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## COBEM-2017-2152 EVALUATION OF ROOMS ACOUSTIC CONDITIONS FOR MUSIC TEACHING

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**Abstract.** *The spaces used for music teaching and practice must be acoustically appropriate so the musicians who use these enclosures are able to perceive the musical sound with quality. In order to acoustically distinguish enclosures reserved for musical teaching and practice in an institution, studies and measurements have been carried in 17 music classrooms and an auditorium for musical performance from data obtained from acoustic impulse response measurement following ISO 3382-1: 2009 recommendations. The acoustic parameters were determined by the reverberation time (RT), early decay time (EDT), clarity (C80), definition (D50) and speech transmission index (STI). In addition, musicians' who occupied these rooms informed their perception about the acoustic quality through a questionnaire. Overall, it can be said that the rooms are somewhat reverberant, requiring changes within in order to improve the sound quality so that the musicians can perform better.*

**Keywords:** *room acoustics, musical acoustics, acoustic quality, clarity.*

### 1. INTRODUCTION

The acoustic quality of a music room is directly related to several sound impressions that occur in the room (FIGUEIREDO, 2005). The determination of acoustic parameters in these rooms can be obtained through on-site experimental tests or even through computer simulations. It can be affirmed that the musical perception and as a result the quality of the music played are directly affected when the place used for the study is not appropriate.

When acoustics are for musical purposes, the definition of a suitable acoustic environment is a little more complex, since theory and singing classes require different conditions than instrument practice ones, for example. In the first case the purpose of the environment is to facilitate speech comprehension. In the second parameters such as reverberation time become essential.

Many of the places for teaching and music practice are not designed for this specific purpose, which can hinder the development of the musician. According to the renowned cellist Mstislav, a good room is as important as a good instrument (SÁ, 2010).

Studies conducted in the USA and England indicate that the implementation of an acoustic project for a building implies an additional cost on the order of 3% of the total budget of the work (RIBEIRO, 2008).

### 2. AIM

The aim of this article is to present the results obtained for the acoustic characterization of rooms and an auditorium used for teaching of music in a university by analyzing the parameters of Reverberation Time (RT), Early Decay Time (EDT), Clarity (C80), Definition (D50) and Speech Transmission Index (STI). From measurements of the acoustic impulse response in each room, it will be presented in this article the requirements of quality, energy and speech intelligibility for those enclosures.

### 3. METHODOLOGY

This article was divided into three main stages. First, the dimensions and materials of the enclosures were studied. Also at this stage, a questionnaire was applied to the users of the rooms (students and professors) in order to compare what had been obtained in the acoustic measurements and the user's preference concerning the acoustic condition of the rooms. After that, acoustic measurements were made in the rooms to determine the acoustic parameters: TR, EDT, C80, D50 and STI. The last stage consists on the treatment of the data from the measurements and the analysis of their results.

### 3.1 Description of Music Rooms

The rooms and the auditorium analyzed are placed on a two floors building. On the first floor are the registry room; the auditorium; rooms 1, 2, 3 and 18. On the upper floor, it is possible to find the other rooms. They are separated in collective study rooms (7, 8, 10, 12 to 16) and individual study rooms (4 to 6, 9 and 11). Table 1 presents information regarding the geometric characteristics of the enclosures. The rooms designed for the individual study or test for small groups of musicians have a volume between 22,87 m<sup>3</sup> and 47,79 m<sup>3</sup>. The practice rooms for large groups as well as regular classrooms have volumes between 114,87m<sup>3</sup> and 175,60m<sup>3</sup>.

The auditorium has the largest volume among all the rooms evaluated in this article. With a total volume of 221,36 m<sup>3</sup>, it attends periodic recitals of students, as well as rehearsals of the string orchestra of the university. The rooms have floor plans in rectangular format, with parallel surfaces to the north-south and east-west. The ceiling height of the rooms is 3,30m, except for the auditorium whose height is variable in the sitting area.

The environment around the places under study is characterized in most part by the parking lot that attends to those who study and work in the institution. The building is also connected to the other departments of the campus - courses in scenic and visual arts, design and fashion.

Table 1. Description of the geometric characteristics of the rooms from the music department under analysis

Room	Geometric characteristics (m <sup>3</sup> )			Room	Geometric characteristics (m <sup>3</sup> )		
	Dimension	Area	Volume		Dimension	Area	Volume
DMU 01	3,19 x 4,54 x 3,30	14,48	47,79	DMU 10	3,30 x 4,32 x 3,30	14,26	47,04
DMU 02	4,44 x 7,84 x 3,30	34,81	114,87	DMU 11	2,28 x 5,72 x 3,30	13,04	43,04
DMU 03	5,80 x 9,10 x 3,30	52,78	174,17	DMU 12	6,78 x 7,86 x 3,30	53,29	175,6
DMU 04	2,12 x 3,28 x 3,30	6,95	22,95	DMU 13	6,78 x 7,86 x 3,30	53,29	175,6
DMU 05	2,12 x 3,28 x 3,30	6,95	22,95	DMU 14	4,50 x 7,83 x 3,30	35,24	116,28
DMU 06	2,12 x 3,28 x 3,30	6,95	22,95	DMU 15	4,50 x 7,83 x 3,30	35,24	116,28
DMU 07	3,24 x 4,40 x 3,30	14,26	47,04	DMU 16	4,50 x 7,83 x 3,30	35,24	116,28
DMU 08	3,24 x 3,24 x 3,30	10,5	34,64	DMU 18	2,10 x 3,30 x 3,30	6,93	22,87
DMU 09	2,14 x 3,22 x 3,30	6,89	22,74	Auditorium	7,80 x 8,60 x 3,30	67,08	221,36

### 3.2 Preparation of questionnaires for students and professors

The questionnaires were placed in the hall of the building where teaching and musical practice rooms are located between the months of May and June 2015.

Without any identification, the user should classify the rooms considering the acoustic preferences of each room taking into account the audience perceptions of the instrument performed in this place, indicate if adjacent rooms transferred some type of noise and, if so, which ones; which instruments could easily be heard outside the rooms. The ordinal and qualitative scale to classify the room preference used five levels, being: 1 (very bad) 2 (bad), 3 (regular), 4 (good) and 5 (great).

For those musicians who had already used the auditorium, it was asked about the sound fold back of the instrument on the stage; whether there were internal and / or external noises that hampered recitals and, if so, which ones. It was asked to identify the instrument they use, the average weekly hours practiced and, the opinion of each one for what would be a suitable environment for the study of music.

Of the interviewees, 40% were pianists, 15% violinists, 12% singers and the other musicians were divided between students of viola, cello, acoustic bass, guitar, electric guitar, percussion and wind instruments.

### 3.3 Acoustic Tests

The acoustic impulse response of the rooms under study was obtained through acoustic measurements according to ISO 3382-1: 2009 standard. The measurements were defined considering the volume of the enclosure.

The sound pressure meter SOLO was connected to the laptop, and data processing was performed with the software for measurement of acoustics in buildings dBATI32 (2002). "Figure 1" shows the equipment (microphone, sound pressure meter and software) and the generator source of the impulse (giant balloon) used to obtain the acoustic response of the room. Acquisition of the acoustic signal and its processing enabled the parameters TR, EDT, C80, D50 and STI to be obtained for each room in the octave frequency bands 125 - 8.000 Hz.

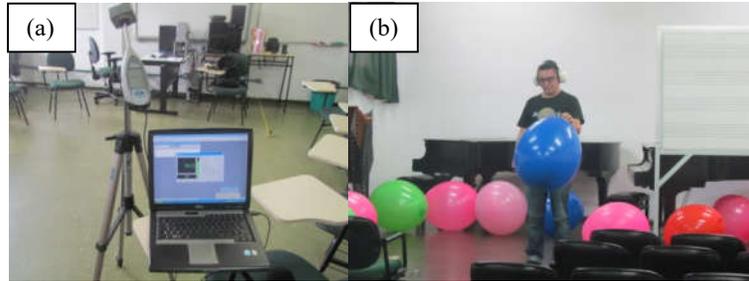


Figure 1. SOLO equipment installed to measure acoustic parameters (a); generator source – giant balloon bursting (b)

The sound pressure meter was placed on a specific area of the enclosure and the positioning for balloons bursting varied according to the volume of the room. For rooms with a volume of  $28 \text{ m}^3$  or less, at least one bursting position has been performed. For volumes close to or larger than  $330 \text{ m}^3$ , as the auditorium, four impulse response generation points were performed. It should be noted that for each bursting position, two repetitions were made, in a total of three measurements. This is recommended in ISO 3382-1: 2009 standard for the reliability of the results. The microphone and sound source were respectively 1,2 and 1,5 m away from the ground. All the microphone positions were at least 1,0 m away from the walls.

#### 4. RESULTS

Due to the number of enclosures analyzed and in order to facilitate the results, the rooms were grouped according to their volumes. Table 2 shows the four groups chosen, their type and the maximum and minimum ranges of volume.

Table 2. Grouping of rooms according to type and volume

Group	Type	Enclosures	Maximum and minimum values ( $\text{m}^3$ )
I	Individual/collective	4, 5, 6, 9 e 18	22,74 - 22,95
II	Individual/collective	1, 7, 8, 10 e 11	34,64 - 47,79
III	Group	2, 14, 15 e 16	114,87 - 116,28
IV	Group	3, 12, 13 and auditorium	174,17 - 221,36

##### 4.1 Reverberation Time (RT)

Reverberation time (RT) is defined as the time in seconds in which the sound pressure level in an environment decays 60 dB, after the interruption of sound source. The RT is directly associated with the volume of the room and the sound absorption of the materials and furniture inside it and exposed to the sound incidence.

Besides the possibility of obtaining the reverberation time by calculation, it can also be obtained from acoustic measurements. The experimental method adopted in this article consisted in obtaining for each evaluated enclosure the acoustic response to the impulse. The generation of the impulse was caused by the burst of giant balloons and using the sound pressure meter SOLO P for acoustic signal acquisition. The data were processed using dBBA132 (2002) software to calculate the acoustic parameters of each room: RT, EDT, C80, D50 and STI. The results obtained from RT for all rooms are presented in "Fig. 2", separated by groups according to the volume of the enclosures.

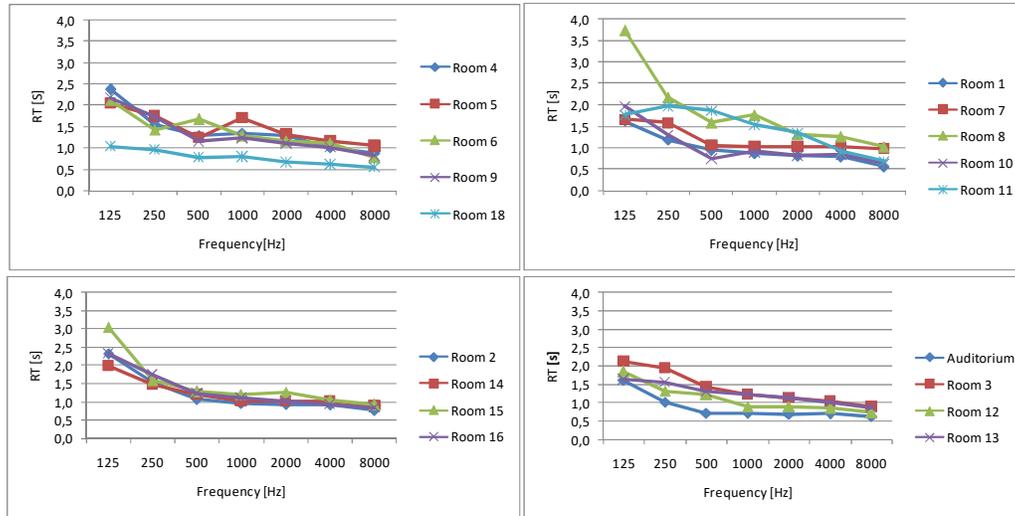


Figure 2. Reverberation time (RT) values in octave frequency bands (125-8.000 Hz) for each group of enclosures

When studying the acoustics of enclosures used for the music performance, it is relevant to point out that large concert halls and rooms for musical practice have different characteristics. Although both of them need to provide appropriate acoustic conditions, they become different when used. In addition, the user's perception changes according to the instrument studied, since the frequency bands are different.

Once the reverberation time values were obtained, they were analyzed according to the volume and frequency range and compared to the bibliography. According to Table 3, for rooms with a volume up to 30m<sup>3</sup> the appropriate RT would be around 0,6 seconds. Turning to “Fig. 2”, somewhat elevated values are easily observed for the first group of rooms. Only room 18 would be close to those recommended values, however, only for frequencies above 2.000 Hz.

Table 3. Average Reverberation Time for Practice and Music Teaching Rooms

Reference	Practice/group	Practice individual	Teaching (musical theory)	Frequency (Hz)
Lane e Mikeseika (1955)	-	0,4 a 0,7s	0,55 a 0,8s	100
Karsai (1974)	-	0,8s (105 m <sup>3</sup> )	-	125
Lambertv (1980)	-	0,5 a 0,9s (33-154 m <sup>3</sup> )	-	500
Nagata (1989)	-	0,3 a 0,5s (100 m <sup>3</sup> )	-	125-4k
Cohen (1992)	0,3 a 0,5s (30-40 m <sup>3</sup> )	-	-	125-4k
Teuber e Videker (1993)	0,2 a 0,6s (30-200 m <sup>3</sup> )	0,2 a 0,6s (30-200 m <sup>3</sup> )	0,2 a 0,6s (30-200 m <sup>3</sup> )	63-10k
ANSI S12.60-2002 (2002)	< 0,6s (38-150 m <sup>3</sup> )	< 0,6s (14-30 m <sup>3</sup> )	< 0,6s (120-210 m <sup>3</sup> )	500-2k
DRES (2002)	0,5 a 1,0 (33-150 m <sup>3</sup> )	0,3 a 0,6s (14-30 m <sup>3</sup> )	0,4 a 0,8s (120-210 m <sup>3</sup> )	500-2k
BB93 (2003)	0,5 a 1,2s (38-150 m <sup>3</sup> )	< 0,8s (14-30 m <sup>3</sup> )	< 1,0s (120-210 m <sup>3</sup> )	500-2k
Loiski e Salmensaari (2007)	0,7s (245 m <sup>3</sup> )	0,5 a 0,6s (10-120 m <sup>3</sup> )	0,5 a 0,6s (10-120 m <sup>3</sup> )	1k
Ryherd (2008)	0,8 a 1,0s	-	0,4 a 0,5s	1k

Source: Vergara et al. (2017)

For the second group of rooms, with a maximum volume of around 48m<sup>3</sup>, the situation is even more hindered, especially with low frequencies (< 250 Hz). Peaks of RT as generated in the band of 125 Hz for room 8 can be justified by the phenomenon of acoustic resonance (presence of axial acoustic modes); that occurs when the natural oscillation frequency of an object coincides with the oscillation of the sound source.

In enclosures with larger volumes as in the case of the auditorium the situation may also be considered inadequate, but in this case due to excess of absorption. Rooms for musical concerts and with volumes close to 220 m<sup>3</sup> have recommended RT values of 1,0 seconds (OSAKI AND SCHMID, 2009).

The sound condition provided by an enclosure causes different interpretations of what is heard. Through researches developed by Beranek (1962), preferences among experienced musicians are shaped according to the musical style – the music piece performed - in relation to the volume of the enclosure. Many of them claim that the performance of pieces such as Bach’s concertos become better in small rooms whose reverberation time is somewhat smaller. On the other hand, pieces like Toccata and Fuga from the same composer become better performed when executed in enclosures with long reverberation time. Such statement can be justified by the fact that high reverberation time contributes to silences being

filled by the previously played chords. The reduced reverberation time in this case would cause the piece to have long silence intervals, changing the fundamental peculiarities of the piece.

## 4.2 Early Decay Time (EDT)

Taking into account acoustics for musical purposes, another essential parameter for the analysis concerns the early decay time. The EDT is the time in seconds in which the sound energy decays 10 dB and it is measured in the same way the reverberation time is (BERANEK, 1996). While the reverberation time is directly associated with the physical aspects of the rooms, the EDT is linked to the listener's perception of the reverberation. As a parameter whose result is directly influenced by the measurement position, it becomes an excellent reference for the analysis of different sound perceptions depending on the positions inside an (closed) enclosure (MARROS, 2011).

Although there are no specific standards to determine appropriate values for initial decay time, it can take into consideration Beranek's studies which consider reference values between 2,25 and 2,75 seconds for an unoccupied room and values between 1, 4 and 2,0 seconds for less favored rooms.

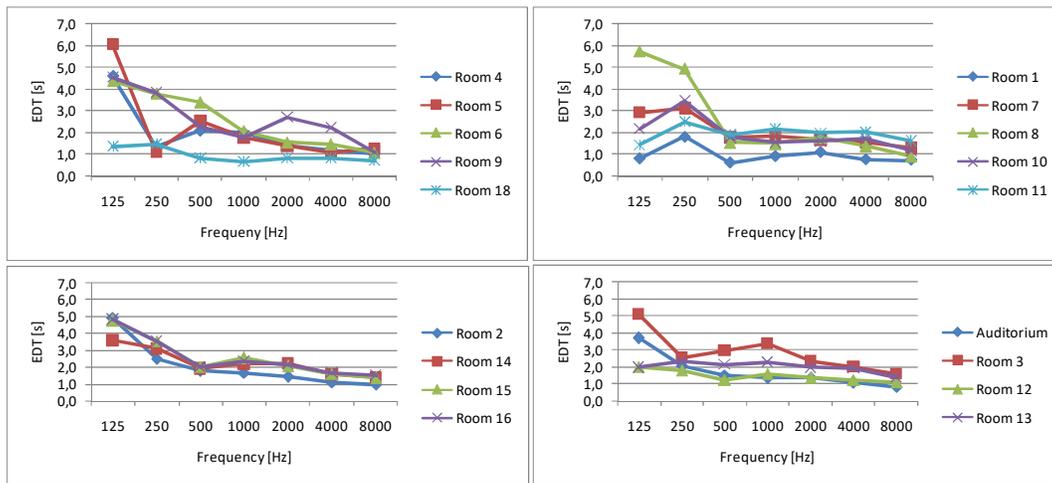


Figure 3. Initial decay time (EDT) values in the octave frequency bands (125-8.000 Hz) for each group of enclosures

According to information from “Fig. 3”, none of the enclosures presents a proper reverberation perception. Room 18 from group I is in particular the one that presents a lower perception of RT, by virtue of the higher absorption. This can be justified by the position of the room in relation to the others, as well as the presence of furniture with higher sound absorption coefficients. As already mentioned in the RT section lower values of reverberation time hinder musical environments, since the notes played end up causing sound sensations of isolated notes (as if there were excessive silence).

Also for “Fig. 3”, there are high values in the low frequencies, easily interpreted in rooms like number 8 from group II, reaffirming what was obtained in the data related to reverberation time.

## 4.3 Clarity (C80), Definition (D50)

The ease individual sounds can be distinguished during the execution of a song or the spoken word can be described by acoustic parameters as clarity and definition respectively.

Clarity presents different limits of time intervals when associated with musical perception and speech. When it comes to music its range is limited to 80 ms; and in the case of speech to 50 ms.

$$C80 = 10 \log \frac{\int_0^{80ms} p^2(t) dt}{\int_{80ms}^{\infty} p^2(t) dt} [dB] \quad (1)$$

$$D50 = \frac{\int_0^{50ms} p^2(t) dt}{\int_{50ms}^{\infty} p^2(t) dt} 100\% \quad (2)$$

Analytically, clarity and definition can be obtained by “Eq. (1)” and “Eq. (2)” respectively. In the study, these and the other analyzed parameters were obtained from the impulse acoustic response.

Music rooms have acceptable clarity when the results for this parameter can vary between -4 and +4 dB (BERANEK, 1996). For the definition, the closer to 100%, the more accurate will be the spoken word and the execution of a musical piece.

Both parameters are correlated and can be said that for low values of C80 and D50 the sound is qualified as indefinite and confusing. When the enclosure under analysis is considered a live room from the acoustic point of view the values of clarity and definition are higher than for dead reverberant rooms.

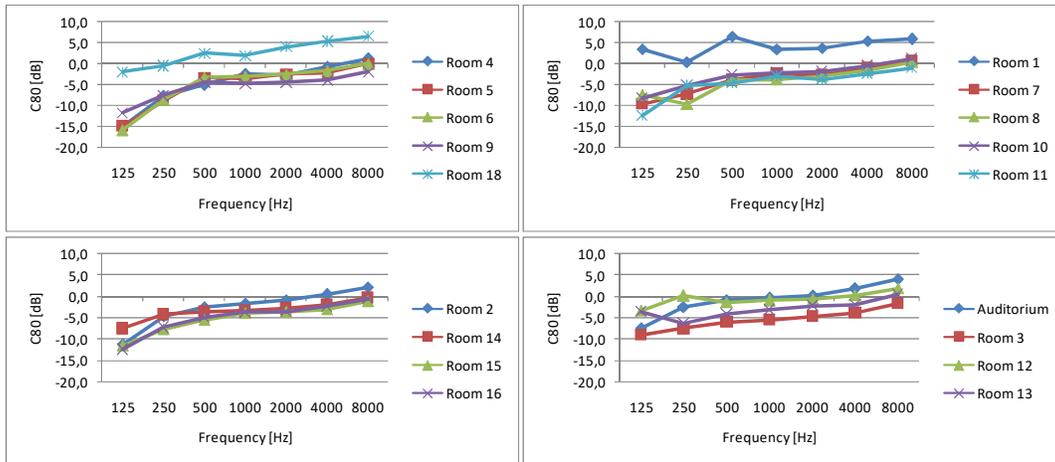


Figure 4. Clarity values ( $C_{80}$ ) in the octave frequency bands (125-8.000 Hz) for each group of enclosures

Analyzing “Fig. 4” it is possible to observe that none of the rooms present sound clarity ( $C_{80}$ ) for the set of evaluated frequencies. In rooms used for studying, as in group I (rooms 4, 5, 6, 9 and 18) and in group II (rooms 1, 7, 8, 10 and 11), almost all rooms present critical situations, most at low frequencies (125 and 250 Hz). Considering acceptable values between -4 to +4 dB (BERANEK, 1996), some rooms may reach values close to -15 dB for low frequencies. The rooms with lower RT values tend to have higher values of  $C_{80}$ , as is the case of room 18. This is one of the only enclosures that is closer to suitable conditions for study practice; although it can still be said that not for all music instruments (not even all frequencies) the situation remains similar.

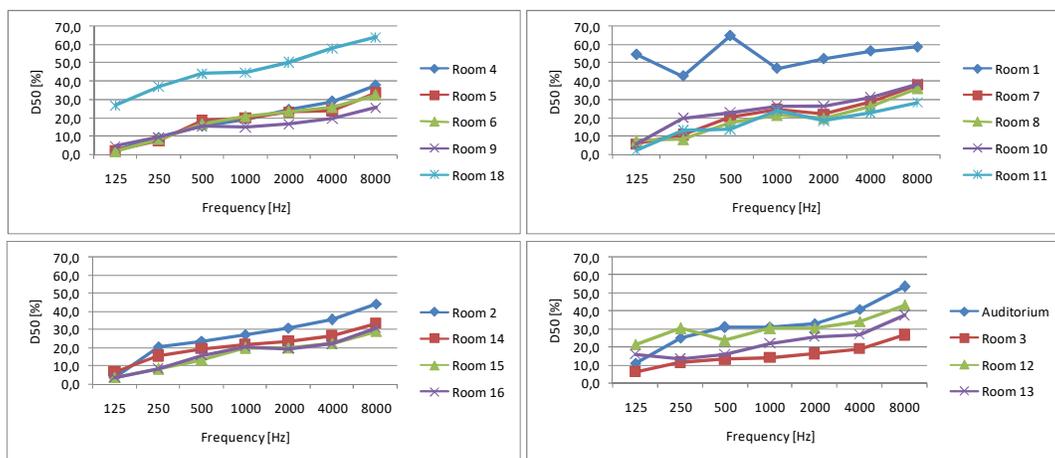


Figure 5. Definition Values ( $D_{50}$ ) in octave frequency bands (125-8.000 Hz) for each group of enclosures

“Figure 5” confirms the hypothesis that the enclosures do not guarantee an appropriate sound perception to distinguish between the sounds emitted. For the analysis of the definition it becomes even clearer that almost all rooms do not even reach 50% of what would be a good result for this parameter. This shows that the sound quality of speech is reduced. As for clarity parameter, rooms 1 and 18 present values less distant from those recommended in the bibliography. In the first room there are two grand pianos protected by blankets, a bookshelf, curtains, about ten cushioned chairs, and the piano chairs. If compared to the rest of its group room 18 also has a desk, a computer sound speakers and extra sound equipment.

The presence of additional materials with higher absorption coefficients is one of the reasons for the different results for these two rooms.

#### 4.4 Speech Transmission Index (STI)

The STI parameter can be justified due to the use of rooms for theory classes, singing and vocalization practices. The understanding of the syllables and understanding of what is spoken, in this case sung, becomes essential for the quality of enclosures used by singers for studying and rehearsing.

Table 4 shows the STI values calculated for each analyzed room and its classification according to IEC 60268-16 (2003) standard. The only room considered good for speech is room 18; which did not mean it is a good result for the practice and teaching of musical instruments.

Table 4. Classification of STI

Enclosure	STI	Classification	Enclosure	STI	Classification
Auditorium	0,55	Fair	Room 9	0,39	Poor
Room 1	0,48	Fair	Room 10	0,49	Fair
Room 2	0,49	Fair	Room 11	0,42	Poor
Room 3	0,38	Poor	Room 12	0,53	Fair
Room 4	0,43	Poor	Room 13	0,45	Fair
Room 5	0,42	Poor	Room 14	0,45	Fair
Room 6	0,42	Poor	Room 15	0,4	Poor
Room 7	0,46	Fair	Room 16	0,41	Poor
Room 8	0,43	Poor	Room 18	0,62	Good

Note then that the STI of collective rooms is in general better than for individual teaching rooms. This does not make it possible to state that larger rooms are in good condition for this parameter. It is important to emphasize that the STI is being analyzed in a broader way, without separation between singers according to the voice range (low or high frequencies).

#### 4.5 Background Noise

The acoustic measurements in the rooms and the auditorium were carried out in February of 2016, during the academic recess of the institution. The rooms were analyzed as isolated enclosures, it means that the individual and separate conditions of each were studied without taking into account the interference that one may cause in the other.

Even with no classes and activities during the on-site acoustic measurements process, the sound pressure level of the background noise was measured to complement the study. The values of these levels ranged from 33 dB(A) to 44 dB(A). These values are close to the recommendations of NBR 10152 (1987) standard for classrooms and auditoriums.

#### 4.6 Qualitative Analysis

When it comes to acoustics for musical purposes, the acoustic treatment of rooms is even more delicate, since the hearing sensation caused to different instrumentalists and different purposes for rooms (collective or individual study) affects their design conditions. A room designed for orchestra practice, for example, will not necessarily be satisfactory for the use of the spoken word, such as lectures and singing lessons.

Table 5 shows the result of the qualitative evaluation of the rooms according to the acoustic preference of the musicians. They should evaluate the rooms from 1 to 5 according to the acoustic condition. It is possible to note that for rooms with volumes lower than 50 m<sup>3</sup> users rated the acoustic preferences as poor (37,5-50%), or bad (20-30%). An extreme condition concerns room number 11, although its volume is larger than those analyzed in group I, it is the only room whose half of its walls are made up with glass. The rooms with volumes between 100 and 180 m<sup>3</sup> were classified as regular by 25% of the musicians.

Table 5. Percentage evaluation of preference and quality of rooms

Room	Room quality					Volume (m <sup>3</sup> )
	Very bad	Bad	Regular	Good	Great	
DMU 01	41,67	25,00	20,00	7,00	6,33	47,79
DMU 02	45,00	17,50	25,00	7,50	5,00	114,87
DMU 03	40,00	20,00	27,50	7,50	5,00	174,17
DMU 04	47,50	30,00	17,50	2,50	2,50	22,95
DMU 05	50,00	27,50	20,00	2,50	0,00	22,95
DMU 06	50,00	27,50	20,00	2,50	0,00	22,95
DMU 07	50,00	27,50	20,00	2,50	0,00	47,04
DMU 08	37,50	27,50	22,50	7,50	5,00	34,64
DMU 09	37,50	27,50	22,50	7,50	5,00	22,74
DMU 10	37,50	27,50	22,50	7,50	5,00	47,04
DMU 11	65,00	20,00	10,00	5,00	0,00	43,04
DMU 12	45,00	20,00	25,00	5,00	5,00	175,60
DMU 13	45,00	17,50	25,00	7,50	5,00	175,60
DMU 14	45,00	17,50	25,00	7,50	5,00	116,28
DMU 15	45,00	22,50	25,00	7,50	0,00	116,28
DMU 16	45,00	22,50	25,00	7,50	0,00	116,28
DMU 18	45,00	30,00	20,00	5,00	0,00	22,87
	Group	I	II	III	IV	

In the questionnaire applied a special section was made for analysis of the auditorium. Of the interviewees, 90% stated that external noise interferes in the music presentation. Among the noises mentioned it can be observed: conversations in the external area, sound from other rooms, rehearsal of the choir and even the noise of a lawn mower. As far as internal noise is concerned, it does not affect musical performances. Of those interviewed, 50% say they are hampered by the noise from the internal air conditioning device, 25% say they are indifferent and the rest say they do not feel harmed. Still with regard to the auditorium, 55% of the musicians say they do not have a good sound fold back of the instrument on the stage.

In general, the musicians evaluated the rooms both individually and in groups as acoustically reverberant; which coincided with the values of reverberation time and early decay time measured as presented in sections 4.1 and 4.2.

## 5. SUMMARY AND CONCLUSIONS

The acoustic characterization of classrooms and auditorium used for teaching and musical practice was obtained from measurements of their acoustic response to the impulse. The results of the acoustic parameters (TR, EDT, C80, D50 and STI) from the 18 evaluated rooms indicate that the acoustic quality references were not satisfactory. This shows that these enclosures need acoustic improvement to achieve better conditions as recommended for the development of musical activities (teaching and practice), especially with regard to reverberation times, musical clearness and speech intelligibility.

The 18 rooms evaluated were separated into four groups according to the air volume and the musical activity developed in them (individual or groups). In general, the rooms were categorized as small rooms (volume less than 50 m<sup>3</sup>) and medium rooms (volume between 100 and 180 m<sup>3</sup>). Small defined rooms were acoustically classified as poor and bad by most musicians (around 70% of opinions). The medium rooms were classified as acoustically regular by 25% of the musicians.

Preferences and opinions mentioned by musicians, for the musical execution enclosures, were confirmed by the results of the acoustic parameters (TR, EDT, C80, D50 and STI) according to the measurements performed in each one.

## 6. ACKNOWLEDGMENT

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