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Acoustical Quality in Educational Buildings: Measurements in Brazilian Public Schools

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The importance of good acoustical quality in schools has been widely discussed in scientific media. It is undeniable that proper acoustical features influence student achievement. After studying architectural characteristics of schools and subjective data from students and teachers presented in former meetings, this paper presents the results of an acoustical measurement evaluation of schools in Southern Brazil. It was measured the background noise levels ($Leq_{(a)3min}$), reverberation times (RT) and early decay times (EDT), of five standard schools types. The results of $Leq_{(a)3min}$ are above the recommended limits of several international standard in all of five schools. The results range from 51.5 to 70.5 dB(A). Considering the recommended signal-to-noise ratio of +15 dB(A) to obtain good intelligibility, in the worse case the teacher would have to raise his voice to 80.5 dB(A), value that he might bring him vocal problems. The RT and EDT values are also above the recommended 0.5 seconds and the results range from 1.15 to 1.68 seconds for RT and from 0.83 to 1.30 seconds for EDT. The correlation of $Leq_{(a)3min}$ and S/N Ratio with reverberation times, as proposed by Bradley, the result for the school with best acoustical condition indicates a level of intelligibility of 88%. The result can be considered poor since this is the best condition in the classroom and also because it is desired values as close as possible to 100%.

* Session: Architectural Acoustics

INTRODUCTION

Acoustics in school buildings must have a major importance to provide satisfactory conditions for everyday necessities of teaching-learning activities. It has been frequently discussed in the scientific media its importance for each one involved, students and teachers specially. To achieve desired conditions, architecture should be designed in a way to offer a better acoustical environment.

Among many of important features, the background noise levels (BNL), the signal-to-noise ratio (S/N), the reverberation time (RT) and the early decay time (EDT) have great importance to achieve higher intelligibility levels.

BNL depends either on the building components properties (mass law) when the sound source is outside the room or on the amount of sound absorption, when the source is within the room (reverberant field).

An important aspect is that the requisites of acoustical insulation from outside noise are contradictory in relation to thermal environmental comfort in tropical countries. Most of the research in the area are carried out in countries with cold temperatures, where windows remain closed most of the time. Indirectly, it contributes to provide a better airborne sound insulation. In Brazil, a developing country located mainly in the tropical region, it is not possible to keep the windows closed. It is necessary to have them opened in order to circulate air and get natural ventilation. Also, economical restrictions do not allow public state schools to have mechanical air conditioning. Therefore, architects have a hard time to find solutions for both situations. Normally acoustics is treated as the least important subject in building design, even concerning schools, which should have special treatment.

According to Gibbs (1998), external noise whenever possible should be controlled by site and building planning. Sound insulation of building envelope should only be used as last resource. This gets more importance in places where it is not even possible to use building envelope due to financial restriction, like in Brazil.

In schools, to evaluate the BNL is important not only to measure Leq but also the peak Sound Pressure Levels (SPL). Even when Leq is within the recommended levels, transitory peaks of SPL influence on the user achievement because peak levels can make students and teachers loose the focus and distract them. Table 1 presents recommendations of BNL in different countries.

Table 1 – Background Noise Levels (BNL) recommended for classrooms in different countries (Vallet 2000)

Country	Year of the standard	Noise descriptor	Recommended BNL
Belgium	1977/ 87	Leq (A)	30-45
Brazil	1987	dB(A)	40-50
France	1995	Leq (A)	38
Germany	1989	–	30
Italy	1975	–	36
Portugal	–	–	35
Sweden	1995	Leq	30
Turkey	1986	Leq	45
UK	1997	Leq 1h	40

Bradley (2002) shows that an ideal S/N ratio in classrooms is about +15dB. Similar value is recommended by Airey (2000). However this is hardly achieved. Elliot (1982) said that normally S/N ratio found in classroom is about +6 dB or less. Even Bradley (2002) presented that it is rare to find S/N ratios close to the +15 dB.

Lower differences of S/N ratio mean teachers higher vocal effort to be understood by the students. On the other hand, students located far from the teacher, in the back of the class, or close to sound sources such as open doors, windows and fans are in bad listening conditions. In these cases, the voice of the teacher can become part of the reverberant field (Seep et al 2000).

Concerning about RT, Bradley (1986a) suggested that it is important to keep it in lower levels but never close to zero because the early reflections that are important to reinforce the teacher's voice, specially when the he is not talking direct to the students. Although, it is necessary to be careful because an ideal balance between early and late reflections is desired. In the same way, Hodgson and Nosal (2002) reported that RT near zero seconds are desirable for listeners close to the teacher and for those located away, it is necessary a RT different than zero to allow later reflections.

EDT is an important acoustical parameter to evaluate classrooms. EDT considers the early energy is important to better intelligibility. Hodgson (2001) presented the physical aspects that influence EDT: room dimensions (size and shape) and its internal surface sound absorption (quantity and distribution).

Kuttruff (1979) said that RT does not show significant variations with room shape. It happens because the sound decay curve is formed by many reflections with different delays. On the other hand, EDT is made by strong and isolated reflections and depends on the measurement position, being more sensitive to the room geometry. Bradley (1986b) also included EDT in his intelligibility studies, aiming to get different measurements and concluded that correlation between S/N-RT and S/N-EDT had similarities for the studied case. Table 2 presents recommended RT for classrooms in different countries.

Table 2 – Values of Reverberation Timers (RT) recommended for classrooms in different countries (Vallet 2000) (Fernandes 2002).

Country	Standard	Recommended RT	Comment
Brazil	–	–	–
Finland	–	0.6 – 0.9	–
France	–	0.4 – 0.8	250 m^3 rooms, 500 – 2kHz
Italy	–	0.5 – 2.0	Depends of frequency and vol.
Portugal	Lei 251/87	0.6 – 0.8	500 – 4kHz
UK	BB 87	0.5 – 0.8	–
USA	ANSI	0.6 – 0.7	S/N ≥ 15 dB(A)
USA	ASHA	0.4	S/N ≥ 15 dB(A)
WHO	–	0.6	–

Bradley et al. (1999) and Bradley (2002) suggested that two main aspects may be followed to achieve good classroom acoustics. The first one is the reduction of BNL aiming to include it on levels around 30 dB(A) (Bradley 1986a). Consequently, this reduction would create a better S/N ratio, contributing to better intelligibility levels and decreasing vocal effort by teachers. Bradley (2002) showed that S/N variations have more influence to intelligibility than other acoustical conditions in rooms. The second one is the correction of RT to values around 0.5 seconds among 500 e 4k Hz octave band (Bistafa-Bradley 2000). Different combinations between BNL and RT could also be possible and still reach desirable intelligibility. Bradley et al. (1999) related that it is not worth adequating RT without correct the S/N ratio. Still, Bradley (1986b) pointed out that EDT has better correlation with subjective sensation of people. Values close to 0.5 seconds are also desirable.

METHODOLOGY

Five classrooms in five different schools were selected to perform the acoustical measurements. Due to instrumentation availability, it was not possible to measure all 39 schools. The criteria used to pick up the schools was the similarity among the whole group. Hence, it were chosen 5 standard schools that characterize the group, concerning their typology and some particular aspects, such as the location of the classroom regarding the noise source (road, street, playground, etc). Other architectural acoustical details were considered such as geometry plans, room height, volumes, vaulted ceiling, etc. It was obtained a heterogeneous group configuring wide acoustical condition.

Two $Leq_{(a)3min}$ and SPL_{peak} measurements were planned in each classroom, the first one, featuring the acoustical worst situation, and the second, the acoustical best situation. Thus, the first one had doors and windows opened and the later, closed.

For the RT and EDT measurements, the sound source was located at the teacher place, in front of the blackboard. The data acquisition points were distributed all over the classroom, in five different places, in a similar height to the ear of the students. Door and windows were opened during the usual school day. It was performed the interruption method and made 3 measurements in each spot to get the medium value. The signal was pink noise.

The values of EDT were obtained from the decay curve of the RT measurement. Some values were considered spurious since the results were too different from others in frequencies that did not characterize significant modal behavior.

RESULTS AND DISCUSSION

The modern construction technology includes many light materials that are used in combination with techniques that are not acoustically satisfactory. Almost the financial costs and time of construction are the only parameters considered. “How much it is going to cost” and “how fast can you do” are the main questions to be solved. In the past, the buildings were constructed with heavy masonry, stones, thick layers of floors covering, and other satisfying sound insulators according to mass law. Nowadays, light materials such gypsum and thin wood panels, and inadequate zoning of the ambient regarding sound sources, are used in detriment to acoustical efficiency. None of the chosen classrooms had any sound absorption concern.

Background noise levels results

The results of background noise levels and sound pressure levels (peak) are shown in Figures 1 and 2. In the first room analyzed, the main sound source was the recreational activities in the patio and some adjacent classrooms. The difference between the two measurements can be considered small because there is a window covering great percentage of the wall. This window has single 3mm glazing and many broken parts. The poor maintenance helps to make the situation worse. Both measured levels are high. Peaks of 83.8 dB(A) are not acceptable within classrooms.

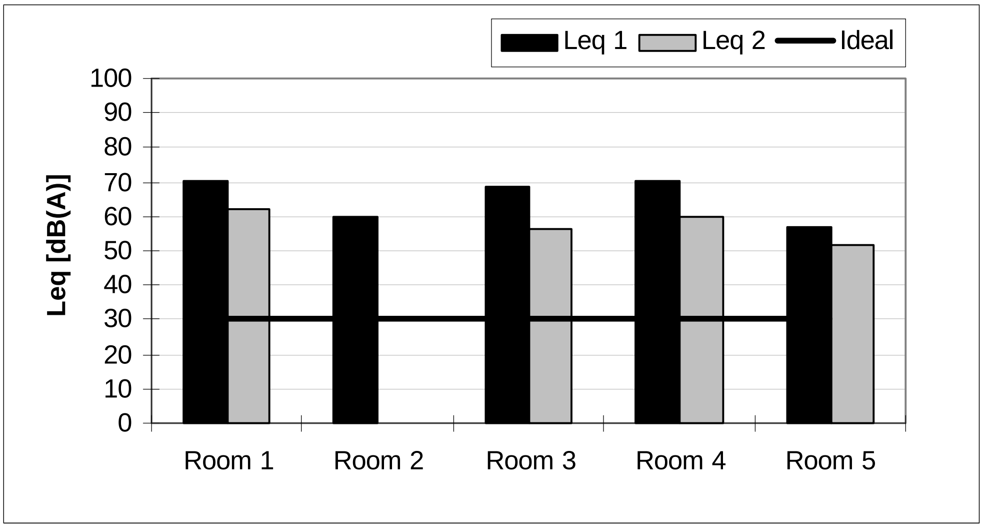

Figure 1 – Measured $Leq_{(A)\ 3min.}$ values inside 5 classrooms in different schools.

In the second classroom, only one measurement was carried out. Door and windows were open and the fan was on. This classroom is located just 6 meters from a heavy traffic avenue (4 lanes). There is only a wall separating the room and the avenue. Close by there is a bus stop so the buses stop and accelerate right in front of the class. There were no students inside the classroom. The results present a better situation compared to the first one, but still too high $Leq_{(A)\ 3min}$ around 59.6 dB(A) and SPL peak of 79.1 dB(A).

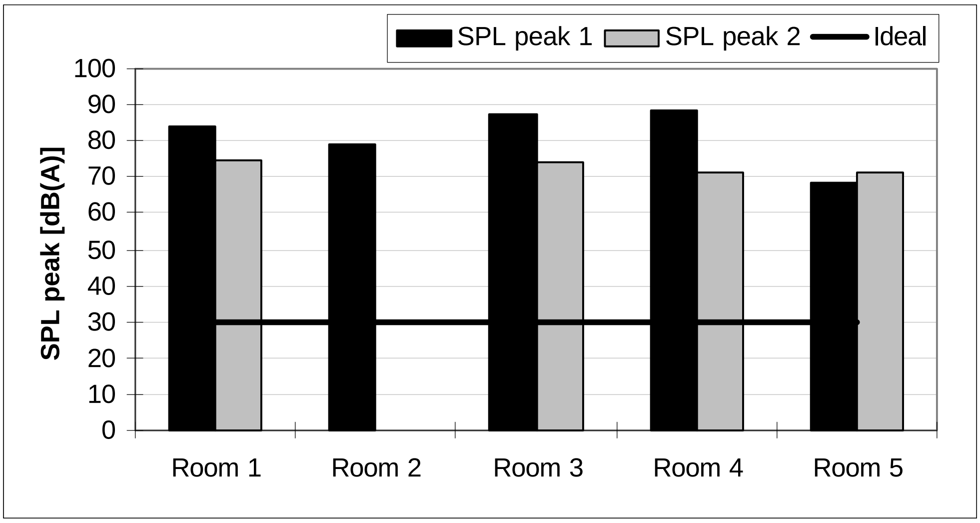

Figure 2 – Measured SPL_{peak} values inside 5 classrooms in different schools.

The third and fourth schools had similar results, $Leq_{(A)\ 3min}$ around 68.6 and 70.4 dB(A) respectively. Lower levels range from 56.5 to 60 dB(A). Peaks around 87.3 and 88.3 dB(A) respectively. In the fourth school, the measurements were carried out during physical education classes. The classroom is located beside the sport court. Children screaming, talking and whistles made peak SPL very high.

The last school had the best results among the five measured. $Leq_{(A)\ 3min}$ of 56.8 and 51.5 dB(A) and peaks of 68.5 and 71.2 dB(A). This classroom location is similar to the second classroom, very close to an important road, in this case. This road has two traffic lanes only, which explains why it has lower levels. There were no children in this school because it was a vacation season.

Reverberation time and early decay times results

The reverberation and early decay times are presented in Figure 3. The first classroom was occupied. The results show RT around 1.2s and EDT around 0.94s due to the volume of the class (190 m^3) and the hard surfaces. The second classroom was empty. The volume was 145 m^3. RT of 1.39s and EDT of 1.09s.

The third classroom had high ceiling and volume of 4.65m and 220m^3, respectively. RT was 1.67s and EDT 1.30s. A third measurement were performed to simulate the situation in cold weather, with windows and doors closed. The result is RT of 2.26s. This value makes listening conditions almost impossible for students. Therefore, intelligibility is very low.

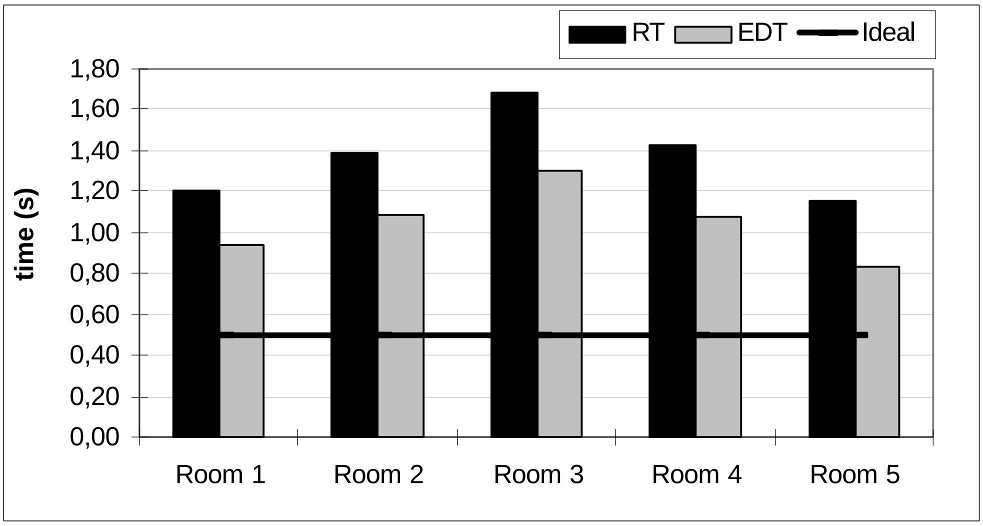

Figure 3 – Average measured RT and EDT (1kHz) values in 5 classrooms in different schools.

The fourth classroom was occupied, with 3.80m height and 182.4m^3. Results of RT and EDT were 1.43s and 1.08 seconds, respectively. This school had just been refurbished. Hence, even after being remodelling it is still in inadequate acoustical conditions. The results confirm that acoustics was not under consideration.

As for the BNL results, the last classroom analyzed had the best RT and EDT results, 1.15s and 0.83s, respectively. Small volume ($123.5m^3$) gave lower reverberation times as it was expected.

Intelligibility results

Considering normal voice SPL of 63 dB(A) at 1 meter distance (Egan 1988) and L_{eq} de 56.8 dB(A), in the last classroom analyzed, the result is a S/N ratio of 6.2 dB(A). Introducing this value in Bradley's (198a) graph to obtain intelligibility scores, together with RT of 1.15s, it is reached a value of 88% of intelligibility, in the best possible condition. Students far away have worse conditions.

This result can be considered poor since this is the best condition in the classroom and also because it is desired values as close as possible to 100%.

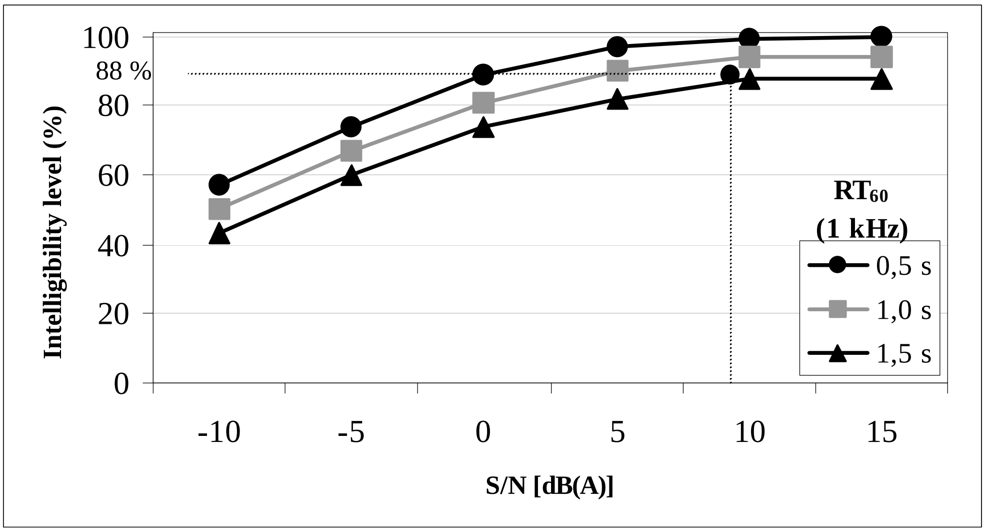

Figure 4 – Estimated Intelligibility level for the school with best acoustical condition.

SUMMARY

This paper presented the results of acoustical measurements evaluation concerning background noise levels, signal-to-noise ratios, reverberation times, early decay times and intelligibility levels in five standard public schools in southern Brazil.

Background noise levels in all of the five classroom analyzed have $Leq_{(a)3min}$ above the recommended limits of several international standards. The values range from 51.5 to 70.5 dB(A). These results show that to achieve the minimum S/N ratio of +15 dB(A), teachers would have to raise their voice up to levels around 85 dB(A) in some schools. Such a situation may bring up vocal disorders, since most of them spend all day long in classroom (at least 8 hours).

RT and EDT in all classrooms evaluated are above the 0.5 seconds recommended. Values range from 1.15 to 1.68 seconds for RT and 0.83 to 1.30 seconds for EDT. Again, this situation interfere on the correct use of the classroom.

Finally, the correlation of $Leq_{(a)3min}$, S/N ratio and RT, aiming to find the intelligibility level, in the best condition, showed a result of 88%. This result is very

poor, since all of the others classrooms are bellow it and values closer to 100% are desirable.

These results complete the whole study performed in these public state schools. Data from architectural surveys, questionnaires and interviews, presented in former meetings (Losso et al 2003, Losso et al. 2004) led to the same conclusions.

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