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ACOUSTICAL COMFORT IN CLASSROOMS - CASE STUDY AT THE UNIVERSITY OF BRASÍLIA

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ABSTRACT

The acoustic conditions in school spaces are fundamental for the success of the learning process. This article aims to present the results of acoustic comfort by the analytical method of 9 classrooms with different geometric characteristics of the University of Brasília. In classrooms the background noise limits are 40 to 50dBA and considering that the teacher's voice reaches a certain 65 decibels we can highlight that it can be heard clearly by the students. However in an environment with a lot of reverberation of sounds the teacher will have to exert more effort to be understood. The sound perception in a room depends on the intensity and temporal relationship between the direct sound and the indirect sound reflected by the walls of the room, therefore, in the present study were verified two parameters namely the reverberation time and speech intelligibility. The results obtained were compared with the normative parameters of ANSI S12.60: 2010 and it was verified that all rooms are not suitable for teaching-learning activity. To guarantee an environment with better conditions of concentration and learning for the students, acoustic coverings were suggested in order to fit the normative limits.

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INTRODUCTION

The noise present in a classroom on academic teaching interferes in student learning and occupational health of the teacher.

Many of the problems in classrooms can be aggravated by improper room acoustics. Acoustic parameters, such as reverberation rate and speech transmission index (STI), can be used to evaluate if a room is within the ideal standards for a good acoustic learning condition. As a baseline for the present assess, sound requirements from schools on some country was taken in consideration and can be used in projects for the construction of schoolrooms with adequate acoustics. However, in Brazil there is still no specific standard for classrooms.

In order to ensure a good acoustic condition, the performance of classrooms must be considered in the architectural project, achieving efficiency, and economic viability, since the space is destined to perform tasks that require a high level of concentration.

The intervention after the development or the acoustic correction after its construction, in general, does not allow simple solutions.

According to Uría (2005) the academics development and the performance of studies involves the interference of noise in the educational activities and school performance, in this case, the importance is the consequences of these effects on the students attention reduces both physical performance and intellectual.

On the other hand, we have the vocal problems of the teachers that, according to Uría (2005), are damages caused by the effort to improve the degree of intelligibility. Therefore, any problem in their ability to transmit knowledge will cause damage to the teacher and also to the students who will have greater difficulty in absorbing what is being said.

Uría (2005) analyzed six classrooms in a public school and concluded that all classrooms studied based on levels of sound pressure, background tone, reverberation time and speech intelligibility, and all classrooms seems inappropriate for an activity in which they are intended. while Ferreira (2010) analyzed 15 classrooms, of which 8 were built in the 1960s and 7 were built in the year 2000. the classes built in the 1960s, had satisfactory acoustic conditions, while the rooms built in 2000 did not achieved standards of usage.

Andrade (2009) determined the same parameters as Uría (2005), but in rooms of two types, one fixed and one modular, and concluded that the rooms are also inadequate. However, in its study, it was verified that such parameters can be corrected through the addition of acoustic materials.

The study by Guidini et al. (2012) had as objective to verify if there is a relation between the environmental noise with the intensity of the voice and vocal alterations of the teachers, through sound measurements. The results indicate that there is a relationship between environmental noise and vocal changes in 70% of teachers. The result of the sonic measurement, without students, was between 41 and 50 dB, and with the presence of the children, during the lesson, the sound level was between 45 and 65 dB, demonstrating that teachers increase the intensity of their voices due to environmental noise.

Zannin et al. (2013) conducted a study that had as objective to verify the noise levels within the Federal University of Paraná. Acoustic maps were performed to show that noise levels within the university exceeded the limit of Leq 50 dBA, which is above the current legislation.

All the studies presented confirm that the acoustic quality of the classrooms does not meet the normative limits and do not have the conditions necessary for these environments to fulfill their main objective, namely to provide means for an optimal level of learning, so in the present study, will be evaluated the classrooms of the University of Brasília in which they have different typologies.

REVERBERATION TIME

The definition of the reverberation time of an environment according to Sabine (1992) is the time interval, in seconds, that the sound pressure level leads to decay of 60 decibels (dB) from the interruption of the source.

Therefore, the greater the coefficient of absorption of the materials of the room the smaller the reverberation time of the environment.

According to Eniz (2004), when the classroom has reverberation above what is necessary, this effect negatively affects the speech signals, in which the reflected and direct sounds overlap occurs and, therefore, masks the messages intended by the teachers.

Obtaining the reverberation time values can be calculated by means of mathematical equations and measurements with adequate instrumentation as described in the methodology. The most widespread equation for the calculation of reverberation time appeared at the end of the 19th century. Harvard physics professor Wallace Clement Sabine studied the criteria for establishing satisfactory acoustic conditions and developed the first formula for calculating reverberation time, which was given his surname. The Sabine formula is given by Equation 1.

$$T_R = 0.163\,\frac{V}{\sum(S\alpha)}$$

Where:
Tr = room reverberation time (s);
V = room volume (m^3);
$\sum S\alpha$ = surface areas multiplied by the absorption coefficient

Sabine's pioneering work (1922) had a technique in which he used scaled-room models and photographic techniques to obtain a view of the propagation of sound waves in the rooms studied. Over time the models continued to be used while the photographic technique was replaced by laser-based techniques. The great difficulty in using these models in scale was the construction of models that did not faithfully represent the absorption of the materials, with this, computational models tend not to have this limitation and allows different models with different materials.

Sabine's formula should be used in the presence of some conditioning factors such as the average absorption coefficient is low (less than 0.2), the absorbent materials are evenly distributed in the room.

As in Brazil we do not have normative values, it follows in Table 1 the parameters of other countries.

Table 1 – Recommended reverb times for classrooms in different countries

Country	Legislation	Reverberation Time (s)	Observation
Portugal	Lei 251/87	1,0	125-250 Hz
		0,6-0,8	500-4000Hz
France	-	0,4-0,8	Rooms até 250 m³, 500-2000Hz
United Kingdom	BB 87	0,4-0,8	Rooms between 72 e 210m³
United Kingdom	BS 8205	1,0	Practical classes <1000m³
U.S	ANSI	0,6-0,7	S/R ≥ 15 dB(A)
U.S	ASHA	0,4	S/R ≥ 15 dB(A)
Finland	-	0,6-0,9	-
Italy	-	0,5-2,0	Depends on frequency and volume
Belgium	-	0,9-1,5	Rooms between 100 e 1000m³
Japan	-	0,5-0,7	-
Sweden	-	0,5-0,8	-
Switzerland	SAI181/11	0,6-1,0	-

NOTE: Where S / R is the signal-to-noise ratio for the rated environment.

After choosing the rooms, the materials were identified with their respective coefficients of sound absorption per frequency. From these data were calculated by the method of Eyring and Sabine.

The acoustic absorption coefficients inserted in the calculations were extracted from the table contained in the book by Carvalho (2010), which was obtained from the tests performed by industries and normative values. Only the coefficients of the materials present in the rooms under study will be inserted in the table.

INTELIGIBILITY OF SPEECH

According to Uría (2005) intelligibility can be applied in several situations such as singing, music and articulate word that is the case in study of this work. The intelligibility of language is more usual, since the voice is the sound heard in more than 90% of the times in a person's day-to-day life.

In this context are the consonants that determine the comprehension of the oral message and the information contained in the vowels has less relevance. In this way the degree of intelligibility of the speech is closely related to the correct perception of the consonants in high frequencies.

For acoustic comfort to be correct in a room it is necessary to avoid the existence of echoes that in most cases is related to the inadequate geometry of the room. Thus, according to Uría (2005), large reflective parallel walls should be avoided by applying a small slope (of the order of 5 °) to one of the two walls or, therefore, applying an absorbent material to at least one of the two problematic walls.

For the calculation of intelligibility in a room requires knowledge of the factor of directivity Q. This factor is defined from the relation of the sound pressure level of a source in the direction considered and the level that would be obtained if the source was not direct.

The variation of this coefficient for vowels and consonants can be observed in Figure 1.

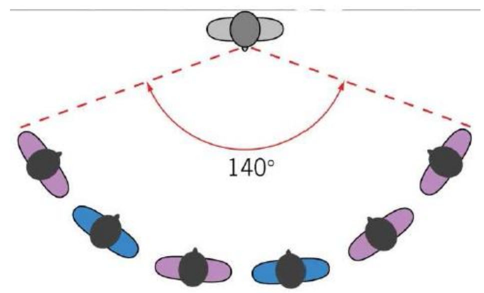

Fig. 1 – Speech directivity
Source: Andrade (2009)

As the frontal direction is considered of greater directivity to the human voice due to the system of phonation and the form of the head. Although directivity increases with frequency, for practical purposes the directional factor of the human voice in the frontal direction is considered to be Q = 2.

Fernandes (2000) understands that the speech intelligibility that can be defined as the percentage of phonemes understood by the receiver is the set of acoustic factors such as background noise and reverberation of the environment.
According to Carríon (2001) the loss of information will be associated with an incorrect perception of consonants, Peutz denominates Consonant Articulation Loss Percentage (% ALCons), which is a parameter indicative of the loss. In conclusion, the higher the% ALCons, the worse the degree of intelligibility.

The intelligibility can be expressed in terms of percentage, and the higher the index, the greater the understanding of the acoustic signal according to Table 2.

Table 2 – Acoustic quality according to the values of intelligibility

Values of Intelligibility	Acoustic Quality
I≥90%	Great
85%≤I<90%	Very good
80%≤I<85%	Good
75%≤I<80%	Satisfactory
70%≤I<75%	Regular
60%≤I<70%	Bad
I<60%	Unacceptable

Source:Ferreira (2010)

The intelligibility consists in determining the difference of the NPS (LD - LR) between the values obtained for the direct and reverberant fields, using the equation below and, together with the value of the Reverberation Time for the octave band corresponding to the frequency center of 2 kHz to determine the value of% ALCons.

For the determination of the NPS (L_{D-L_R}) difference, Equation 2 is used.

$$L_{D-L_R} = 10\log\left(\frac{Q.R}{r^2}\right) - 17dB \qquad (1)$$

Where the value of Q = 2 Directional Factor of the sound source in the considered direction (Q = 2 in the case of the human voice, considering the front direction of the speaker).

The value of the Room Constant is defined according to Equation 3.

$$R = \frac{S_T\bar{\alpha}}{(1-\bar{\alpha})} \qquad (2)$$

The calculation of Reverberation Time considers the values of $\bar{\alpha}$ for the frequency band of 2kHz (highest contribution to speech) obtaining the value of the constant with Equation 4.

$$\bar{\alpha} = \frac{\sum(S\alpha)}{S_I} \qquad (3)$$

The value of r is considered by the distance from the sound source (teacher's voice) to the student located in the last row.

The Classification of Intelligibility is done through Figure 2 which allows to determine the value of% ALCons (left ordinate axis) from the values of TR (right ordinate axis) and the difference $L_D - L_R$ (abscissa axis).

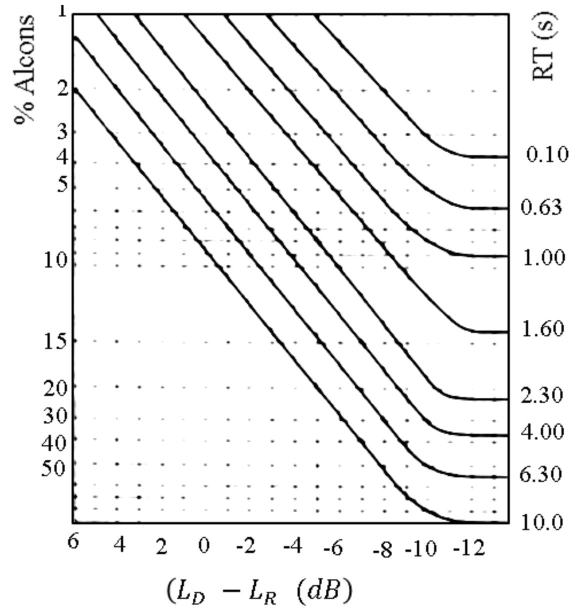

Fig. 2 – Obtaining the% ALCons from TR and from LD - LR. Source: URÍA (2005)

MATERIALS AND METHODS

Types of rooms

(2)

The school buildings of the University of Brasília the main and most iconic building of the UnB, the linear and curved building of the Central Institute of Sciences (ICC) - or the "Minhocão", as it is known - with its 696 meters extension, Constructive view: the pre-cast in reinforced concrete, which houses most institutes, colleges, classrooms, laboratories and amphitheatres. In this building they have rooms of different geometries and materials of lining, but in all of them the walls and the floor are in reinforced concrete and glass.

However, classrooms have different linings and frames, keeping the simple sealing in reinforced concrete. Amphitheaters have a treatment in the liner to improve the acoustic conditions of the environment.

In the first moment, which involved the study of literature and the specific context, the techniques of logging as well as field diary were used. According to Flick (2009) the observations are a fundamental element in all stages of the investigative process, including the formulation of the problem and the interpretation of the investigated phenomenon. This stage of the field work has extreme relevance in the circularity of the research process.

A survey was carried out throughout the ICC to identify the rooms that are currently used to teach classes. Rooms not intended for use as a laboratory and for postgraduate classes due to the type of activity and the configuration of use were not considered in this study.

Rooms with the same geometry but with different lining linings were identified with different typology.

Table 3 shows the number of typologies in which the 88 rooms surveyed were classified.

Table 3 – Number of classroom typologies raised at the University of Brasília

Tipology	Quantity	Average area in m²	Average student capacity
1	2	109,85	40,00
2	3	48,76	20,00
3	13	63,20	25,00
4	8	47,39	20,00
5	26	54,90	30,00
6	15	270,67	140,00
7	1	261,94	140,00
8	1	361,06	140,00
9	19	46,79	45,00

For a better understanding, Figure 3 presents a photo of each typology in which different lining geometries, room dimensions and frames can be observed.

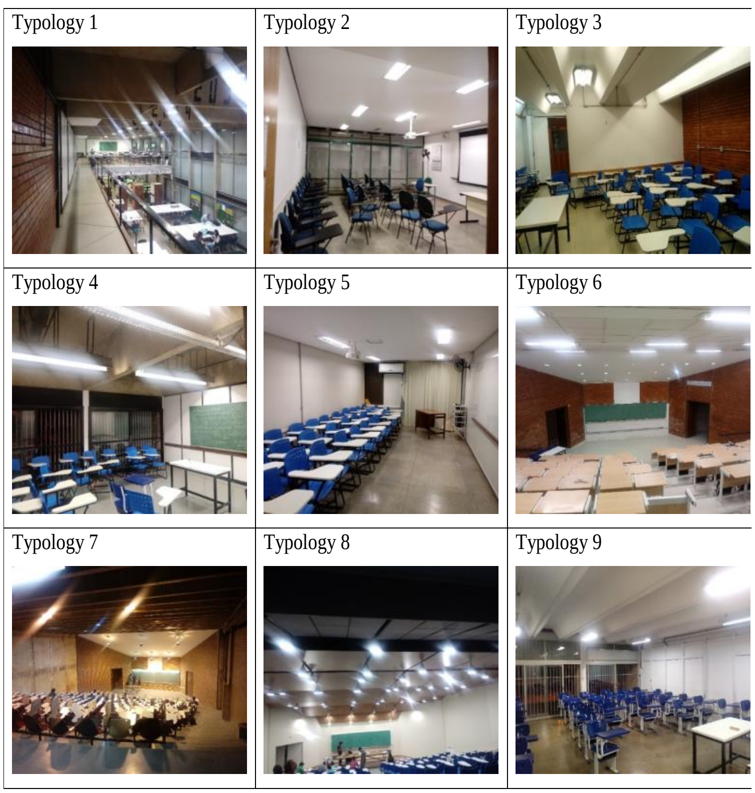

Fig. 3 – Identification of classroom typologies

To perform the reverberation time calculations will be used Equation 1 and for the calculation of intelligibility Equations 2, 3 and 4.

RESULTS

The result of the calculations indicates in Figure 4 that the lowest reverb time found was 3.29s in 500Hz and according to ANSI 12.60 the value should be between 0.6 and 0.7s for classrooms.

It should be noted that typology 7 is well above the average of the values of the other typologies. This was due to the room's cladding materials and also to its geometry which is identical to that of an auditorium

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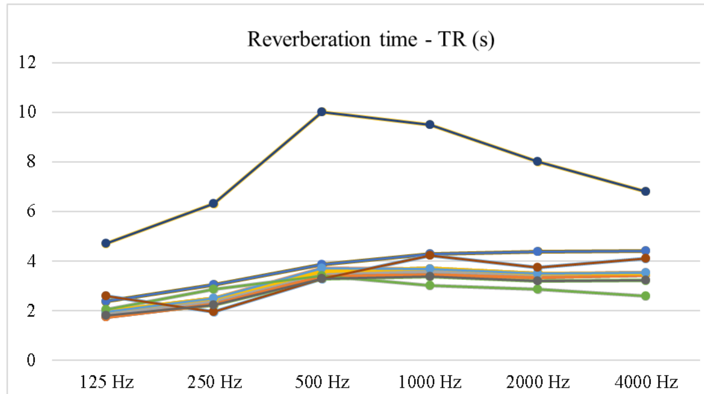

Fig. 4 – Identification of classroom typologies

In Figure 5 it is possible to identify the $L_D - L_R$ difference in which is used in Figure 2 to obtain the% Alcons.

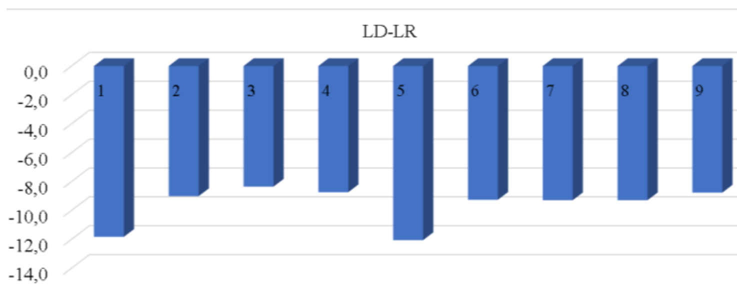

Fig. 5 – Calculation of the difference $L_D - L_R$

According to Table 4 the rooms are with the value of intelligibility classified as bad and unacceptable. Therefore it is necessary to perform the correction of the reverberation time.

Table 4– Number of classroom typologies raised at the University of Brasília

Tipology	1	2	3	4	5	6	7	8	9
% ALCONS	35	25	17	17	38	16	70	25	18

CONCLUSION

In this research it was possible to conclude that the typologies of the studied classrooms of the University of Brasilia do not meet the minimum normative parameters. Studying in a comfortable environment increases student productivity and learning. In this way it is important that acoustic corrections be made and an intervention option is the exchange of the lining when existing or addition of acoustic material with greater absorption.

A suggestion of acoustic material is the fiber polyester from bottles that when installed glued to the slab with a thickness of 50mm has the absorption coefficient according to Table 5.

Table 5– Absorption coefficient of pet wool of 50mm thickness and 30kg / m³ of density

Frequency Hz	250	500	1000	2000	4000
	0,60	0,80	0,80	0,80	0,70

Further studies like this should be done not only to prevent students from impairing their hearing and learning level, but also to improve professional knowledge of teaching environments.

REFERENCES

[1] Andrade, J.M.F.M. Caracterização do conforto acústico em escola. Dissertação de mestrado integrado em engenharia civil, FEUP, (2009).

[2] Carrión, I.A. Diseño acústico de espacios arquitectónicos. barcelona: editorial alfaomega, Barcelona, Espanha, (2001).

[3] Carvalho, R.P. Acústica arquitetônica. 2ed. Brasília, (2010).

[4] Eniz, A. O. Poluição sonora em escolas do Distrito Federal. Dissertação de mestrado - Universidade Católica de Brasília, programa de pós-graduação stricto sensu em planejamento e gestão ambiental, Brasília, (2004).

[5] Fernandes, J. Inteligibilidade acústica da linguagem. xix encontro da Sobrac . ufmg – Belo Horizonte, (2000).

[6] Ferreira, B. J. Análise de níveis sonoros em salas de aula. dissertação de mestrado. coimbra, (2010).

[7] Guidini, R.F; Bertoncello. F; Zanchetta. S; Dragone. M.L.S. Correlações entre ruído ambiental em sala de aula e voz do professor. Revista da sociedade brasileira de fonoaudiologia, (2012).

[8] Sbine, W. C. Collected papers on acoustics. cambridge: havard university press, (1922).

[9] Uría, M. G. T. Avaliação acústica de salas de aula em escolas públicas na cidade de Belém-Pará: uma proposição de projeto acústico", Pará, (2005).

[10] Zanin, P.H.T.; et al. Noise mapping of an educational environment. Canadian acoustics, v. 41, n. 1, p. 35-41, (2013).