IMPACT OF THE USE OF CURTAINS ON THE SPATIAL DISTRIBUTION OF THE PARAMETER DEFINITION (D_{50}) IN BRAZILIAN CLASSROOMS

Cristina Yukari Kawakita Ikeda (1); Fulvio Vittorino (2); Rosaria Ono (3)

(1) Doctor, architect and urban planner, cristinak@ipt.br, Institute for Technological Research – IPT, Av. Prof. Almeida Prado, 532 – Prédio 36 – Butantã - 05508-901, São Paulo, SP, Brazil, 55 (11) 3767-4555.

(2) Doctor, mechanical engineer, fulviov@ipt.br, Institute for Technological Research – IPT, Av. Prof. Almeida Prado, 532 – Prédio 36 – Butantã - 05508-901, São Paulo, SP, Brazil, 55 (11) 3767-4553.

(3) Doctor, architect and urban planner, rosaria@usp.br, Faculty of Architecture and Urbanism of the University of São Paulo - FAUUSP, Rua do Lago, 876 – 05508-080 - SP, Brazil, (11) 2065-8001

ABSTRACT

When the understanding of the spoken message is crucial, just some of the several of the acoustic descriptors used to evaluate the acoustic quality of rooms tend to attract more attention. The usage of curtains in Brazilian schools is a low-cost method typically used for solar protection, although their use might correct the values of the acoustic descriptors by getting these parameters within acceptable ranges. The spatial distribution of the definition (D_{50}) parameter in classrooms with open and closed curtains is the main topic of this paper. Computer simulation was used to estimate the sound behavior. Reverberation time measured in the rooms was used to adjust the simulated classroom models. Two closed window arrangements, with open and closed curtains, were studied for the classrooms. In this study, the effect of opening the curtain was variable depending on the frequency, but for all the cases, higher values of D_{50} were obtained with the closing of the curtains. Since D_{50} is a parameter that can be modified by using sound absorption, the designers can make interventions to improve the homogeneity of the parameter spatial distribution.

Key words: classroom, acoustic simulation, definition

1. INTRODUCTION

Poor communication between teacher and students makes the learning process more difficult. The social and economic costs of designing classrooms without acoustic quality are difficult to determine, but they can be high and can cause cumulative damage to students if they remain as occupants of such environments over several years (BRADLEY, 2002).

Beranek (1962) was the first to systematize a comprehensive set of criteria with the aim of classifying the acoustics of music halls. Until so, acoustic designers did not have sufficient quantitative elements to assess the acoustic quality of concert halls. He determined at a set of parameters that even with some modifications and considerations, were consolidated as fundamental for evaluating the acoustic quality of rooms up to the present day (FIGUEIREDO, 2005). There are a number of acoustic descriptors used to evaluate the acoustic quality of rooms, such as the reverberation time (RT), early decay time (EDT), speech transmission index (STI), bass ratio (BR), center time (Ts), and definition (D_{50}) and some of them are typically more taken into account when understanding the spoken message is crucial (IKEDA, 2019).

The most adopted standard term used to describe acoustical design is reverberation time. Nonetheless, it is important to notice that, apart from reverberation time, the parameters may show large differences between different seats, both objectively and subjectively (GADE, 2007). There are ranges of values for other descriptors in the literature that are not applied in classrooms because there are no specific research on them.

Moreover, these indicators are typically used to characterize the entire environment using a single value, disregarding any spatial gradients. This paper is a part of a series o studies on how certain acoustic descriptors, such as RT (IKEDA, 2020a), EDT (IKEDA,2020b), and Ts (IKEDA, 2021) are distributed spatially This work is focused on the spatial distribution of the Definition parameter in classrooms, taking into account the opening and closing of curtains. They are a simple and affordable solution in already built environments.

The definition factor (D_{50}) is usually applied to evaluate rooms dedicated to the spoken word, and consists of the linear ratio between the energy that arrives in the first 50 ms (milliseconds) and the total energy. In a dry acoustic room, D_{50} will be greater than in a reverberant room, because the decay of sound energy in the reverberant room is slower and, therefore, more energy will be concentrated in the final part of each sound, decreasing the ratio between initial and final energy (MARROS, 2011). D_{50} just like Ts are related to the subjective aspect of the perceived clarity of the sound.

Arau (1999) apud Ribeiro (2002) recommends D_{50} values above 0.65 for conference rooms. Marshall (1994) apud Ansay and Zannin (2016) establishes as a reference for excellent acoustic quality the range of 0.86 to 1.0 and for good acoustic quality the range of 0.67 to 0.86. Ikeda (2019) suggests the operating ranges for the 1/1 octave bands from 63 Hz to 8,000 Hz, with the lower limit value of 0.25 for 63 Hz and the higher upper limit value of 1.0 for the frequency ranges above 500 Hz.

Using curtains in Brazilian schools is a low-cost solution that is typically employed for solar protection and it might improve the values of the acoustic descriptors by bringing these parameters into acceptable ranges. So, if moving the curtains will improve the “definition” distribution and lower the disparities below the JND (Just Noticeable Difference), which is the perception threshold of a human being in relation to a parameter sensorially detected.

2. OBJECTIVE

The study's goal was to determine whether using curtains affects how the acoustic descriptor "definition" is distributed spatially in a classroom.

3. METHOD

The study was carried out using the following procedures:

a) a classroom from an elementary school with only standard furniture was selected in the state of Sao Paulo's private network;
b) a digital model of this room was constructed, in which an optimized mesh size was defined based on the sound pressure level measurements;
c) the acoustical properties of this model were calibrated by comparing measured reverberation time with the reverberation time obtained in preliminary simulations, and
d) final simulations were carried out. All calculations and measurements were performed for a horizontal plane 1.20 meters above the ground.

The studied classroom and the steps for determining the digital model and the simulation mesh is next described:

3.1. Object of study

The studied classroom has a floor area of 39.2 m^2 and a ceiling height of 3.65 m, in addition to the following construction and furniture characteristics: stone tiles-covered floor; masonry walls covered with mortar, plaster and paint; mineral tiles on the ceiling; wooden school furniture, with decorative high-pressure laminate tabletops (Figure 1).



Figure 1 – View of the classroom

Using computer simulations with the software Odeon, the classroom's sound behavior was estimated. The software uses a hybrid computational technique that combines the image source method and the ray tracing method (CHRISTENSEN; RINDEL, 2005). The basis for the image source approach is the idea that by replicating the source in the plane of the reflecting surface, a specular reflection can be mathematically created. The number of possible image sources increases exponentially with the order of reflections, and therefore the method is not suitable for rooms such as concert halls in which reflection orders of several hundred are relevant to the audible reverberant decay. The ray tracing method is based on the geometrical/optical law of reflection by following a large number of sound beams from a source point up to high order reflections (RINDEL, 2010).

According to the Odeon software manual, the "engineering" option was chosen for the simulations since it is quicker than the "precision" mode, without much compromise in the quality of the results (ODEON, 2018). The program's database's values for the sound absorption coefficients were initially employed, and, thereafter, they were modified in accordance with the model's calibration procedure.

3.2. Simulation mesh

A preliminary investigation was conducted in order to optimize the mesh size due to computational cost. In a classroom, A-weighted sound pressure level measurements were made with microphones spaced every 25 cm in both the longitudinal and transverse directions. A class 1 sound level meter was used. A dodecahedron source was employed as the sound source to amplify the pink noise. This sound source was in the teacher's usual spot in the front of the room, in the center. Sound pressure levels were measured in 378 separate locations during 20 seconds at each point.

After analyzing the data, it was determined that a mesh of 1 m was extremely coarse because more than 1 student would be positioned inside a computation cell, and that a mesh of 25 cm, while more precise, would extremely lengthen the simulation duration. Hence, a 50 cm mesh was used because the experiment's sound field did not fluctuate significantly, approximately 1 to 2 dB, and this distance is more consistent with how far apart students sit from one another.

3.3. Digital model

The virtual model of the classroom was created using the SU2Odeon plug-in and the program SketchUp17. The geometry of the room (Figure 2) was designed, exported to the software Odeon, in which the surfaces were given different materials with corresponding absorption and scattering coefficients, similar to those found in classrooms. The materials' attributes from the software material library are displayed in Table 1. The software material library's default scattering coefficient of 0.05 was used for all materials.

The classroom models have been modified to as closely match the 1,000 Hz reverberation time as possible, tolerating a deviation of up to 5% that is within the ISO 3382-1 perception threshold (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2009). The difference in the RT value is the minimal stimulus intensity change necessary to result in a significant fluctuation (JND), especially at frequencies above 1,000 Hz (BORK, 2000). So, for example, if the mean measured RT value in the room for 1,000 Hz was 0.60 s, it was acknowledged a RT value acquired from the computer simulation between 0.57 s and 0.63 s.

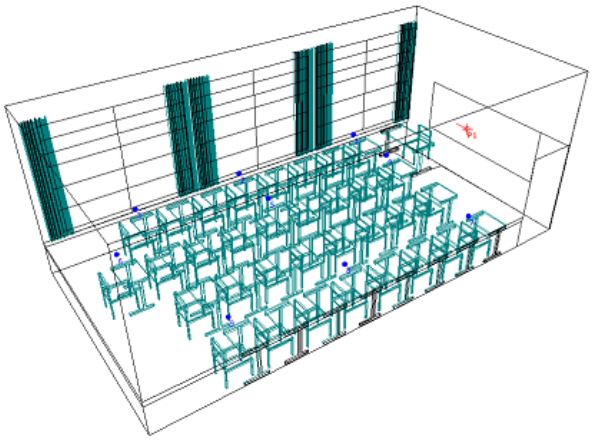

Figure 2 – Digital model of the classroom

Table 1 – Sound absorption of materials applied to the surfaces (ODEON A/S, 2009)

Surface of the classroom	Material at Odeon	Sound absorption							
		63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Window, glass door	Glass, ordinary window glass	0.35	0.35	0.25	0.18	0.12	0.07	0.04	0.04
Wall	Smooth concrete, painted or glazed	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Floor	Smooth unpainted concrete	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.05
Ceiling	20% absorbent	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Desks	Desks	0.01	0.01	0.03	0.07	0.07	0.08	0.10	0.10
Crash guards for wall protection	Thin plywood panelling	0.42	0.42	0.21	0.10	0.08	0.06	0.06	0.06

4. RESULTS

The "D_{50}" spatial distribution diagrams for the scenarios of closed and open curtains, both with closed windows, are displayed in Figures 3 to 10. The results are presented for the frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

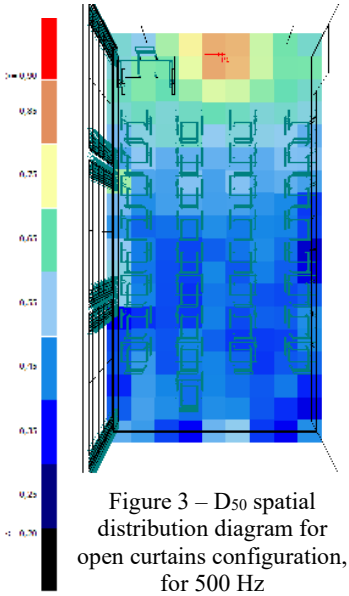

Figure 3 – D_{50} spatial distribution diagram for open curtains configuration, for 500 Hz

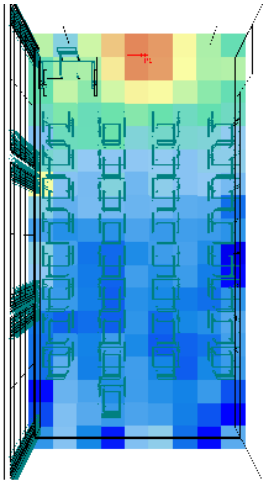

Figure 4 – D_{50} spatial distribution diagram for open curtains configuration, for 1,000 Hz

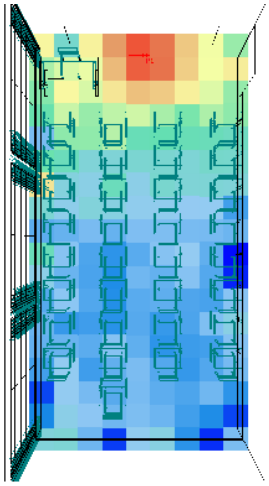

Figure 5 – D_{50} spatial distribution diagram for open curtains configuration, for 2,000 Hz

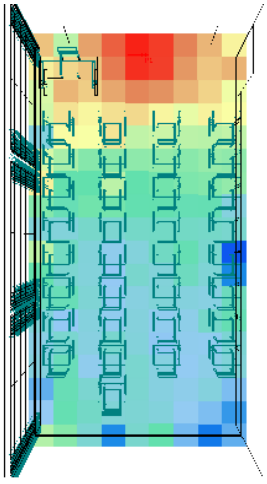

Figure 6 – D_{50} spatial distribution diagram for open curtains configuration, for 4,000 Hz

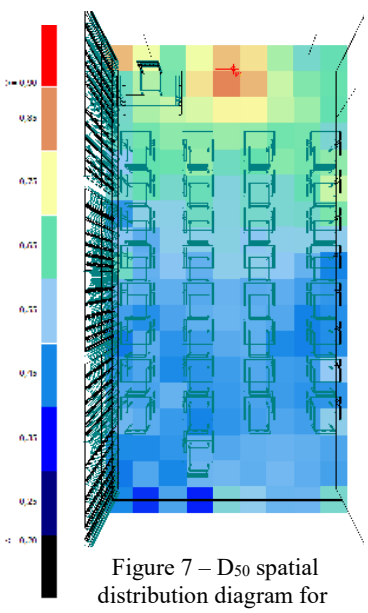

Figure 7 – D_{50} spatial distribution diagram for closed curtains configuration, for 500 Hz

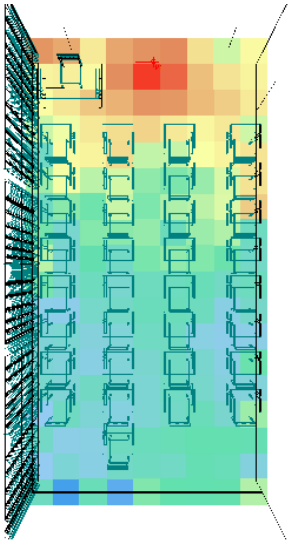

Figure 8 – D_{50} spatial distribution diagram for closed curtains configuration, for 1,000 Hz

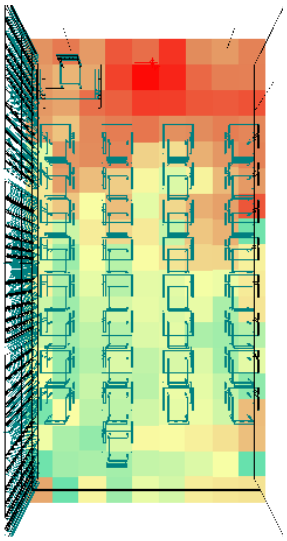

Figure 9 – D_{50} spatial distribution diagram for closed curtains configuration, for 2,000 Hz

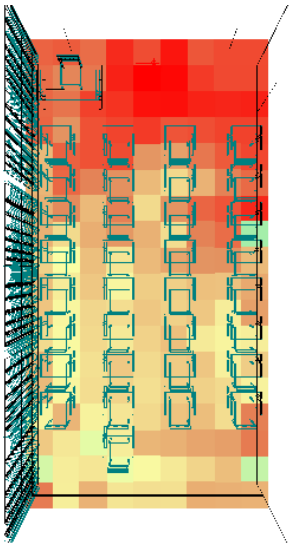

Figure 10 – D_{50} spatial distribution diagram for closed curtains configuration, for 4,000 Hz

Table 2 displays D_{50} values by frequency (500 Hz, 1000 Hz, 2000 Hz and 4000 Hz), as a function of its accumulated frequency of occurrence (%), both for the situation of open curtains (OC) and closed curtains (CC). The differences in D_{50} for 50% of the points in the room ($D_{50}75$- $D_{50}25$) and for 90% of the points in the room ($D_{50}95$- $D_{50}5$) are also shown in this table.

Table 2 – Definition as a function of the frequency of accumulated spatial occurrence (%) and the sound frequency (Hz)

Accumulated frequency of occurrence	**Sound frequency (Hz)**							
	500		**1000**		**2000**		**4000**	
	OC	**CC**	**OC**	**CC**	**OC**	**CC**	**OC**	**CC**
5%	0.38	0.45	0.41	0.57	0.46	0.68	0.53	0.76
25%	0.42	0.49	0.45	0.61	0.50	0.72	0.58	0.78
50%	0.46	0.52	0.50	0.65	0.54	0.76	0.63	0.81
75%	0.57	0.64	0.60	0.74	0.64	0.83	0.72	0.87
95%	0.72	0.74	0.75	0.83	0.80	0.89	0.85	0.92
D_{50}75- D_{50}25	0.15	0.15	0.15	0.14	0.14	0.11	0.13	0.09
D_{50}95- D_{50}5	0.34	0.29	0.34	0.26	0.34	0.21	0.32	0.17

For the D_{50} criterion recommended by Arau (1999) apud Ribeiro (2002) which are values above 0.65, for conference rooms, considering 1000 Hz, about 20% of the points of the room, in the case of open curtains and 50% of the points of the room, in the case of closed curtains, would be adequate. For the criterion established by Marshall (1994) apud Ansay and Zannin (2016), the same points are classified as with good acoustic quality. For the D_{50} criterion suggested by Ikeda (2019) recommending values above 0.32, for classrooms, considering 1000 Hz, less than 5% of the points of the room, in the case of open and closed curtains, are considered unsatisfactory.

For all the situations, for both condition of open and closed curtains, the differences of D_{50} values determined in 50% of the room ($D_{50}75$- $D_{50}25$) and for 90% of the room ($D_{50}95$- $D_{50}5$), for 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, are greater than the just noticeable difference (JND), which is 0.05 (ISO 3382-1). It is possible to verify that, for this room, the effect of opening the curtain is variable depending on the frequency, but for all the cases, higher values of D_{50} were obtained with the closing of the curtains. This effect did not necessarily happen for the values of reverberation time (IKEDA, 2019).

5. CONCLUSIONS

Some of the descriptors for the acoustic quality of rooms, such as auditoriums and conference rooms, were originally developed for the evaluation of music-specific spaces. These rooms, however, differ from classrooms in their configurations and volumes. The spatial distribution of the D_{50} parameter in a classroom was the subject of this exploratory investigation.

For both 50% and 90% of the points of the room the differences of D_{50} values are greater than the just noticeable difference (JND). The parameter is perceived differently across the room. Opening or closing the curtain in the room under study did not improve the distribution of the D_{50} and did not reduce the differences below the JND. Nevertheless, since D_{50} is a parameter that responds to sound absorption, the designer is still able to modify this parameter by making changes to the materials and built components.

In the context of classrooms, this study and its continuation are important as an initial exploration of the numerous variables that influence the comfort of students and teachers. In addition to the impact of using curtains, the use of open or closed windows, as well as the lighting and ventilation conditions of these environments are important aspects that interrelated with the acoustics of the rooms and they must be considered in the user's decision-making process regarding opening or closing windows and curtains in classrooms.

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