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Elementary classroom acoustics: what really matters

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Abstract
This work answer the question on what are the optimal acoustic conditions for speech communication and learning in classroom. In order to do this, a simple protocol to carry out measurements to characterize classroom acoustics is provided and the thresholds of the main parameters to guarantee an adequate sound environment for educational facilities have been identified. In 29 first-grade classrooms, background noise level in silence and during group activities, reverberation time also in unoccupied conditions, speech clarity, ratio of useful to detrimental energy and speech signal were acquired along the main axis. Correlation analyses allowed for the selection of reverberation time or speech clarity in the central position as the essential parameters to evaluate the acoustical quality of classrooms, which were clustered either in bad or good acoustic group based on the cluster analysis. The thresholds for the reverberation time and speech clarity in the central position are 0.8 s and 2.6 dB, respectively. Further investigations were performed on the early, late and total components of the sound strength parameter.

Keywords: good classroom acoustics, acoustic measurements, speech intelligibility, learning.

1 Introduction

A listener is particularly challenged in the discrimination of useful sounds by long reverberation times and excessive noise. Children aged up to eight years are maximally influenced by the acoustic quality of the environment in which they are immersed for most of the time, i.e., their classrooms, as it affects both the speaking and the listening tasks [1–5]. On talkers' side it is mandatory to reduce teachers' vocal effort and load, in order to prevent vocal disorders and to preserve their vocal health [3]. Classroom acoustics also has consequences on students' and teachers' well-being, influencing their perceptions, their feelings of joy, comfort and discomfort, as well as their functioning and relationships [15, 21-28].
National and international standards are not met by a huge number of the existing classrooms. In USA around 30% of all schools resulted to be excessively noisy [29]. In Europe the reported acoustic quality resulted to be unsatisfactory, with excessive internal noise levels and insufficient protection against outdoor noise [21, 30].
Starting from the 80's, many studies have been conducted aiming at identifying the preferred acoustical criteria that best enhance students' performance in educational facilities. In order to reach this goal, parameters related to reverberation, speech intelligibility and noise have been investigated by several researchers. On one side, there are many scientific studies that have proven the negative effect of noise and reverberation on speech intelligibility and academic performance [6, 7]; on the other side only a small number of studies consider other parameters directly related to speech intelligibility as signal-to-noise ratio (S/N), early-to-late ratio (C) and useful-to-detrimental ratio (U) [7–9[10]]. If the majority of the studies

present results in terms of noise levels and reverberation time, their acquisition procedures change from one reference to another.

So far, this work stems from the need of having comfortable teaching and learning environments and represents an attempt to identify the minimum number of parameters to best characterize the acoustics of the classroom. Acoustical parameters along the main axis of 29 primary school classrooms have been measured and statistical analyses have been carried out on the collected data. The analyses cover correlations between the obtained quantities as average values across positions or as single point values or values related to the whole classroom. From such amount of data a cluster model allowed to group bad and good acoustic conditions and to draw reference values for a list of parameters in both cases. Finally, the relationship between occupied and unoccupied setting have been investigated from the measurements. These steps led to the creation of the simplified protocol, that can be universally applied when performing acoustic measurements in classrooms and that can effectively guide any intervention or project.

2 Materials and methods

Measurement campaign were carried out in 29 classes of 13 primary schools located in Torino, where about 550 pupils aged from 6 to 7 years participated in this study during the scholastic year from 2016 to 2019.

2.1 Schools and classrooms

The 29 classrooms involved in the present study are scattered in the metropolitan area of Turin. They differ in terms of construction time, location, geometry and orientation. Most of the classrooms have a rectangular shape, with a volume ranging from 120 m^3 to 290 m^3 and their height from 3.0 m to 5.3 m. The ceiling can be flat or vaulted, while the floor´s finishes are mainly made of venetian tiles. The furniture consists in student´s desks and chairs, bookshelves and blackboards. In all the classrooms there was a traditional distribution of the seating area for the pupils, so desks were positioned over 3 or 4 rows and sometimes they were coupled, while the teacher’s desk was parallel to one of the shorter sides of the room. Measurements were carried out under occupied and unoccupied conditions, with 18 children on average.

2.2 Acoustic measurements

Measurements were carried out with a calibrated NTi XL2 sound level meter, a NTi Audio TalkBox source and a clapperboard. Figure 1 shows the standard measurement setup used in each classroom. Measurements have been performed for one source positions (S1). A fixed reference position, REF, that has placed at 1 m from the source mouth, at the same height, was common across all the classrooms, then a maximum of 6 microphone positions were selected case-by-case.

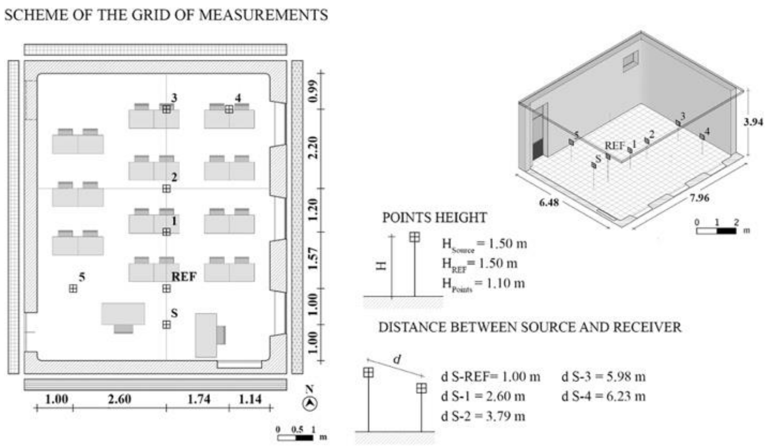

Figure 1 - Measurement setup in a typical classroom.

Room impulse responses were acquired from exponential sine sweep signals emitted by the TalkBox and recorded by the SLM in positions REF, 1, 2, 3, and 4.
Reverberation time (T20, s) was averaged in the range 0.25–2 kHz and speech clarity (C50, dB) in the range 0.5–1 kHz. An optimal occupied T20 was set between 0.5 and 0.8 s, according to a number of recent studies [3, 13–16]. An optimal value of C50 should be greater than around 3 dB, as given in [7].
Reverberation time was also measured under empty classroom conditions ($T20_{\_e}$), without the presence of pupils and teachers. According to [12], a wooden clapper, i.e. two wooden boards hinged together, was used as described in [3]. Reverberation time values in unoccupied classroom were averaged between 0.5-1 kHz according to [11].
Background noise level (L_N, dBA) was considered in terms of indoor A-weighted equivalent sound pressure level. 3-min acquisition measurements [17] were carried out with children in silence, L_{N_sil}, and with the children performing group activities, L_{N_gr}. According to [6, 18] the L_{N_sil} recommended value must be less than or equal to 35 dBA.
For the measurement of the speech signal (L_S, dBA) the TalkBox was positioned in S and emitted a voice signal to 60 dBA at 1 m in anechoic conditions. The speech signals were acquired in positions REF, 1, 2, 3, and 4.
The ratio of useful to detrimental energy (U50, dB) was obtained for each position in the range of 0.5-1kHz and, as given in [19], an optimal value should be greater than 1 dB.
Overall, the acoustic parameters that are distance dependent (i.e., C50, L_S, and U50) were measured point by point and then processed to have single values. In particular, C50 and U50 values were averaged to have a spatial mean ($C50_{\_M}$, $U50_{\_M}$). Furthermore, L_S values were associated to obtain their slope per double distance (mL_S) [1]. Sound Strength (G) was examined in terms of slope per double distance too. G has been measured according to the ISO 3382-1 [31] and it represents the logarithmic ratio of the sound energy of the measured impulse response to that of the response measured in a free field at a distance of 10 m from the sound source. In particular its components G50, G_{late} and G_{tot} have been investigated, being, respectively, the first 50 ms of sound energy, the sound tail after 50 ms, and the sound energy globally considered [8].

2.3 Statistical Analysis

The statistical analysis was carried out with SPSS (IBM Statistics 20, IBM, Armonk, NY, United States).
Before starting any analysis, Cook's distance was used in regression analysis between the reverberation time in occupied condition (T20) and each variable, i.e. acoustic parameter, to find influential outliers. This method allowed to identify the points (classrooms) that did show anomalous tendencies based on the expected relationship with reverberation time (T20), so these cases have been considered outliers and thus cancelled from the database. For every parameter, observations with a Cook's distance of more than 3 times the mean was considered an outlier and less than 15% of the data was deleted.
Once checked the normality of the distribution for each acoustic parameter, their relationships were investigated through the nonparametric and non-linear correlation estimator Spearman's rho [20]. Correlations with a significant coefficient minor than 0.01 were considered significant. They have been further analysed through linear regression techniques.
After standardizing the variables, classrooms have been divided in two groups through a 2-means cluster analysis. Its attempt was double: in one hand the objective was to classify the cases based on their acoustic quality considering all the selected parameters; in the other hand the cluster analysis pointed to obtain thresholds for each parameter. The significance of the differences between the mean values of the acoustic parameters in good and bad classroom acoustics was assessed with the Mann–Whitney U Test (MWU), used for two groups of independent observations.

3 Results

Table 1 shows the measured values of the acoustic parameters for each individual classroom, i.e. A1, A2, A3, and so on. Comparing the measured values with the thresholds from the literature, the acoustics measured in this study results to be poor and insufficient for half of the classrooms, from A1 to O1. Better conditions are shown for cases from A3 to H4, with the exclusion of the values related to L_{N_sil}, L_{N_gr}, L_{S_REF}, mL_{S}.

Table 1 – Acoustic parameters. T20 is the reverberation time while children in classroom, while T20_e refers to empty conditions. L_{N_sil} is the noise acquired with students in silence, L_{N_gr} is the noise acquired while students were performing group activities. The speech level was recorded at 1 m from the source, L_{S_ref} , then in other positions and its slope per double distance, mL_S, was evaluated. The mean distribution of a parameter in the classroom is referred to with "M" (e.g. C50_M); the value of a parameter measured in the center of the classroom is referred to with "ctr" (e.g. U50_ctr). Standard deviations are indicated in parentheses when available. Bold is used when the values meet the standards. n.a. is for not available.

ID	T20 [s]	$T20_{\_e}$ [s]	L_{N_sil} [dB]	L_{N_gr} [dB]	L_{s_REF} [dB]	mL_S [dB/dd]	$C50_{\_M}$ [dB]	$C50_{\_ctr}$ [dB]	$U50_{\_M}$ [dB]	$U50_{\_ctr}$ [dB]
A1	0.9 (0.1)	0.9 (0.1)	51.7	n.a.	61.3	-1.9	1.3 (1.2)	1.0	-1.2 (1)	-1.1
A2	0.9 (0.2)	**0.8 (0.1)**	49.0	64.7	61.2	-2.4	2.2 (1.8)	0.0	0.2 (1.1)	-1.3
D1	1.2 (0.1)	1.4 (0.1)	51.2	68.0	63.0	-1.8	0 (0.9)	-0.6	-1.5 (1)	-2.1
D2	1.3 (0.2)	1.4 (0.1)	52.0	n.a.	62.7	-2.1	-0.3 (1.1)	0.0	-1.8 (1.4)	-1.6
E1	1.2 (0.1)	1.3 (0.1)	54.0	66.6	62.1	-1.4	1.1 (0.9)	0.7	-1.2 (0.6)	-1.5
E2	1 (0.1)	1.0 (0.2)	54.3	73.7	61.5	-1.9	2.7 (1)	3.8	-0.9 (0.8)	0.0
F1	1.2 (0.1)	1.5 (0.1)	52.0	75.1	62.1	-1.7	-0.3 (1.8)	1.1	-2.2 (1.6)	-0.9
F2	1.4 (0.3)	1.7 (0.1)	52.0	73.8	62.9	-1.8	-0.1 (1.2)	-1.1	-1.8 (1.3)	-2.7
G1	0.9 (0.1	1.2 (0.1)	51.5	72.2	62.3	-2.1	2.6 (1)	3.3	0.9 (0.9)	**1.3**
I1	1.4 (0.1)	1.3 (0.1)	45.7	59.9	61.9	-1.6	-2.2 (0.2)	-2.2	-2.6 (0.2)	-2.6
I2	1.2 (0.4)	1.3 (0.1)	42.3	71.1	63.3	-2.3	0 (0.9)	-0.3	-0.2 (0.9)	-0.5
L1	1.0 (0.1)	n.a.	47.9	67.4	61.1	-1.9	1.6 (1)	1.2	0.4 (1.1)	0.0
L2	1.1 (0.1)	1.2 (0.1)	46.0	71.6	62.0	-2.2	0.5 (2)	0.6	-0.2 (2.1)	-0.1
L3	1.0 (0.1)	1.3 (0.1)	43.0	81.3	62.6	-2.3	1.4 (1.7)	0.7	**1.1 (1.7)**	0.3
M1	0.9 (0.1)	1.1 (0.1)	52.0	81.9	63.0	-1.7	2.1 (1.3)	2.3	0.4 (0.9)	0.5
N1	1.3 (0.9)	1.1 (0.1)	54.3	76.1	63.9	-1.4	1.4 (0.7)	0.9	-1.0 (1)	-1.4
O1	1.0 (0.1)	1.1 (0.1)	49.6	76.7	62.3	-1.9	2.3 (1.1)	2.4	0.6 (1.2)	0.7
A3	**0.8 (0.1)**	**0.8 (0.1)**	38.4	61.8	60.3	-2.0	**4.1 (0.9)**	**5.1**	**3.8 (0.9)**	**4.8**
A4	0.7 (0.1)	**0.7 (0.1)**	47.1	69.2	61.3	-1.6	**4.7 (1.4)**	**4.4**	**3.4 (1.4)**	**3.4**
A5	0.7 (0.1)	**0.8 (0.1)**	46.3	78.4	61.0	-2.3	**5.4 (0.4)**	**4.8**	**3.9 (0.6)**	**3.5**
B1	**0.5 (0.1)**	**0.6 (0.1)**	49.3	66.3	60.8	-2.1	**7.6 (1.5)**	**7.3**	**4 (1.9)**	**2.9**
B2	**0.5 (0.1)**	**0.5 (0.1)**	39.9	66.3	61.7	-2.6	**7.0 (1)**	**8.1**	**6.5 (0.9)**	**7.3**
C1	**0.8 (0.1)**	0.9 (0.1)	49.3	62.2	62.8	-1.6	**3.3 (0.8)**	2.8	**2.2 (0.6)**	**1.9**
G2	**0.6 (0.1)**	0.9 (0.1)	51.9	65.3	60.7	-0.8	2.9 (0.9)	**3.5**	0.8 (0.7)	**1.4**
G3	0.7 (0.1)	0.8 (0.1)	52.5	63.5	n.a.	0.0	**4.4 (0.3)**	**4.7**	n.a.	n.a.
H1	**0.8 (0.2)**	0.8 (0.1)	51.6	71.9	61.5	-1.1	**3.6 (0.2)**	**3.8**	**1.5 (0.2)**	**1.4**
H2	**0.6 (0.1)**	0.9 (0.1)	55.9	68.1	62.4	-2.2	**5.3 (0.3)**	**5.4**	-0.8 (0.5)	-1.0
H3	**0.7 (0.1)**	1.0 (0.1)	45.5	63.9	62.9	-1.8	**3.8 (0.3)**	**3.8**	**3.2 (0.3)**	**3.0**
H4	**0.7 (0.1)**	0.8 (0.1)	53.1	65.5	62.9	-2.1	**4.1 (0.6)**	**3.5**	0.6 (0.6)	-0.1

Table 2 returns the results in terms of mean value for each parameter. Here the standards are not met by any parameter.

Table 2 – Descriptive statistics excluding the outliers from the original dataset. Standard deviations are indicated in parentheses.

Parameter	Average
T20 [s]	0.9 (0.3)
$T20_{\_e}$ [s]	1.0 (0.3)
L_{N_sil} [dB]	50.3 (3.2)
L_{N_gr} [dB]	70.1 (5.7)
L_{S_REF} [dB]	62 (0.9)
mL_s [dB/dd]	-1.9 (0.3)
$C50_{\_M}$ [dB]	2.4 (2.2)
$C50_{\_ctr}$ [dB]	2.1 (2.1)

$U50_{M}$ [dB]	0.5 (2.0)
$U50_{ctr}$ [dB]	0.4 (2.0)

Table 3 shows that the majority of the acoustic parameters are very well correlated. A very tight connection is shown the reverberation time in occupied conditions and the speech intelligibility indexes C50 and U50. the positive and significant correlations between T20 in occupied and unoccupied conditions, and between C50 and U50 parameters suggest the use of only one quantity instead of two to represent respectively reverberation time and speech intelligibility. to a similar conclusion bring the very tight connection between central and mean values of both the quantities C50 and U50, indicating that only one measurement in the center of the room can well describe the behaviour of the whole classroom in terms of speech intelligibility.

Table 3 – Correlation matrix of the acoustic parameters. Spearman correlation coefficients with p-value less than 0.01 are shown.

	T20	$T20_{e}$	L_{S_REF}	$C50_{M}$	$C50_{ctr}$	$U50_{M}$	$U50_{ctr}$
T20		**.842****		**-.950****	**-.864****	**-.837****	**-.836****
$T20_{e}$			**.604****	**-.865****	**-.701****	**-.724****	**-.657****
$C50_{M}$					**.920****	**.886****	**.849****
$C50_{ctr}$						**.811****	**.906****
$U50_{M}$							**.939****

Starting from the correlations, significant regressions were found. The regression analyses between $C50_{M}$ and $C50_{ctr}$, $U50_{ctr}$ and $C50_{ctr}$ with R^2 of 0.9 and of 0.8, respectively, suggested the use of only one quantity instead of two to represent speech intelligibility. Finally, the parameters L_{S_REF} is positively related to $T20_{e}$.

Table 4 shows that cases from A1 to O1 belong to the group of bad acoustics (BA), while cases from A3 to H4 were attributed to the group of good acoustics (GA). The subdivision was determinate considering all the selected parameters and confirmed the results already obtained in [21], where the criteria for the division was based only on the T20 value of each classroom, respectively over or under 0.8 s. Furthermore, the division aimed to obtain new thresholds for each parameter on the basis of which easily attribute a specific classroom to the group of BA or GA and to be compared with the literature ones. Table 4 returns the new thresholds obtained which were identified halving the sum between the 25^{th} and the 75^{th} percentile of the worse (higher) and better (lower) group data, respectively, in the case of reverberation time (T20, $T20_{e}$) and noise level during group activities (L_{N_gr}), and halving the sum between the 75^{th} and the 25^{th} percentile of the worse (lower) and better (higher) group data, respectively, in the case of the speech intelligibility indexes Clarity (C50) and Useful-to-detrimental ratio (U50). In such a way classrooms with T20 in occupied conditions higher than 0.8 s, T20 in empty conditions higher than 0.9 s and noise level during group activities higher than 68 dBA have been included in the BA group, which also correspond to classrooms with average C50 lower than 3 dB and with average U50 lower than 0.9 dB, or with central C50 lower than 2.6 dB and with central U50 lower than 0.7 dB.

Table 4 – Descriptive statistics of the acoustical parameters considering the division in BA and GA. Standard deviations are indicated in parentheses, while n.a. is for “not available”.

		Average	Threshold	p-value
T20 [s]	BA	1.1 (0.19)	0.8	0.000
	GA	0.7 (0.09)		
$T20_{e}$ [s]	BA	1.2 (0.21)	0.9	0.000
	GA	0.8 (0.13)		
L_{N_sil} [dB]	BA	50.4 (3.28)	n.a.	0.833
	GA	50.2 (3.32)		
L_{N_gr} [dB]	BA	72.9 (5.18)	68	0.005
	GA	66.9 (4.65)		
L_{S_REF}	BA	62.2 (0.71)	n.a.	0.125

[dB]	GA	61.7 (0.95)		
mL_S	BA	-1.9 (0.3)	n.a.	0.978
[dB/dd]	GA	-1.9 (0.38)		
C50_M	BA	1 (1.38)	3.0	0.000
[dB]	GA	4.6 (1.09)		
C50_ctr	BA	0.8 (1.58)	2.6	0.000
[dB]	GA	4.2 (0.82)		
U50_M	BA	-0.6 (1.13)	0.9	0.000
[dB]	GA	2.6 (1.34)		
U50_ctr	BA	-0.8 (1.18)	0.7	0.000
[dB]	GA	2.5 (1.46)		

Figure 2 shows through regression that the slope per double distance of the signal level in BA and GA is around -2 dB/dd.

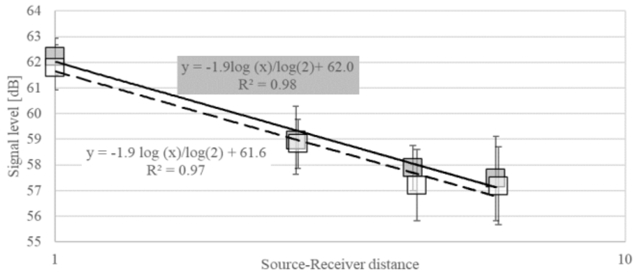

Figure 2 – Regression lines of the propagation of the measured signal level L_S in BA (gray square and solid line) and GA classrooms (white squares and dashed line). The regressions are obtained considering the mean values of BA and GA cases in position ref, 1, 2, and 3.

Figure 3 shows that to further investigate if any differences occur in the early and late reflections slopes per double distance in BA and GA, the Sound Strength G_{tot}, G_{50} and G_{late} have been represented along the main axis of the classrooms. The same slope per double distance of -2.7 dB/dd has been obtained for G_{50} in BA and GA, as expected, while G_{late} showed -0.6 dB/dd and -0.9 dB/dd, and G_{tot} showed -2.0 dB/dd and -2.2 dB/dd in BA and GA, respectively. The slope per double distance of G_{tot} is around -2.0 dB/dd as mL_s.

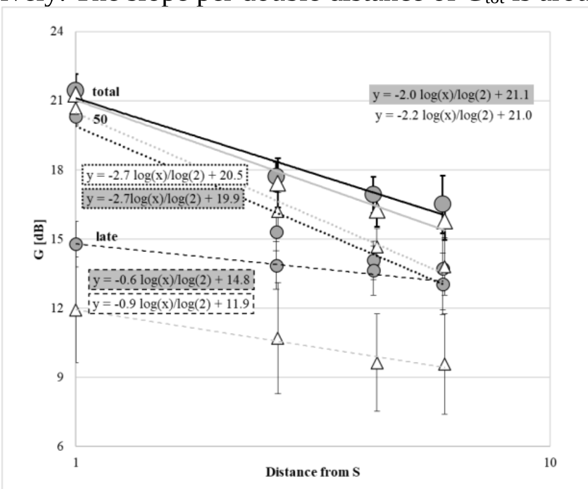

Figure 3 – Regression lines of the propagation of the calculated G_{tot} (solid line), G_{50} (round dot line) and G_{late} (dashed line) levels in BA (values are grey circles and regression lines are black) and GA (values are white triangles and regression lines are light grey) classrooms. The regressions are obtained considering the mean values of

BA and GA cases in positions ref, 1, 2 and 3.

4 Discussion

Sato and Bradley **Error! Reference source not found.** illustrate an approach to the acoustical design of classroom aiming to focus on the difference between G_{50} and G_{late} at the more distant listening location from the teacher. They also suggest to use a design approach that selects the optimum reverberation time as the one that maximizes U50 values, since they combine the detrimental effects of late-arriving speech and ambient noise relative to the useful direct and early reflected speech sounds. Figure 4 shows the relationship between reverberation time in occupied conditions and G_{tot}, G_{50} and G_{late} levels, and U50. The figure identifies the optimal reverberation time based on G_{late} difference from G_{50} at a 6 m distance from the teacher. In particular, it has been assumed that G_{late} should be 3 to 6 dB lower than G_{50} in any position inside the classroom, especially at the more distant listening location from the speech source. Considering these differences between G_{late} and G_{50}, optimal conditions can be achieved over quite a broad range of reverberation time values from 0.6 to 0.9 s. Following the indications of Bradley *et al.* **Error! Reference source not found.**, for which the U50 must be at least 1 dB, then the optimal reverberation time must be equal to or lower than 0.75 s.

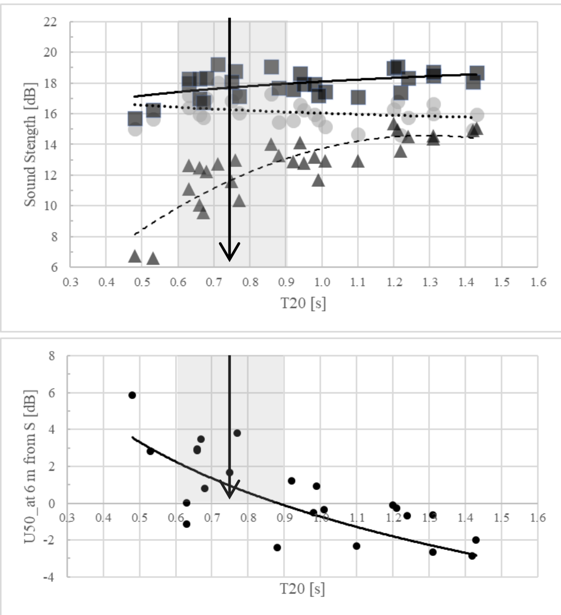

Figure 4 – Relationship between reverberation time in occupied conditions and G_{tot} (solid line and squares), G_{50} (round dot line and circles) and G_{late} (dashed line and triangles) levels, and U50. The shaded area indicates the range of optimal reverberation times and of distances between G_{late} and G_{50}. The vertical line highlight the optimal reverberation time of 0.75 s identified based on U50 of 1 dB.

5 Conclusions

The present work answered the question on what are the optimal acoustic conditions for speech communication and learning in classroom. In order to do this a useful protocol for acoustics measurements in

classrooms has been provided. The measurement protocol was based on a minimum number of parameters and positions which allow for smooth and fast classroom acoustic characterization.
The present study involved 29 primary school classrooms in Turin. Half of the classrooms were characterized by an insufficient sound quality compared to the optimal reference values. The intelligibility is good in classrooms with good acoustics, while it is mainly insufficient in the other classrooms. For both good and bad acoustics environments were recorded values of noise level beyond the limit, both in silence and during group activities.

Results show that most of the parameters are strictly correlated. Reverberation time T20 and speech clarity in the central point $C50_{\_ctr}$, both in occupied conditions, can be chosen as the most representative parameters to characterize classroom acoustics, and particularly the speech intelligibility conditions. Based on T20 and $C50_{\_ctr}$ it is then possible to estimate the useful-to-detrimental ratio U50, which best relates to speech intelligibility accounting for both noise and room acoustics. The noise level in silence L_{N_sil}, the slope per double distance of the speech signal mL_S and the speech level in the reference point (@ 1 m from the source) L_{S_ref} , do not emerged as primary parameters to characterize classroom acoustics. In conclusion, classroom acoustics can be fully characterized from a single measure, that can be alternatively T20 or $C50_{\_ctr}$.

In order to reduce the measurement points to a minimum number, it is advised to first characterize classrooms by means of speech clarity in the central position, $C50_{\_ctr}$. This position is also effective for estimated parameters, such as the useful-to-detrimental ratio in the central point $U50_{\_ctr}$. As far as T20 is concerned, a spatial average is needed to the aim.

Only reverberation time was measured in both occupied and unoccupied conditions, which resulted to be positively and significantly correlated. $T20_{\_e}$ was also significantly correlated with C50 and U50 parameters, although they have been measured only in occupied conditions. Based on this, measurements can be performed in unoccupied conditions, getting smoother and faster, and the related parameters can be estimated indirectly.

References given by literature have been updated and new thresholds between bad and good acoustics are proposed based on clusters analysis. In particular, the thresholds are:

- for reverberation time 0.8 s and 0.9 s in occupied and unoccupied conditions, respectively;
- for noise level during group activities 68 dBA;
- for speech clarity 3 dB and 2.6 dB when considered as a spatial average or a single value in central position, respectively;
- for useful-to-detrimental ratio 0.9 dB and 0.7 dB when considered as a spatial average or a single value in central position, respectively;

L_{N_sil}, mL_S and L_{S_ref} remain excluded from the threshold identification as they did not differ significantly in BA and GA.

As far as reverberation time is concerned, the inspection of the early component G_{50} and the late component G_{late} of sound strength allowed for the identification of GA with an optimal reverberation time in the range 0.6÷0.9 s, which also guarantees optimal speech intelligibility at the most distant position from the source. An optimal reverberation time lower or equal to 0.75 s also guarantees an optimal U50 equal to or greater than 1 dB. This reverberation time also best support the voice of teachers in classroom.

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