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ASSESSMENT OF REVERBERATION TIME IN THREE RENOVATED CLASSROOMS THROUGH FIVE INTERNATIONAL STANDARDS

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Abstract. *In room acoustic theory is well-known that any change in a room can dramatically alter the acoustic comfort on it. Consequently, before furthers changes, the room designer should evaluate if the changes are beneficial or not, especially when considering sensitive establishments as classrooms. Accordingly, this work is a case study that aims to make an acoustic assessment of three classrooms, built in the 60's decade, which in 2007 those classrooms underwent a renovation, that changed the original acoustic ceiling revetment, CELOTEX M1, to a PVC ceiling. This assessment was done by measuring the Reverberation Time (RT) using IS0 3382-1, at two distinct time frames, the first one, in 2004 and the second, in 2017. The RT values were then compared to the values recommended by international standards from Brazil (12179/1992), France (Decree/1995), Japan (JIS A 1419/2000), United States of America (ANSI-ASA S12.60/2010) and World Health Organization (WHO), which stated the RT for classrooms. The results evidenced that the change of acoustic ceiling by the PVC impaired the acoustic quality in all studied classrooms. The current classrooms, with PVC acoustic ceiling, are considered inadequate for the intelligibility, according to the standards used. In conclusion, it was possible to demonstrate how important it is considering the impact of any change in the classroom regarding its acoustic comfort.*

Keywords: *Classroom Renovation, Reverberation Time, Room Acoustics, Acoustic quality.*

1. INTRODUCTION

The unplanned growth of urban centers, the new techniques used in construction, the appearance of diseases related to noise pollution, among other factors has caused a significant increase in the study of issues related to acoustic quality in classrooms. Acoustical comfort has been sought by architects and engineers in various scenarios, besides, currently, architectural acoustics is not limited to theaters, cinemas, studios, and churches, but also, encompasses environments of day to day life as in homes, offices, and classrooms (Houtte, 2011).

Notably, classroom noise interferes heavily in the teaching-learning relationship and can cause, under certain circumstances, health risks. Also, several negative effects are present, including psychophysiological ones, such as stress and blood pressure increase (Hustim, 2018). In addition, changes in auditory thresholds, tinnitus, fatigue, too much effort to maintain concentration and loss of some of the content taught are manifested (Stansfeld and Clark, 2015; Peng, Zhang, and Wang, 2018; Paiva, Cardoso and Zannin, 2019; Wallas et al., 2019). Often, this noise competes with the teacher's voice, which leads to a low intelligibility rate in the classrooms, resulting in the loss of comprehension of numbers and words in complex sentences. This effect is found to be pronounced in literacy-level students and early school-age students (Musacchia et al., 2018). Nonetheless excessive classroom's noise could be avoided due to a proper classroom acoustic design, moreover, the Reverberation Time (RT) can be used quantitatively to evaluate if a classroom is in compliance with the standards for a good acoustic condition designed for learning (Yang and Bradley, 2009).

As Cavanaugh, Tocci and Wilkes (2010) recognize that RT is one of the fundamental descriptors of acoustics. They define RT as the time required for the sound level of excitation to undergo successive reflections and absorptions on surfaces, such as walls, ceilings, and floor until the sound pressure level of that excitation ceases and becomes inaudible, or that it equals ambient background noise. RT is intrinsically associated with the purpose of use to which the room is intended, e.g., an RT considered to be optimal for activities involving speech is not necessarily the same if the room is used for musical purposes. For educational purposes, the RT has considerable variability, since many countries adopt their own subjective criteria of what will be their optimal reverberation time. Thus, in order to compare RT at a broader range, special attention should be paid to such recommendations, which may establish specific restrictions depending on the country's standard. For example, the British standard BB93 (DFE, 2015) states that the RT is to be measured in unoccupied and unfurnished rooms, while the German standard DIN 18041:2004 (DIN, 2004) classifies rooms by its volume with specific abacuses and the room must be unoccupied.

Then, this work has two main objectives, the first objective is to evaluate the acoustic quality of three classrooms in the Federal University of Paraná (UFPR), at Polytechnic Center campus, through RT measurements. Additionally, these classrooms were built in the 1960's decade and underwent some changes over time, including a major change of the original Celotex M1 ceiling to a newer PVC ceiling. Afterward, the second objective is to verify if the ceiling change was beneficial or not, regarding the optimal values established for RT presented in five international standards for classroom acoustics quality assessment.

2. METHODOLOGY

This work was divided as (1) measurement of reverberation time into three classrooms namely, PG 01, PG 05 and PG15, following the guidelines of ISO 3382-1; (2) comparison between the previous measured RT values from Zannin and Ferreira (2009) using the original ceiling, composed by the Celotex M1 material, which had a higher mean sound absorption coefficient (0.54), in front of the newer ceiling, that was made of Polyvinyl Chloride known as PVC, with lower mean sound absorption coefficient (0.05) as shown in Tab. 1

Table 1. Comparison of the ceiling's sound absorption coefficient between the original and the renovated classrooms

Octave Band frequency (Hz)	125	250	500	1k	2k	4k	8k	Mean
Celotex M1 (Original room setup)[(1)]	0.12	0.48	0.50	0.79	0.93	0.48	0.48	0.54
PVC ceiling (renovated room) [(2)]	0.03	0.03	0.04	0.05	0.05	0.06	0.06	0.05

[(1)] Knudsen (1978), [(2)] Forouharmajd et al. (2016)

Figure 1 shows the comparison of the original ceiling manufactured in the 1960's decade and the renovated ceiling from the 2010 decade.

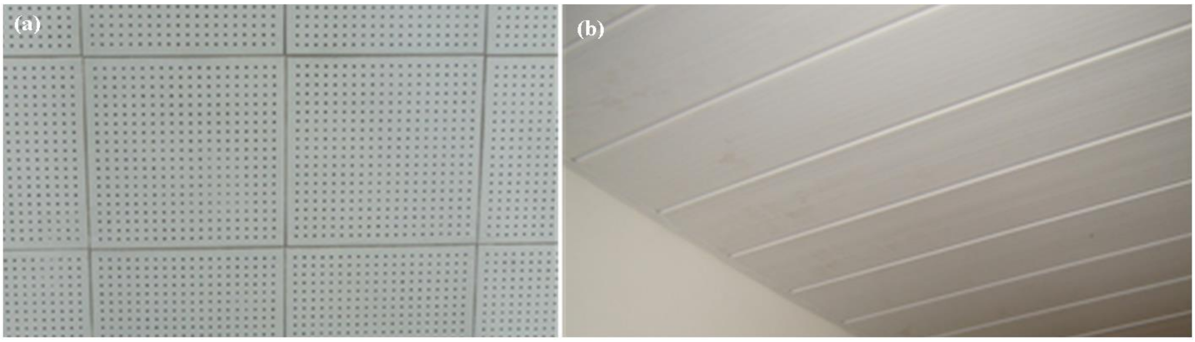

Figure 1. Comparison of ceiling type; (a) Original - Celotex M1; (b) Renovated - PVC

RT measurements were performed in furnished and unoccupied classrooms, with the doors and windows closed and on rainless days. This work used the impulse response method for the measurements following the guidelines from ISO 3382-1 (ISO, 2009). Figure 2 shows the employed equipment and the measurement chain.

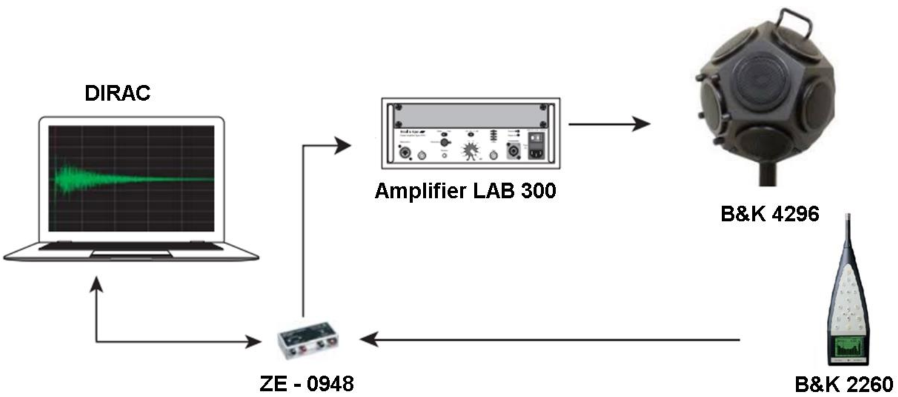

Figure 2. The instrumentation set up to measure RT via impulsive response method

The DIRAC 5.0 software was set up to measure the reverberation time (T60) using an e-sweep signal, as the excitation signal. The duration of this signal sized to be 1.5 times greater than the value of the estimated reverberation time by means of a previous measurement with the excitation time greater than 4 seconds. The dodecahedral sound source was positioned at a height of 1.5 m above the ground and at a distance of more than 1.2 m from the walls, measurements were taken in at least 4 receiver positions for using B&K 2260 analyzer.

Figure 3 shows the measurement's instrumentation and its setup, which were: a) DIRAC 5.0 software Burel &Kjaer 7841 or B&K 7841, installed on Sony VAIO notebook; b) B&K USB Audio Interface ZE-0948 c) power amplifier Lab. Gruppen LAB 300; d) sound pressure level analyzer B&K 2260 and e) omnidirectional dodecahedral sound source B&K 4296.

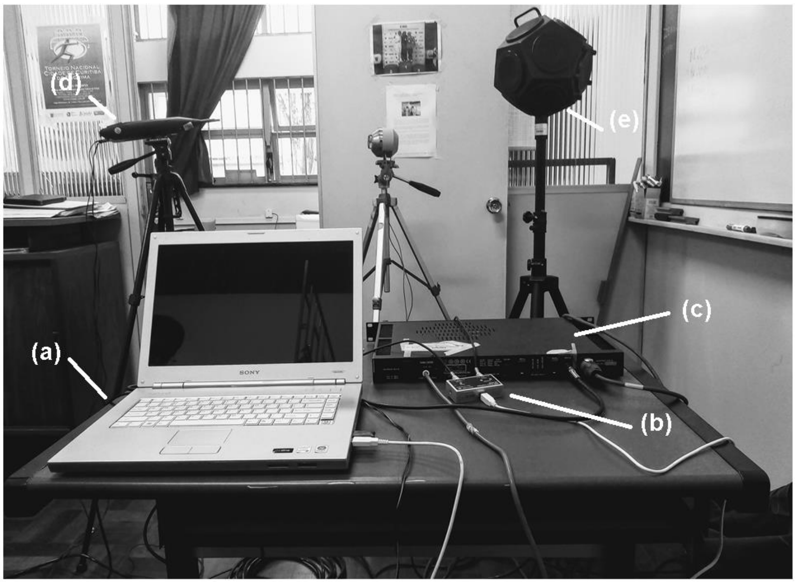

Figure 3. Measurement's instrumentation chain and its set up

Regarding classrooms, numerous standards have different reference values for RT. Then, Tab. 2 shows the optimum RT used in several countries as a function of room volume. In addition, Tab. 2 encompasses the general recommendation of the World Health Organization (WHO), which requires an average reverberation time about 0.6 s, regardless of the classroom volume.

Table 2. Recommend RT in various countries[1]

Country / Standard	Recommend time (s)	Volume (m^3)
Brazil / NBR – 12179:1992	0.6 up to 0.7	$270 \leq V \leq 600$
France / Decree:1995	$0.4 < RT \leq 0.8$ $0.6 < RT \leq 1.2$	$V \leq 250$ $V > 250$
Japan / JIS A 1419:2000	RT = 0.6 RT = 0.7	$V \leq 200$ $V > 300$
United States of America / ANSI/ASA S12.60:2010	RT = 0.6 RT = 0.7	$V \leq 283$ $283 \leq V \leq 566$
World Health Organization (WHO)	TR = 0.6	--

[1] Zannin et al. (2011)

As a note, the Brazilian Standard, NBR 12179, evaluates the reverberation time at 500 Hz only, and for room use, it was considered the conference rooms category, which is defined in NBR 12179 (ABNT, 1992). But seeking to make a fair comparison of the RT for each standard it was calculated the mid-frequency reverberation time, that is the mean value of RT for 500 Hz, 1000 Hz and 2000 Hz for furnished and unoccupied rooms.

3. RESULTS

Table 3 shows the measured RT values at each classroom, in both situations, that was the original classroom ceiling (Celotex M1) and the renovated classroom ceiling (PVC). The original ceiling acoustic revetment of the three classrooms was replaced in 2007 by a PVC ceiling, according to an acoustic evaluation in classrooms conducted by Zannin et al (2011).

Table 3. RT's comparison values between original and renovated classrooms

	RT (s) to original classrooms(1,2)			RT (s) to renovated classrooms		
Octave band (Hz)	PG 01	PG 03	PG 15	PG 01	PG 03	PG 15
125	1.3	0.8	1.0	1.4	0.9	1.5
250	0.9	0.8	1.0	1.1	0.9	1.2
500	0.9	0.7	1.0	1.6	1.0	1.5
1000	0.8	0.6	0.9	1.6	1.2	1.7
2000	0.8	0.6	0.9	1.6	1.1	1.6
4000	0.7	0.5	0.7	1.4	1.1	1.4
Mean	0.85	0.65	0.95	1.5	1.5	1.5

(1)Zannin and Ferreira (2009) (2)Zannin, Fiedler and Bunn (2013)

Figure 4 shows a graphical comparison between RT, before and after the classroom's renovation design. It can be inspected based on Fig. 2 that RT increased after classroom renovation.

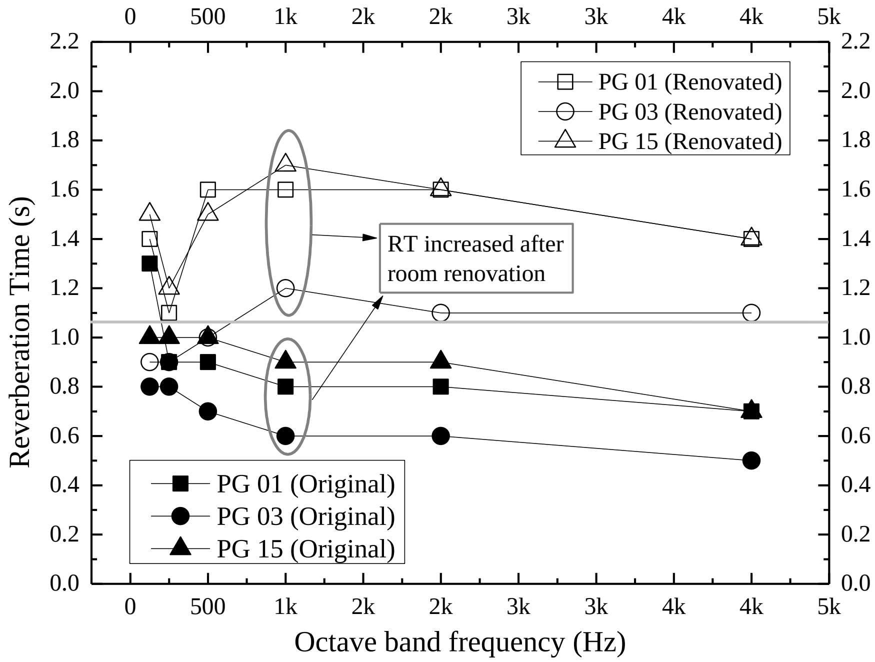

Figure 4. Reverberation time versus frequency. It shows the overall increase in RT after room renovation

Also, in spite of the volume difference between the studied classrooms, it can be asserted that the, in general, the reverberation time, increased after the classroom renovation process, as shown in Table 4. The classroom volumes for PG 01, PG 03 and PG 15 were 367.18 m^3, 294.74 m^3 and 350.53 m^3 respectively.

Table 4. RT percentage increase after classroom renovation

Octave band (Hz)	PG 01	PG 03	PG 15
125	7,69%	12,50%	50,00%
250	22,22%	12,50%	20,00%
500	77,78%	42,86%	50,00%
1000	100,00%	100,00%	88,89%
2000	100,00%	83,33%	77,78%
4000	100,00%	120,00%	100,00%

Based in Tab. 3, that showed the RT measurements results for those 3 classrooms, they were compared to the standards as shown in Tab. 5.

Table 5. Comparison of original and renovated classrooms with various standards

Room	Condition	Brazil	France	Japan	USA	WHO
PG 01	Original	Inappropriate	Appropriate	Inappropriate	Inappropriate	Inappropriate
	Renovated	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate
PG 03	Original	Appropriate	Appropriate	Appropriate	Appropriate	Inappropriate
	Renovated	Inappropriate	Appropriate	Inappropriate	Inappropriate	Inappropriate
PG 15	Original	Inappropriate	Appropriate	Inappropriate	Inappropriate	Inappropriate
	Renovated	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate

Not all classrooms using the original acoustic revetment, CELOTEX M1, are in compliance with all international standards as shown in Table 4, but it was evident that the substitution by PVC worsened the acoustic quality of the rooms. The value of RT almost doubled for the renovated classrooms. Correspondingly, after the renovated classrooms design none of the classrooms are adequate by the Brazilian standard NR 12179.

4. CONCLUSIONS

This work had two main objectives: first, evaluate the acoustic quality of three classrooms, through the reverberation time descriptor. And secondly, to verify if the change of the acoustic ceiling, that happened a few years ago, by PVC ceiling has impaired this quality. It was also observed that the classrooms are classified as inadequate by most of the standards of several countries after classroom renovation.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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