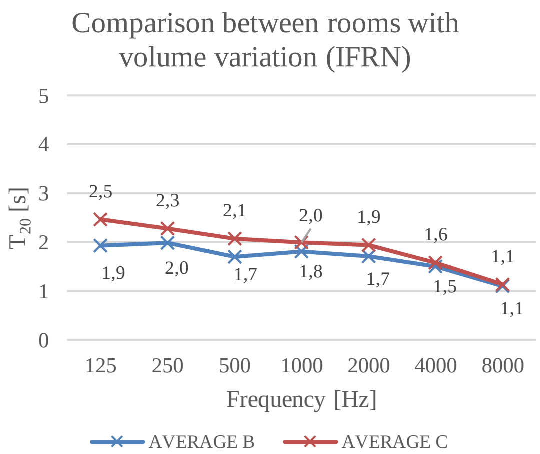

Figure 17 - Graph comparing the reverberation time results between classrooms B and C.

In UFRN classrooms (Figure 18), the height alteration is smaller, and the most significative variation occurs in low frequencies, which have larger wave-lengths. From 250 Hz, the most expressive fluctuation is 0,3 second, that happens in 4 kHz, and is contemplated in the JND to reverberation time. In 125 Hz, the variation is 1,1 second and, although is a high difference, given due consideration to the main use of voice it can be disregarded.

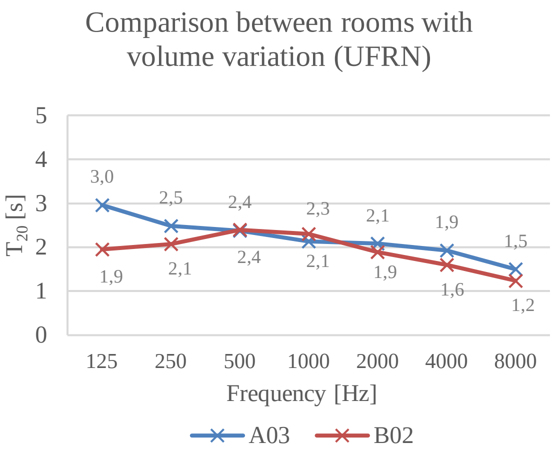

Figure 18 - Graph comparing the reverberation time results between classrooms A03 and B02.

Therefore, it can be concluded that the variation of 35 m³ in function of alteration in the ceiling height do not change the reverberation time in a relevant amount, mainly in the frequencies of the human voice. Considering the JND, the difference founded in most frequencies cannot be distinguish by the human ears.

4. CONCLUSIONS

After all these studies and comparisons, it can be concluded that all classrooms evaluated have a bad acoustical quality with reverberation times much higher than the recommended by standards and other studies. In some of them, it was possible to perceive the reverberation during a normal conversation between the measurement procedures.

It is also possible to consider the MLS as a reliable signal when the INR is not guaranteed. The measurements with pink noise and balloon pop provided similar results and the same tendency of behaviour in the graphs among the frequencies. In order to analyse standardized classrooms, the measurements can be performed in only one room and the results considered for all classrooms with the same features. Also, small variations of volume caused by differences in the ceiling height are considered not so significant for this kind of room, which have approximately 300 m³.

Therefore, considering IFRN and UFRN classrooms, it is recommended a study for the improvement of acoustical quality in these kinds of rooms, aiming the replication of the solution in these standardized rooms. It is fundamental to prioritize a good acoustical quality, as well as good intelligibility, in classrooms since the conception of the architectural design (creation, remodelling or enlargement), in the interest of enhance the learning process for all students, only adjusting the architectural characteristics of the classrooms.

5. ACKNOWLEDGEMENTS

We acknowledge gratefully the Coordination of Improvement of Higher-Level Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES) for the scholarship granted.

6. REFERENCES

[1] D. C. C. K. Kowaltowski, D. C. Moreira, e M. S. Deliberador, “O Programa Arquitetônico No Processo De Projeto: Discutindo a Arquitetura Escolar, Respeitando O Olhar Do Usuário”, in *Simpósio Brasileiro de Qualidade do Projeto no Ambiente Construído,* 2012.

[2] G. C. Jaroszewski, B. S. Zeigelboim, e A. Lacerda, “Ruído escolar e sua implicação na atividade de ditado”, *Rev. CEFAC*, vol. 9, nº 1, p. 122–132, 2007.

[3] H. Kuttruff, *Room acoustics*, 5ª. Abingdon: Spon Press, 2009.

[4] (ANSI) American National Standards Institute, *Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools - Part 1: Permanent Schools.* United States, 2010, p. 28.

[5] A. C. Isbert, *Diseño acústico de espacios arquitectónicos*, 1º ed. Edicions UPC, 1998.

[6] M. Long, *Architectural Acoustics*. Burlington: Elsevier, 2006.

[7] S. R. Bistafa, *Acústica aplicada ao controle do ruído*, 2º ed. São Paulo: Blucher, 2011.

[8] Standard International Organization, “Iso 3382-1”, *Int. Organ. Stand.*, vol. 2009, p. 34, 2009.