USING THE PARAMETERS OF DEFINITION, D50, AND REVERBERATION TIME, RT, TO INVESTIGATE THE ACOUSTIC QUALITY OF CLASSROOMS

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Résumé

Les paramètres de définition, D50, et le temps de réverbération, RT, ont été utilisés dans cette étude pour évaluer la qualité acoustique des salles de classe qui avaient été rénovées. Les paramètres D50 et RT ont été mesurés par la méthode de la réponse impulsionnelle. L'analyse de RT dans les salles de classe après leur rénovation montre que ce paramètre a augmenté. L'analyse des valeurs mesurées de D50 a conduit à la conclusion que, malgré l'augmentation de la RT, de nombreux points à l'intérieur des classes affichées bonne qualité acoustique. Cette découverte suggère que les évaluations de la qualité acoustique des salles de classe devraient impliquer non seulement l'analyse de RT, mais aussi du paramètre de la définition, D50.

Mots clefs: Le Temps de Réverbération, Définition, Salles de classe, La qualité acoustique.

Abstract

The parameters of Definition, D_{50}, and Reverberation Time, RT, were used in this study to evaluate the acoustic quality of classrooms which had been renovated. The parameters D_{50} and RT were measured via the impulse response method. The analysis of RT in the classrooms after their renovation shows that this parameter increased. The analysis of the measured values of D_{50} led to the conclusion that, notwithstanding the increase in RT, many points inside the classrooms still displayed a fair acoustic quality. This finding suggests that evaluations of the acoustic quality of classrooms should involve not only the analysis of RT but also of the parameter of Definition, D_{50}.

Keywords: Reverberation time, Definition, Classrooms, Acoustic quality.

1 Introduction

This article reports on a study of the acoustic quality of two classrooms after they were renovated. The main renovation consisted of the substitution of the ceiling material, after which the faculty members teaching in these classrooms reported that they had the impression that the rooms were "noisier" and that they felt they had to talk louder. In principle, the decrease in acoustic quality was due to the substitution of the original acoustic ceiling tiles for PVC ceiling panels.

Research on acoustic quality of classrooms is described in the current literature, both in public schools and in university classrooms [1-6]. The acoustic performance of classrooms is usually analyzed based on the reverberation time [3-6]. This paper describes a study of the acoustic quality of classrooms based not only on the reverberation time, RT, but also on the parameter of Definition D_{50}, which is described by Fasold and Veres [7].

2 Materials and Methods

2.1 Characteristics of the classrooms before their renovation

The classrooms are located in the Polytechnic Center of the Federal University of Paraná in Curitiba, Brazil. These classrooms, which are referred to here as PG04 and PG 06, were originally built with the same dimensions as an auditorium and a volume of 295 m^3. The ceiling in both classrooms was lowered and covered with acoustic ceiling tiles [5] (see Figure 1). The material shown in Fig. 1 was supplied by the manufacturer in the form of 2 cm thick 30 x 30 cm tiles. After their renovation, the acoustic lining illustrated in Figure 1 was replaced with PVC ceiling panels (Figure 2). Brazilian manufacturers supply PVC ceiling panels with 3.65 m length, 12 cm width and 1 cm thickness.

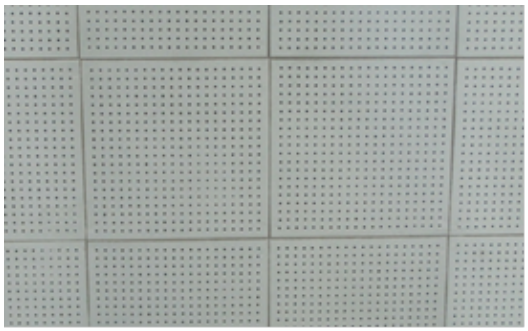

Figure 1: Acoustic ceiling tiles.

Figure 2: PVC ceiling panels.

Table 1 shows the sound absorption coefficient of the materials used in the ceiling of the classrooms before and after the modification. The acoustic ceiling tile absorption coefficient was taken from the book "Acoustical Designing in Architecture," by Knudsen and Harris [5]. The sound absorption coefficient of the PVC ceiling tiles was obtained from the Institute for Technological Research, of the University of São Paulo, which is the largest university in Latin America.

Table 1: Absorption Coefficient of the ceiling.

Absorption Coefficient	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Acoustic ceiling tiles [8]	0.25	0.49	0.69	0.78	0.61	0.48
PVC ceiling tiles [9]	0.01	0.01	0.02	0.02	0.02	0.02

Table 2 shows the reverberation times measured before the ceiling tiles were substituted [4]. No measurements of the parameter D_{50} were taken performed before the classrooms were renovated.

Table 2: RT measured in rooms PG 04 and PG 06

Frequency [Hz]	PG 04	PG 06
125	0.9	1.0
250	0.8	0.7
500	0.7	0.7
1,000	0.7	0.6
2,000	0.6	0.6
4,000	0.5	0.5
Average RT	0.70	0.68

2.2 Characteristics of the classrooms after their renovation

Room PG 04 underwent the greatest changes, with the removal of its floor, which increased its original volume of 295 m^3 to 331 m^3. In addition, the original four-student desks were replaced with individual desks and chairs, as illustrated in Figures 3 and 4.

Figure 3: Room PG 04 today

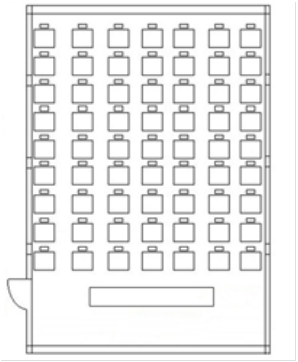

Figure 4: Floor plan of room PG 04.

The original auditorium design and volume of 295 m^3 of room PG 06 were left unchanged, as shown in Figures 5 and 6.

Figure 5: Internal view of room PG 06.

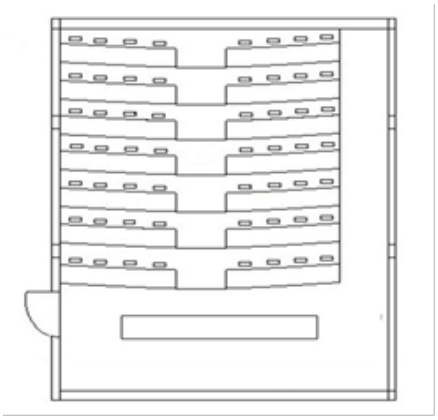

Figure 6: Floor plan of room PG 06.

Measurements were performed with the method of the impulse response, as recommended by the standard ISO 3382-2:2008 – Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms [10]. The measurements were taken with the following devices: a Brüel & Kjaer 4296 omnidirectional sound source, Brüel & Kjaer 2238 sound level meter, DIRAC 3.1 software and Fireface 800 audio interface. The measurements in both classrooms were taken with the sound source located at the center on the stage, in the position typically occupied by the teacher (Figure 7). The sound analyzer was positioned at the location of the students' chairs, at a height of 1.2 m from the ground (Figure 8).

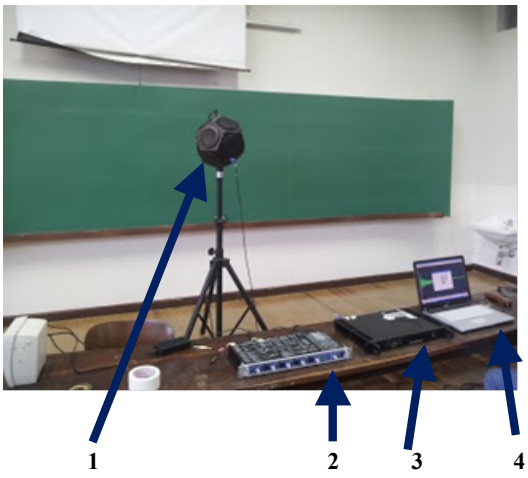

Figure 7: Equipment for measuring RT and D50 : 1) Omnidirectional sound source; 2) Fireface 800 audio interface; 3) Power amplifier; 4) Notebook with Dirac software.

B&K 2238 sound level meter – Room PG 06

Figure 8: Position of the sound level meter at the students' seats.

Figure 9 depicts the positions of the 18 points evaluated in room PG 04 while Figure 10 shows the positions of the 23 points measured in room PG 06.

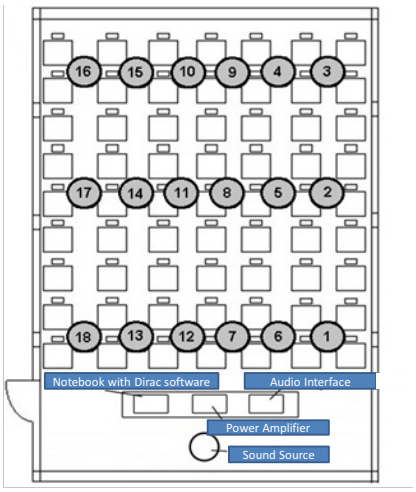

Figure 9: Location of the measuring points in room PG 04.

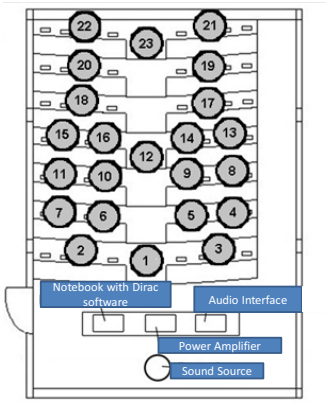

Figure 10: Location of the measuring points in room PG 06.

As reference values for comparison, the values suggested by Marshall [11] were used for D_{50} (Table 3), and those suggested by WHO [12-13] and by the Brazilian standard NBR 12179 [14] for RT (Table 4).

Table 3: D50 values calculated from Figure 6 of Marshall's paper [11].

	D_{50} [%]
Excellent	0.86 to 1.0
Good	0.67 to 0.86
Fair	0.39 to 0.67
Poor	0.17 to 0.39
Bad	0.06 to 0.17

Table 4: Recommended reverberation times for classrooms

Country	Reverberation Time - RT [s]	Volume – V [m^3]
Brazil[14]	0.6 to 0.7	$270 \leq V \leq 600$
WHO[12-13]	RT = 0.6	-

3 Results and Discussion

Table 5 lists the RT measured in room PG 04, and Table 6 describes the values of D_{50} measured in this classroom.

Table 5: Measured RT in room PG 04

Frequency [Hz]	RT [s]
125	0.97
250	1.03
500	1.25
1000	1.17
2000	1.11
4000	1.03
Average RT	1.1

Table 6: Measured D_{50} in room PG 04

Position of the measuring points	D_{50} [%]
1	0.47
2	0.34
3	0.32
4	0.38
5	0.44
6	0.51
7	0.54
8	0.41
9	0.33
10	0.33
11	0.42
12	0.47
13	0.54
14	0.36
15	0.30
16	0.30
17	0.49
18	0.53

The figure 11 below represents the combined results of the RT measurements of classroom PG04 before and after its renovations (changes in acoustic ceiling tiles and room volume) and of classroom PG06 after the change in acoustic ceiling material.

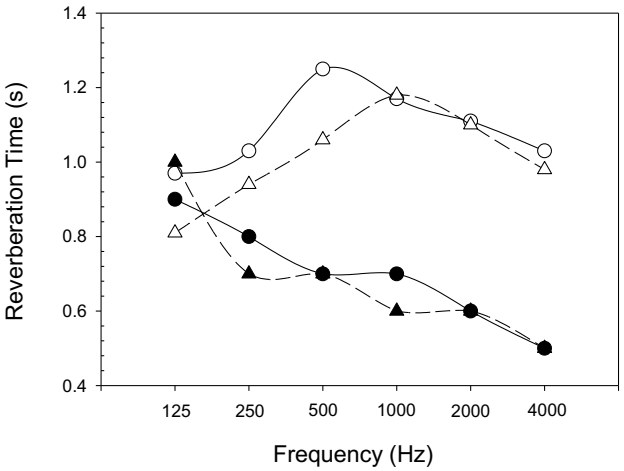

Figure 11: Reverberation times (s) in PG04 (circle) and PG06 (triangle) before (black symbols) and after (white symbols) the renovations.

Figures 12 and 13 show the PG04 classroom fully occupied at the time of measurement of RT. Figure 14 shows the measurements of the RT, in three different situations: 1) With acoustic ceiling tiles – black circles – empty room; 2) After renovation, with PVC ceiling panels – white circles – empty room; and 3) After renovation with PVC ceiling panels, grey circles – room fully occupied. The maximum classroom capacity is of 50 students. The average RT for situation 1 is 0.70 s, for the situation 2 the average RT is 1.1 s and for the situation 3 the average RT is 0.75 s.

Figure 12 : Measurement of RT in room PG04

Figure 13 : Measurement of RT in room PG04

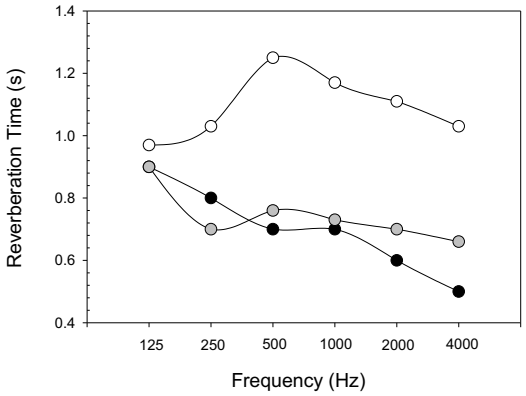

Figure 14: Reverberation time measurements in room PG04

Figure 14 shows that when the classroom is fully occupied, the average RT is equal to 0.75 s, and is slightly above the upper limit set by the Brazilian Standard [14], which states that the optimal RT should be between 0.6 and 0.7 s as can be seen in Table 4.

Table 7 describes the RT measured in room PG 06 while Table 8 lists the values of D_{50} measured in the same classroom.

Table 7: Measured RT in room PG 06

Frequency [Hz]	RT [s]
125	0.81
250	0.94
500	1.06
1000	1.18
2000	1.10
4000	0.98
Average RT	1.0

The RT was analyzed based on a comparison of the values measured before (Table 2) and after (Tables 5 and 7) the renovation. As can be seen, the RT in room PG 04 increased by 57%, passing from an average value of RT 0.70 s to 1.1 s, while in room PG 06 the RT increased by 47%, with the average value passing from 0.68 s to 1.0 s. It was found that after the renovation, the average values of RT exceeded the recommended values listed in Table 4, indicating a decline in the acoustic quality of the classrooms. In room PG 04, the measurements of D_{50} taken at the first row of desks, indicated on the floor plan in Figure 15, show values ranging from 47 to 54%. These values are considered *Fair*, according to Marshall [11] (Table 3). The six measuring points located in the middle of room PG 04 showed D_{50} values ranging from 34 to 49%, varying from *Poor* to *Fair*. The last 6 points in Figure 12 showed D_{50} values of 30 to 38%, which are considered *Poor*. Of the 18 points measured in room PG 04, the acoustic quality reached at 10 points was considered *Fair*, while at 8 points the quality was considered *Poor*. The renovation in room PG 04 involved not only the substitution of its acoustic ceiling tiles but also a change in its volume due to the removal of its floor, which altered the room's original volume of 295 m^3 to 331 m^3 (see Figures 3 to 6)

Table 8: Measured D_{50} in room PG 06

Position of the measuring points	D_{50} [%]
1	0.52
2	0.60
3	0.60
4	0.50
5	0.44
6	0.54
7	0.36
8	0.36
9	0.45
10	0.45
11	0.39
12	0.49
13	0.42
14	0.40
15	0.42
16	0.38
17	0.44
18	0.43
19	0.39
20	0.41
21	0.36
22	0.33
23	0.49

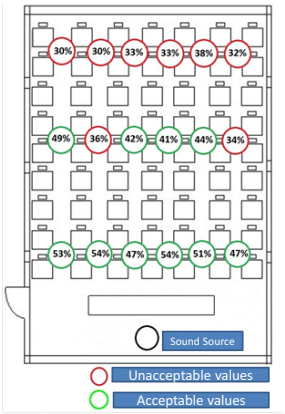

Figure 15: Floor plan of room PG 04, showing the location of the measuring points and the values of D_{50} in percent [%]. The *green color* shows the points within the range of 39% to 67%, which are considered *Fair*, according to Marshall [11].

Figure 16 illustrates the values of D_{50} measured in room PG 06. As can be seen, only 5 of the 23 points measured in this classroom showed an acoustic quality rated as *Poor*

[11]. On the other hand, the vast majority of points, i.e., 18 points, achieved the qualitative evaluation of *Fair* conformed Marshall [11].

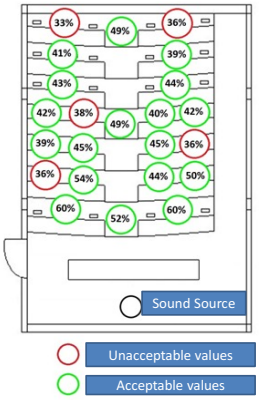

Figure 16: Floor plan of room PG 06, showing the location of the measuring points and the values of D_{50}, in percent [%]. The *green color* shows the points within the range of 39% to 67%, which are considered *Fair*, according to Marshall [11].

4 Conclusions

The present study indicated that the acoustic quality descriptor of Definition, D50, is a parameter that can complement the traditional analysis of quality of classrooms basead on measurements of RT. As shown by the RT measurements taken before and after the renovations, the acoustic quality of the classrooms decreased markedly, as indicated by the increase in the average RT.

This work also shows the mistake with the change in the ceiling of the classroom. It is clear that the use of PVC ceiling increased the RT in classrooms. The measurement of RT in fully occupied PG04 showed that the average RT approached the limit indicated by the Brazilian Standard [14], as can be seen in Table 4.

Also important for assessing the acoustic quality of classrooms is the measurement of STI - Speech Transmission Index [15], but for that it is necessary to have the proper equipment – a *mouth simulator*.

Finally, it should be mentioned that changing the ceiling of the classroom was an administrative decision, without having gone through the evaluation of the Acoustics Laboratory of the Federal University of Paraná.

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