Assessment of the sound quality of classrooms through Speech Transmission Index (STI), Sound Definition (D50) and Reverberation Time (RT)

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ASSESSMENT OF THE SOUND QUALITY OF CLASSROOMS THROUGH SPEECH TRANSMISSION INDEX (STI), SOUND DEFINITION (D50) AND REVERBERATION TIME (RT)

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ABSTRACT

Comfort assessments are the first's steps of the development of strategies for improvement of classrooms, aiming the enhancement of the learning process of pupils and providing good conditions for teaching. This study is investigating room acoustic descriptors with great importance in classroom acoustics, which are Speech Transmission Index (STI), Sound Definition (D_{50}) and Reverberation Time (RT). The investigated classrooms are located in two buildings from the Federal University of Paraná, from the 1960s and 2016. In 2007, some of the classrooms in the old building had a new roof covering. There was the replacement of the old material, with a good sound absorption material, by PVC coating. As expected, the new building presented classrooms with greater acoustic comfort. In the classrooms of the old building, the refurbishment of ceilings decreased their acoustic quality. In short, this paper shows that the decision to replace the original room coverings with PVC resulted in a gross error.

1. INTRODUCTION

The learning process depends on several elements such as lecturer, student, didactic material, environment, climate, among others. Educational institutions must offer proper physical spaces to the development of activities. The acoustic quality of the teaching place is one of the variables that strongly influence students' learning. Unfavourable acoustic conditions make learning activities exhausting [1]

Speech consists of a succession of sounds that vary rapidly from moment to moment in intensity and frequency [2]. Speech intelligibility is described by Long [3] as a method of direct measurement of the understanding of the fraction of words or sentences by a listener. Hongisto, Keranen and Larm [4] describe two main ways of calculating speech intelligibility. The audiological method, described in the American National Standards Institute (ANSI) S12.6 [5], introduces the speech intelligibility index (SII) or articulation index (AI). The modulation transfer function (MTF) method, described in IEC 60268-16: 2011 [6], introduces the speech transmission index (STI). According to Lazarus et al. [7], STI is one of the most comprehensive and important speech intelligibility parameters. The index takes into account most conditions that can cause deterioration of speech intelligibility, such as reverberation time and background noise. This work aims to analyze the acoustic quality with which the teachers' discourse reaches students, to verify the speech intelligibility linked to the classrooms through the impulsive methods STI, RT and D_{50}. In cases where low intelligibility was observed, simulations with material changes are proposed to correct the environment in terms of acoustics.

2. METHODOLOGY

The present work contemplates two stages: the first consists of collecting data through sound measurements and the second in mathematical modelling using the ODEON 11.00 combined software.

2.1 Study Area and data collection procedure

In the data collection stage, measurements of STI, RT and D50 were carried out in the classrooms of the two buildings at the Polytechnic Center of UFPR. One of the buildings was built in the 1960s, and the investigated classrooms were PG03, PG 04, PG05, PG06, PG07 and PG 15. The second building is from the Exact Sciences sector and was built in 2016, where the investigated classrooms were PA01, PA03 PA05 and PA06. This stage was carried out in periods when the rooms were not being used for class (Fig.1). Most of the measurements took place on Saturday afternoons, so there was no interference of students during the measurement period. Birds, as well as distant horn and aeroplane sounds, were the external background sounds present during the recordings. These sounds were considered for mathematical modelling.

Figure 1. Measurements campaign

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The STI measurements were collected using the artificial mouth always in the same position: simulating a lecturer standing on the classroom stage at the height of 1.50 m. The sound level meter, on the other hand, was moved throughout the classroom, in places where students usually sit to watch classes at the height of 1.20 m. The stimuli was a MLS signal, with male filter and 1.37 seconds length.

For the RT and D50 measurements, the same equipment heights and positions from the STI measurements were adopted. The stimulus was an e-sweep with 2.73 seconds length.

2.2 Equipment used in the data collection

In the STI measurements, a computer installed with the software Dirac 3.1 (B&K 7841), a sound card (RME Fireface 800), a sound pressure meter (B&K 2260), an equalizer (Behringer FBQ 800), an amplifier (Lab Gruppen LAB 300) and an artificial mouth (directional speaker B&K 4227) were used. For the measurement of the RT, the same equipment was used with small changes. Instead of an equalizer and an artificial mouth, it was used a dodecahedral loudspeaker (omnidirectional loudspeaker) as a sound source.

2.3 Mathematical modelling

First, the classrooms were built in a virtual environment, using SketchUp software. The classrooms already assembled and with their layers (ceiling, floor, windows, tables, seats, etc.) were finally exported to ODEON 11.00. Classroom dimensions can be observed in Table 1.

Table 1. Classrooms dimensions

Ceiling material	Classroom	Length [m]	Width [m]	Height [m]	Volume [m^3]
PVC	PG03	7.45	11.3	4.07	322
PVC	PG04	7.5	11.46	3.44	286
Celotex M1	PG05	7.47 – 3.20	7.15 – 3.65	3.4	131
PVC	PG06	7.45	11.3	4.07	330
PVC	PG07	10.12	11.24	3.16 – 4.10	396
PVC	PG15	7.47	10.82	2.85 – 4.40	285
Thermotex	PA01	6.8	11	2.64	197
Thermotex	PA03	6.8	12.34	2.75	234
Thermotex	PA05	6.9	10.29	2.75	195
Thermotex	PA06	6.9	7.24	2.64	132

The absorption coefficients for the ceiling materials are observed in Table 2.

Table 2. Absorption coefficients of the ceiling materials

Material	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Clotex M1	0.12	0.48	0.50	0.79	0.93	0.82	0.48
PVC	0.03	0.03	0.04	0.05	0.05	0.06	0.06
Thermotex	0.05	0.05	0.04	0.55	0.65	0.45	0.45

Sources: [8-10]

3. RESULTS

The STI results with male filter are showing that for the old building with PVC ceiling, some classrooms are perfectly calibrated (PG05 and PG15) with similar results between measurements and simulations. In PG03 and PG04 the measurements presented greater results and in PG06 and PG07 the simulations are showing greater results. Regarding speech intelligibility, the classroom with best results was PG05 both for measurements and simulations, with values around 0.75 which is considered an excellent STI. Coincidentally this classroom has the smallest volume compared to the other classrooms with denomination "PG", which presented fair STI averages between 0.4 and 0.6. Another critical factor is the ceiling material of this classroom, which is one of the left classrooms with the original ceiling (Celotex M1), the other "PG" classrooms changed the ceiling material to PVC on a refurbishment in the recent years.

Regarding the STI values distribution, PG15 and PG04 concentrated the results in the first quartile (orange colour) and the other classrooms in the third quartile (grey colour). In the new building with Thermatex acoustic ceiling, it is observed that PA01 presented more remarkable results in the measurements and the other classrooms with denomination "PA" are showing greater results in the simulations. All classroom are classified as with a good speech intelligibility, due to STI values between 0.6 and 0.75. In the classroom with greater volumes, PA01 and PA03, the STI values presented greater variance. In PA03 the variance of STI values occurred in the third quartile (grey colour) (Figure 1).

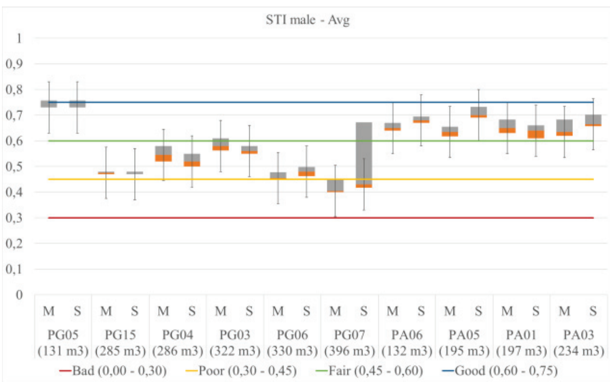

Figure 2. Male STI averages of measurements and simulations in classrooms with PVC ceiling (PG classrooms excluding PG05), Celotex M1 ceiling (PG05) and Thermatex ceiling (PA classrooms)

As observed in the STI averages with male filter, a similar physical behaviour was observed regarding sound definition (D_{50}). In the old building, the greatest values are presented in the classroom PG05, with values between 0.75 and 0.85 and in the new building in PA01, with average values between 0.65 and 0.75. All other classrooms from the old building showed values under 0.6, and in the new building, the average vales are under 0.75. Regarding the averages values distribution in the old building, the majority of the classrooms presents values in the third quartile, with the exception of the classroom PG04. In the new building averages distribution concentrated in the third quartile. The first quartile was highlighted in PG05 at 500 Hz – 2 KHz, PG15 at 500 Hz, and in PG07 at 500Hz and 1 kHz. For the new building, values in the first quartile were highlighted in PA05 at 1kHz and 2 Khz, PA01 and PA03 at 2kH (Figure 3).

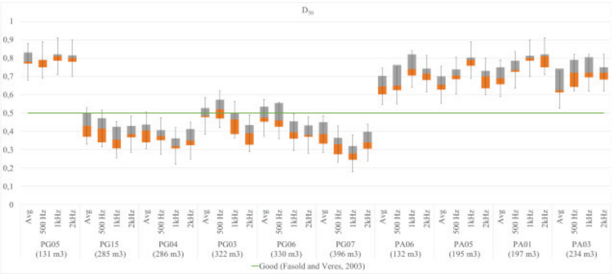

Figure 3. D_{50} averages of measurements in classrooms with PVC ceiling (PG classrooms excluding PG05), Celotex M1 ceiling (PG05) and Thermatex ceiling (PA classrooms)

Regarding T30, small reverberation time averages are observed in PG05 at the old building, with values under 0.5s and in the classroom PA01 of the new building with average values bellow 0.8 s. The greatest average values of T30, indicating a worst acoustic condition are shown in PG07 of the old building. Average values distributed in the first quartile are normally observed in PG 05, PA 06 and PA01. At 500 Hz values distributed in the first quartile are observed in PA06. At 1kHz the first quartile values distribution is highlighted in PG15, PG04 and PG06, as well as in PA03. At 2 kHz the first quartile vales distribution were observed in PG05, PG03 and PG06 in the old building, and in PA05, PA01 and PA03 in the new building.

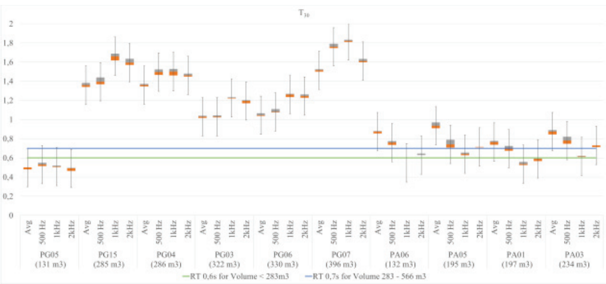

Figure 4. T_{30} averages of measurements in classrooms with PVC ceiling (PG classrooms excluding PG05), Celotex M1 ceiling (PG05) and Thermatex ceiling (PA classrooms)

4. DISCUSSION

As observed in the average measured values of STI, D50 and T30, the PG05 room has the best speech intelligibility, sound definition and reverberation time and, consequently, is the best of the environments analyzed for good learning. It is not by chance that it is the only classroom in the named "PG" classrooms, of the building from the 60s, which maintained the original acoustic ceiling. It represents the acoustics that the classrooms of the building of the 60's should have before the alterations of the original acoustic ceiling by a PVC ceiling.

The standard adopted for measurement, IEC 60268-16: 2011, suggests in its Annex G that the STI value for classrooms should be above 0.62. This reference, further demonstrates the lack of quality of the rooms PG03, PG04, PG06, PG07 and PG15, all of the old construction. In contrast, the rooms in the most recent building and PG05 are within the standard's suggestion for specific application in classrooms.

5. CONCLUSION

This work aimed to analyze the acoustic quality with which the teachers' discourse reaches students, to verify the speech intelligibility linked to the classrooms through the impulsive methods STI, TR and D_{50}.

The findings of the acoustic evaluation and modeling indicated that the exchange of the acoustic ceiling for a PVC ceiling in the older rooms of the Polytechnic Center impaired speech transmission in the classrooms, being confirmed through the results obtained in the simulations carried out. Therefore, it is recommended that UFPR resume the coating to reestablish the acoustic quality of the rooms.

It is important to search for sound-absorbing materials with great coefficients during the maintenance and refurbishment of classrooms. The reduction of classroom volumes or either by lowering ceilings - facilitating the installation of acoustic ceilings - or by raising the floor, like the platforms, are options for the improvement of classrooms acoustic.

6. ACKNOWLEGDMENTS

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