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Reverberation time in classrooms ï Case Study: When an administrative decision changes acoustic quality

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This paper describes a case study about the acoustical quality of classrooms in a public National University relating to the parameter reverberation time (RT). It is shown that, after wrong administrative decisions, classrooms which previously displayed good acoustical quality with respect to RT values, showed a change in this parameter due to a change in the covering of the ceiling. Final RT values after the change in the material covering the ceiling of these classrooms caused them not to fit into the values required by either National or International Standards, or the World Health Organization.

Keywords: classrooms, reverberation time, acoustic quality, measurements.

Introduction

Various sectors of society are affected by noise, particularly noise generated by traffic. Traffic noise causes discomfort and irritation, affecting especially activities requiring attention and concentration. In response to increasing levels of urban and industrial noise, numerous studies have focused on environments intended for activities that involve a high level of intellectual and cognitive activity, such as educational and working environments[1-8]. Several studies have dealt with the problem of environmental noise[9-19].

Education plays a fundamental role in the formation of modern society. The importance of education for humans is expressed thus by renowned Brazilian educator Paulo Freire[20]: *"The fountainhead of man's hope is the same as that of his educability: the incompleteness of his being of which he has become aware. It would be a sorry contradiction if, incomplete and aware of this incompleteness, man were not engaged in a permanent process of hopeful search. This process is education*ò[20].

The classroom is the environment people experience throughout the years from primary school to university. Any nation that aspires to compete in the economic and scientific fields of todayô globalized world includes the education of its citizens in its plans. Therefore, the classroom environment should favor the crucial practice of teaching and learning. This paper discusses an opposite acoustic problem. In general, one starts from the existence of a problem involving the absence of an adequate acoustic environment, for example, too high or too low reverberation time, and then seeks to adjust the environment to render its reverberation time compatible with its intended use, e.g., a classroom. However, this paper discusses a real case of various environments ï different classrooms - whose acoustics were ñimpairedò - as a result of a purely bureaucratic decision that had nothing to do with acoustic engineering and/or room acoustics.

Materials and Methods

An important parameter affecting the acoustic quality of rooms is the reverberation time RT. According to the ISO 3382-1[21], RT can be measured by the interrupted noise method. In this study the measurements were taken with Brüel and Kjaer instruments[22, 23]: 1) an Omni directional source, 2) a sound power amplifier, 3) a BK 2260 sound analyzer. Various acoustic standards present reference values for the RT that should be observed in classroom design. Table 1 lists a few examples of national and international standards and recommended RT values, as well as the RT recommended by the WHO[24, 29].

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In Japan, RT values represent the average in 2-octave bands including 500 Hz and 1000 Hz, and RT is measured in the furnished and unoccupied classroom[25]. In the U.S., RT is given as the maximum RT for mid-band frequencies of 500 Hz, 1000 Hz and 2000 Hz, and RT is measured in the furnished and unoccupied classroom[26]. In Germany, the DIN 18041[27] standard establishes that RT values represent the average in 2-octave bands including 500 Hz and 1000 Hz, and RT is measured in the furnished and occupied classroom. The German standard DIN 18041[27] recommends that, in general, the RT of an unoccupied classroom should not be more than 0.2 s above the required value listed in Table 3. In France, the RT is calculated as the arithmetic mean of the values of RT at the frequencies of 500 Hz, 1000 Hz and 2000 Hz[24]. The Brazilian standard NBR 12179 ï Acoustic Treatment of Closed Rooms[28] ï defines RT at the frequency of 500 Hz as a function of volume, for various types of spaces, such as conference rooms, Catholic churches, etc. Among these spaces, the one that most resembles a classroom is a conference room. Thus, the RT value in Table 1 for Brazil refers to conference rooms.

Description of the classrooms

The evaluation involved four models of classrooms, which were built in the 60s, in the Polytechnic Center at the Federal University of Paraná, Brazil. The classrooms have the following characteristics: 1) **Classroom PG04:** Designed as an auditorium, access to its wooden chairs and desks is up wooden steps, which gives this room an auditorium-like environment. The multiple user desks seat up to three students each. The room has a volume of 294.74 m³; 2) **Classroom PG06:** Designed as an auditorium, the room has a volume of 294.74 m³. It is furnished with wooden chairs and multiple user desks seating up to three students each, accessed up wooden steps; 3) **Classroom PG07:** This classroom has a volume of 367.18 m³. The room has two ceiling heights, one of 3.41m covering 79% of the classroom and the other 2.49 m covering 21% of the room. The desks and chairs are made of wood; 4) **Classroom PG015:** This room has a volume of 330.53 m³. It has a slanted ceiling and is furnished with wooden desks and chairs.

Figure 1 and Table 2 shows the original classroom ceiling material ï Acoustic-Celotex Type C-7 ceiling tiles (Knudsen and Harrisre:[30]). In 2007, the original ceiling tiles were replaced with the PVC, which has an average coefficient of sound absorption of about 0.02.

Results and Discussion

Figures 2 to 5 illustrate the RT, measured in four classrooms with the original ceiling (black curve) and

Table 1ð Recommended reverberation times for classrooms

Country	Reverberation Time, RT [s]	Volume, V [m^3]
Brazil	0.6 to 0.7	$270 \le V \le 600$
France	$0.4 < RT \le 0.8$	$V \le 250$
	$0.6 < RT \le 1.2$	$V > 250$
Germany	RT = 0.6	V = 250
	RT = 0.7	V = 500
	RT = 0.8	V = 750
Japan	RT = 0.6	V ~ 200
	RT = 0.7	V ~ 300
USA	RT = 0.6	$V \le 283$
	RT = 0.7	$283 < V \le 566$
WHO[24, 29]	RT = 0.6	

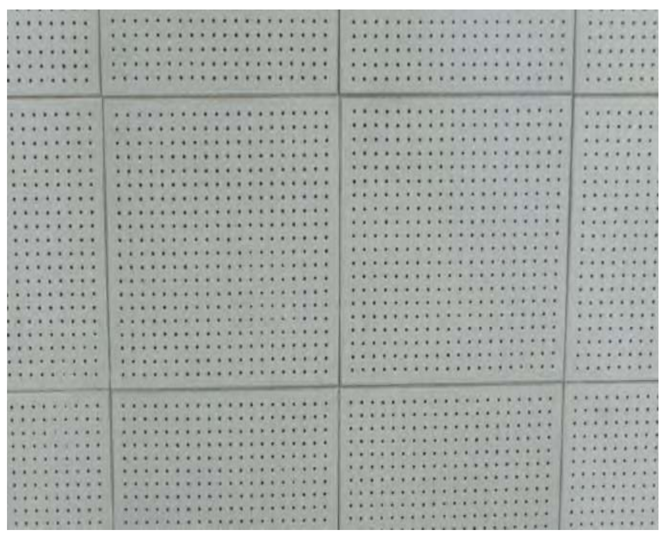

Fig. 1ð Acoustic-Celotex Type C-7 ceiling tiles[30]

Table 2ð Sound absorption coefficient for Acoustic-Celotex Type C-7[30]

Frequency [Hz][30]	128	256	512	1024	2048	4096
Sound absorption coefficient α[30]	0.25	0.49	0.69	0.78	0.61	0.48

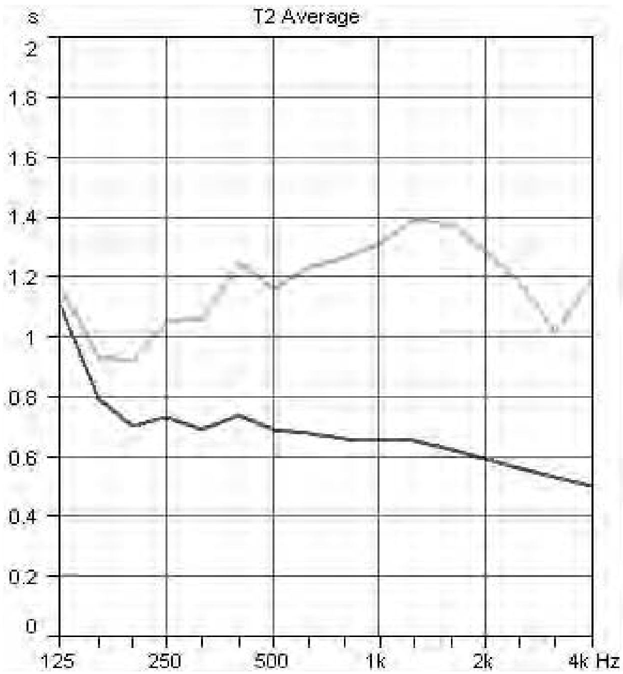

Fig. 2ð Measurement of RT in classroom PG-06.

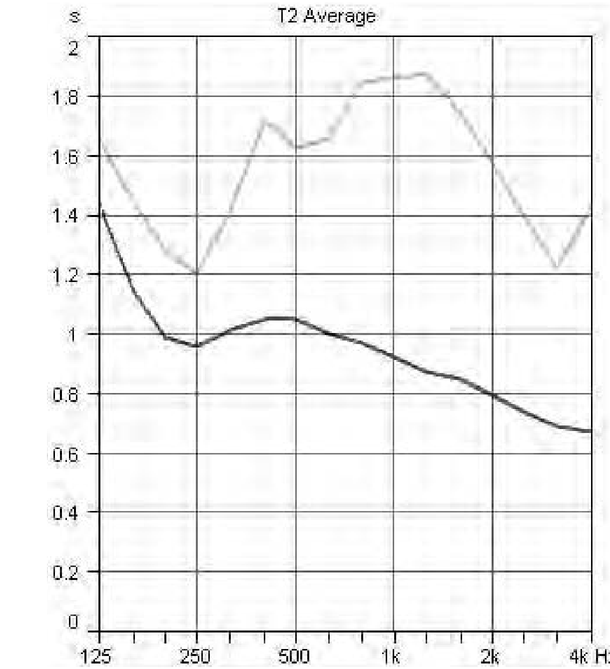

Fig. 3ð Measurement of RT in classroom PG-07.

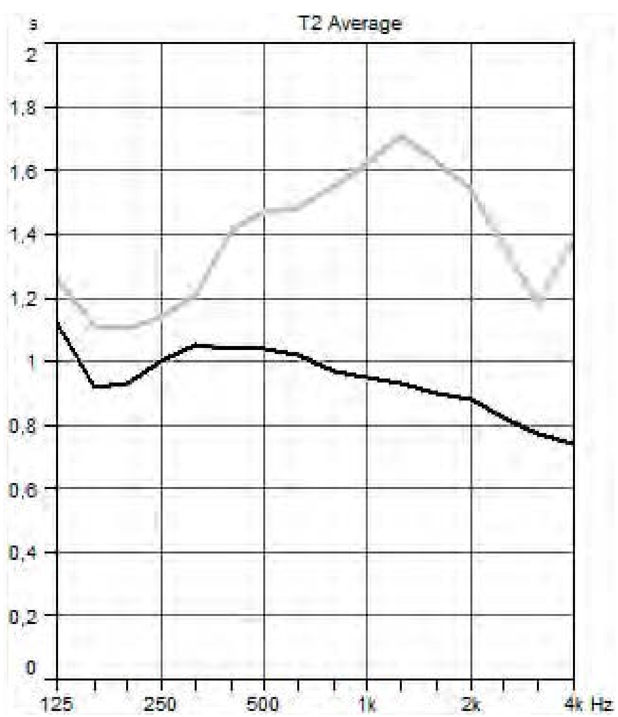

Fig. 4ð Measurement of reverberation time in classroom PG-15

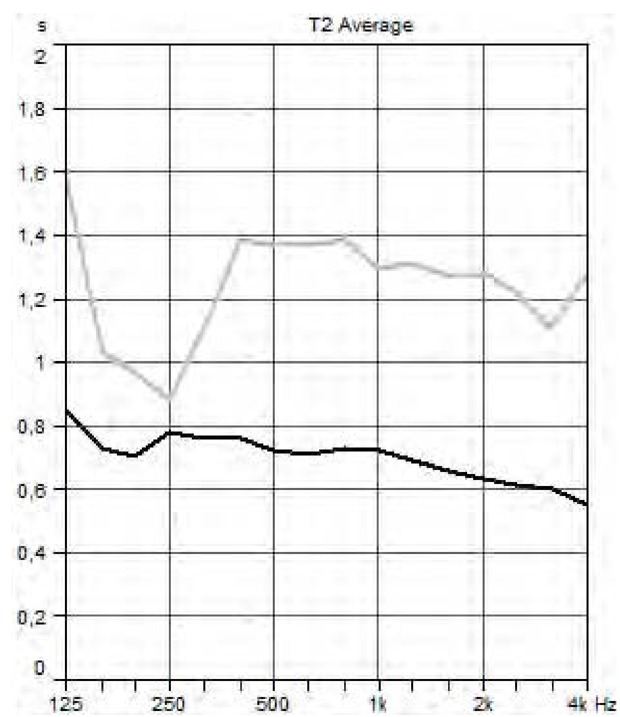

Fig. 5ð Measurement of reverberation time in classroom PG-04.

with the new PVC panels (gray curve). Figures 2 to 5 demonstrate the significant difference between the reverberation times measured in rooms with Acoustic-Celotex Type C-7 ceilings[30] and in rooms with PVC ceilings. Based on the RT values measured in the two situations, the acoustic quality was evaluated against the standards presented in Table 1. Table 3 summarizes this evaluation and demonstrates unequivocally that, prior to the substitution of the ceiling, many of the analyzed classrooms satisfied the quality standards for RT specified by the standards used as reference. After the acoustic ceiling tiles were replaced with PVC panels,

Table 3ð Evaluation of the acoustic quality of classrooms with Acoustic-Celotex and PVC ceilings

Classrooms		American standard	French standard	German standard	Brazil standard	Japan Standard	WHO Recommendation
PG06	Acoustic-Celotex	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
	PVC	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate
PG07	Acoustic-Celotex	Inadequate	Adequate	Inadequate	Inadequate	-	Inadequate
	PVC	Inadequate	Inadequate	Inadequate	Inadequate	-	Inadequate
PG15	Acoustic-Celotex	Inadequate	Adequate	Inadequate	Inadequate	Inadequate	Inadequate
	PVC	Inadequate	Adequate	Inadequate	Inadequate	Inadequate	Inadequate
PG04	Acoustic-Celotex	Adequate	Adequate	Adequate	Adequate	Adequate	Adequate
	PVC	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate	Inadequate

only PG15, when evaluated using the French standard, met the requirements of the reference standards, as indicated in Table 1.

Conclusions

This article describes a real case in which classrooms whose original acoustic quality in terms of reverberation time satisfied national and international standards and recommendations such as that of WHO were transformed into *"acoustically inadequate"* classrooms when their ceiling finishing material was modified. This change was decided by the universityõs administrative office, which failed to consider the following questions: 1) Existing reverberation time measurements that demonstrated the acoustic quality of the a:classrooms; 2) Was the change really necessary; 3) Non-preservation of the universityõs architectural heritage, since these classrooms are located in one of Brazilõs oldest universities.

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