IMPACT OF THE USE OF CURTAINS ON THE SPATIAL DISTRIBUTION OF CENTRAL TIME IN BRAZILIAN CLASSROOMS

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ABSTRACT

There are several acoustic descriptors applied to assess the acoustic quality of spaces, and some of them generally receive more attention when the understanding the spoken message is fundamental. In existing Brazilian schools, the use of curtains is a low cost mechanism generally used for solar protection, but their use could correct values of acoustic descriptors by bringing these parameters to acceptable ranges. The present research paper is focused on the spatial distribution of the central time parameter in classrooms with open and closed curtains. The tool used to estimate the sound behaviour was computational simulation. The classroom models were adjusted using central time measured in the simulated rooms. For the classrooms, two configurations of closed windows were studied: open and closed curtains. For this research, the effect of opening the curtain was variable depending on the frequency, but for all the cases, lower values of central time were obtained with the closing of the curtains. Hence, central time is a parameter that responds to the designer's interventions, since by working with sound absorption, the designer is able to adjust this parameter.

Key words: Central time, classroom, acoustic simulation.

1. INTRODUCTION

The students' understanding and the teachers' physical stress are both affected by the poor acoustic performance in the classrooms. One of the essential factors for the development of class activities, especially those that require a high level of concentration is the acoustic comfort (KRÜGER and ZANNIN, 2004). There are several acoustic descriptors, such as the reverberation time (RT), the early decay time (EDT), the speech transmission index (STI), the bass ratio (BR), the central time (Ts) and the definition (D_{50}), applied to assess the acoustic quality of spaces, and some of them are generally more considered when understanding the spoken message is fundamental (IKEDA, 2019).

The reverberation time is the traditional descriptor used for acoustical design. But it is possible that two rooms with similar reverberation times can be perceived acoustically different by the users of the spaces. By determining additional acoustic parameters it is possible to obtain a closer relationship to people's perception (CAMPBELL; NILSSON; SVENSSON, 2015). In the literature, there are ranges of values for other descriptors that, for lack of specific studies, are not used for classrooms.

And in general, a single value of these indicators is adopted to characterize the entire environment, ignoring any spatial gradients. This research paper belongs to a series of studies of the spatial distribution of some acoustic descriptors such as RT (IKEDA, 2020a) and EDT (IKEDA,2020b). This work is focused on the spatial distribution of the central time parameter in classrooms, considering the impact of opening and closing curtains on this parameter. The use of curtains is an inexpensive and easy to implement solution in already built environments.

The central time corresponds to the center of gravity of the entire impulsive response, measured in milliseconds. A small value of Ts means that the energy is concentrated at the beginning of the impulsive response, helping with the clarity, while a large Ts value means that the energy is distributed over time, giving the impression of a more reverberating space (QUEIROZ et al, 2008). The D_{50} just like the Ts are related to the subjective aspect of the perceived clarity of the sound.

Ribeiro (2002) recommends Ts values below 80 ms for conference rooms. The ISO 3382-1 (2009) establishes limits from 60 ms to 260 ms (500 Hz to 1000 Hz average) for auditoriums. And for classrooms, 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 25 ms for 1000 Hz and the higher upper limit value of 160 ms for 250 Hz.

2. OBJECTIVE

The objective of the work was to verify if the use of curtains impacts on the spatial distribution of the acoustic descriptor "central time". Thus, if opening or closing the curtain improves the distribution of the central time, and it brings the differences below the JND (Just Noticeable Difference). JND is the amount necessary for a person to detect a difference. That is to say, if the parameter aforementioned responds to the designer's interventions, by working with sound absorption, for instance.

3. METHOD

The following steps were taken in order to perform the proposed study:

a) a classroom from an elementary school containing only common furniture was chosen in the private network of the state of Sao Paulo;

b) a digital model of this room was built in which an optimized mesh size was defined based on the sound pressure level measurements subsequently detailed;

c) the acoustical properties of this model were calibrated by comparing measured sound pressure levels with the levels obtained in preliminary simulations; and

d) final simulations were performed. All measurements and calculations were made to a horizontal plane located 1.20 m above the floor.

The studied classroom has a floor area of 51.8 m^2 and a ceiling height of 3.20 m, in addition to the following construction and furniture characteristics: stone tiles-covered floor; masonry walls covered with mortar, plaster and paint; plaster lining; wooden school furniture, with decorative high pressure laminate table tops (see Figure 1). Figure 1 also illustrates the position of the dodecahedron loudspeaker used as a sound source in the measurements. The excitation signal used was sine sweep, generated by the Dirac software.

Figure 1 - View of the classroom with the sound source

The sound behavior, throughout the classroom was estimated using computer simulations. The software chosen was Odeon, which uses a hybrid calculation method combining the image source method with the ray tracing method (CHRISTENSEN and RINDEL, 2005). The image source method is based on the principle that a specular reflection can be geometrically constructed by mirroring the source in the plane of the reflecting surface. In the ray tracing method, a large number of sound rays are traced from a source point up to high order reflections following the geometrical/optical law of reflection (RINDEL, 2010).

In the simulations, the "engineering" configuration was chosen because it is faster than the "precision" mode, without much loss in the quality of the results, according to the software manual (ODEON, 2018). Initially, the values of the sound absorption coefficients contained in the program's database were used and, afterwards, they were adjusted according to the calibration process of the model.

3.1. Simulation mesh

In order to optimize the mesh size due to the issue of long computational processing time, a preliminary study was carried out. A-weighted sound pressure level measurements were carried out in the classroom, placing the microphone every 25 cm, both in the longitudinal and transversal directions. A class 1 sound level meter was used. The sound source used for the generation of the pink noise was a dodecahedron source. This sound source was located in the teacher's typical position, at the center, in front of the room. Sound pressure levels were measured during 20 seconds at 378 different points.

Analyzing the results, a mesh of 1 m was considered very coarse, as there would be more than 1 student located inside a calculation cell and a mesh of 25 cm, although more refined, would increase the time of simulation. Thus, a 50 cm mesh was chosen, as the sound field did not vary much in the experiment, around 1 dB to 2 dB, and this distance is more consistent with the distance that a student sits in relation to the other.

3.2. Digital model

The virtual model of the classroom was generated in the software SketchUp17, using the SU2Odeon plug-in. The geometry of the room (Figure 2) was created and then exported to the software Odeon, where different materials were assigned to each surface, referring to those used in classrooms, with their respective absorptions and scattering coefficients. Table 1 shows the properties of the materials from the software material library. It was adopted the default scattering coefficient of the software material library of 0.05 for all the materials.

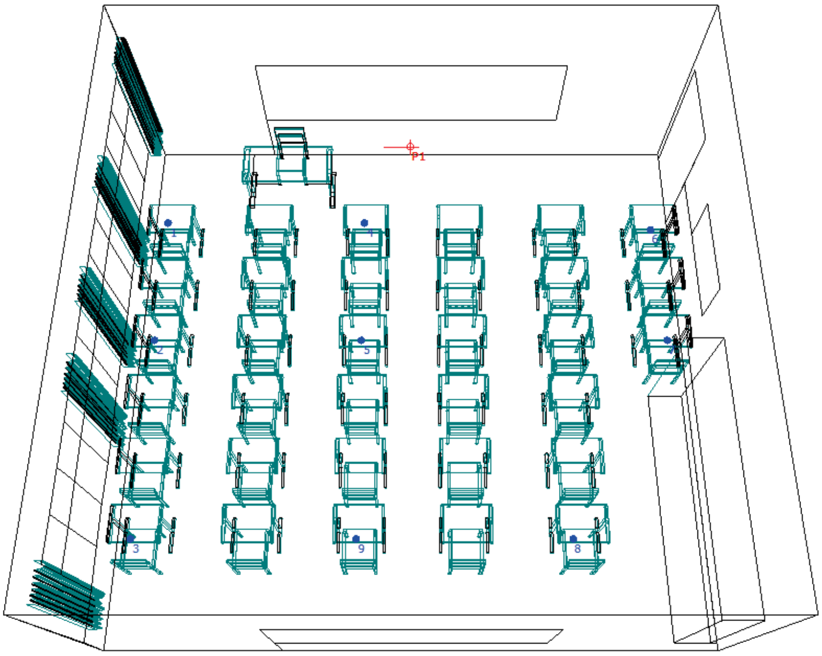


Figure 2 - Digital model of the classroom

Table 1 - Materials applied to the surfaces (ODEON A/S, 2009)

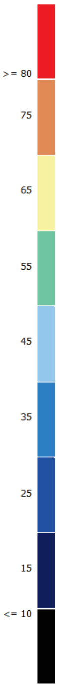
Material at Odeon	Sound absorption							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Glass, ordinary window glass	0.35	0.35	0.25	0.18	0.12	0.07	0.04	0.04
Smooth concrete, painted or glazed	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Smooth unpainted concrete	0.01	0.01	0.01	0.02	0.02	0.02	0.05	0.05
20% absorbent	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Desks	0.01	0.01	0.03	0.07	0.07	0.08	0.10	0.10
Cupboards	0.15	0.15	0.30	0.35	0.30	0.20	0.13	0.05
Thin plywood panelling	0.42	0.42	0.21	0.10	0.08	0.06	0.06	0.06

The curtains were made of medium weight synthetic draped fabric. They were in contact with the wall except at the window in which they were distanced by the sill.

The classroom models have been adjusted to match the reverberation times measured at 1,000 Hz as much as possible, tolerating a variation of up to 5% which is within the perception threshold according to ISO 3382-1 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2009). This variation in the RT value is the minimum amount by which stimulus intensity must be changed in order to produce a noticeable variation (JND), especially at the frequency of 1,000 Hz (BORK, 2000). So, for instance, if the mean measured RT value in the room, for 1,000 Hz, was 0.60 s, it was accepted that the RT value obtained through the computer simulation was between 0.57 s and 0.63 s.

4. RESULTS

Figures 3 to 10 show the central time spatial distribution diagrams for the situations of closed and open curtains, both with windows closed. The results are presented for the frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.



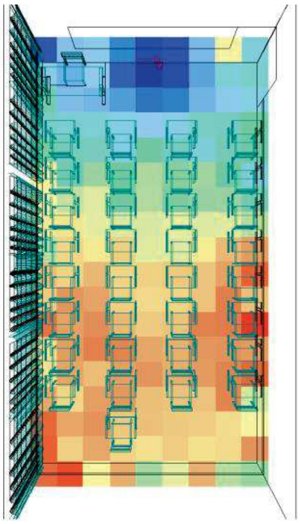


Figure 3 - Ts spatial distribution diagram for closed curtains configuration, for 500 Hz

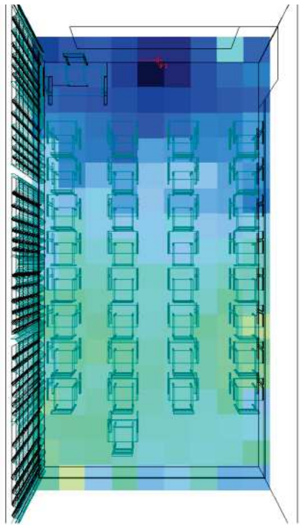


Figure 4 - Ts spatial distribution diagram for closed curtains configuration, for 1,000 Hz

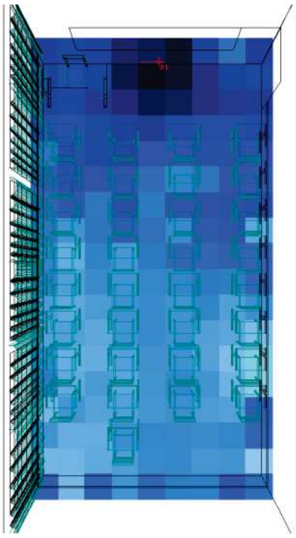


Figure 5 - Ts spatial distribution diagram for closed curtains configuration, for 2,000 Hz

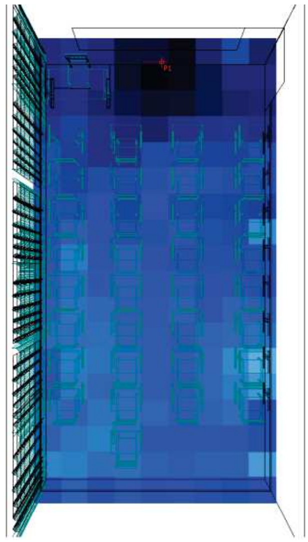
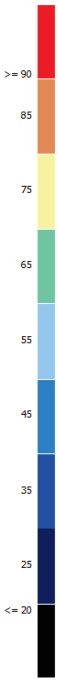


Figure 6 - Ts spatial distribution diagram for closed curtains configuration, for 4,000 Hz



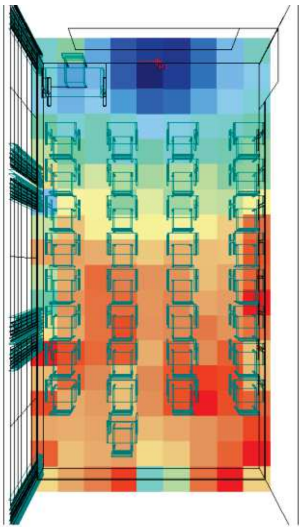


Figure 4 - Ts spatial distribution diagram for open curtains configuration, for 500 Hz

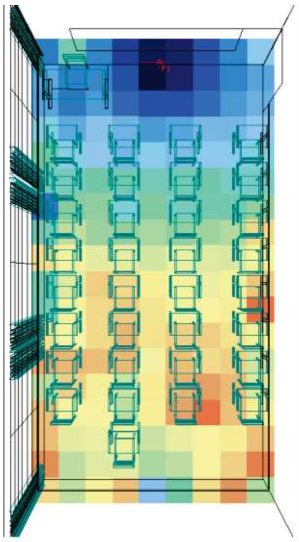


Figure 6 - Ts spatial distribution diagram for open curtains configuration, for 1,000 Hz

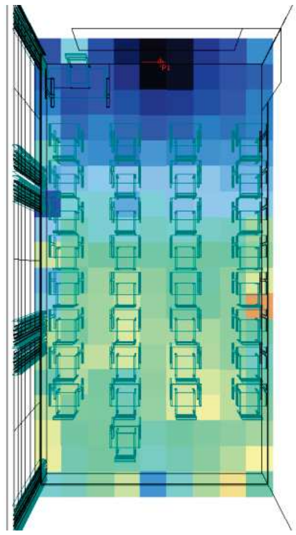


Figure 8 - Ts spatial distribution diagram for open curtains configuration, for 2,000 Hz

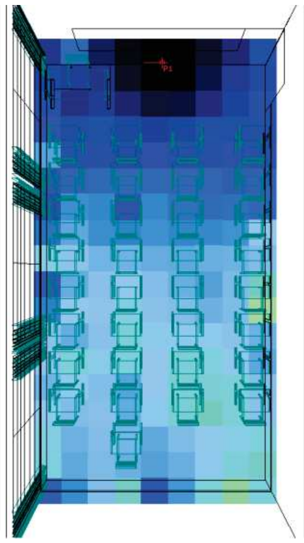


Figure 10 - Ts spatial distribution diagram for open curtains configuration, for 4,000 Hz

Table 2 shows Ts 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 Ts for 50% of the points in the room (Ts75-Ts25) and for 90% of the points in the room (Ts95-Ts5) are also shown in this table.

Frequency distribution groups data by occurrence classes, summarizing the analysis of a large mass of data. The difference between the third (Ts75) and the first quartile (Ts25) is a more stable measure than the total amplitude, as it does not consider the most extreme values. This measure covers 50% of the data and is useful to detect outliers (GUEDES et al, 2005). To compare the distributions, the cutoff points between the 5th percentile (Ts5) and the 95th percentile (Ts95) were also used. These cutoff points were chosen because they discard the most extreme values.

Table 2 - Central time, in milliseconds, 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%	44	36	37	23	30	16	22	12
25%	63	53	56	37	48	27	38	22
50%	80	67	71	48	63	35	51	29
75%	85	71	77	52	68	38	55	32
95%	89	76	81	56	73	42	59	35
Ts75-Ts25	22	19	21	15	19	12	17	11
Ts95-Ts5	46	40	45	33	43	27	37	23

Table 3 shows the difference between the median Ts value (accumulated frequency of occurrence of 50%) and the Ts values determined in 50% of the room (T75-T25), for the frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. For all situations, this difference is significantly greater than the just noticeable difference (JND), which is 10 ms (ISO 3382-1).

Table 3 - Difference between median Ts values in relation to the (Ts75-Ts25) values, in ms

Sound frequency (Hz)	500		1000		2000		4000	
Situation	OC	CC	OC	CC	OC	CC	OC	CC
Percentage difference	58	49	50	33	43	24	34	19

Table 4 shows the difference between the median Ts value and the Ts values determined in 90% of the room (Ts95-Ts5), for the frequencies of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. It appears that, for most situations, this difference is significantly greater than the JDN.

Table 4 - Difference between the median Ts values in relation (T95-T5) values, in ms

Sound frequency (Hz)	500		1000		2000		4000	
Situation	OC	CC	OC	CC	OC	CC	OC	CC
Percentage difference	35	27	27	15	20	9	14	6

For 50% of the measured points, the differences among the Ts and the median values were greater than the JND for all the frequency bands for both conditions: curtains closed or open. For 90% of the measured points, the differences were from 6 ms to 35 ms, and the differences below the JND were observed in 2000 and 4000 Hz.

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, lower values of Ts were obtained with the closing of the curtains. This effect did not necessarily happen for the values of reverberation time (IKEDA, 2019).

5. CONCLUSIONS

Initially designed for the evaluation of spaces dedicated to music, some of the descriptors for the acoustic quality of rooms were studied for spaces intended for speech such as auditoriums and conference rooms. However, these spaces have different configurations and volumes larger than those of a classroom. This was an exploratory study of the spatial distribution of the central time in a classroom.

In the room studied, opening or closing the curtain does not improve the distribution of the central time, and fail to bring the differences below the JND. Nevertheless, Ts is a parameter that responds to the sound absorption, making it possible for the designer to adjust this parameter by making interventions with the materials and built elements.

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