Acoustic reclamation in a school gym

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Summary

The school gymnasium are often characterized by an unfavourable acoustic climate. The effectiveness of speech communication is deeply restricted because of the very poor intelligibility rating; moreover this acoustic climate produces a remarkable stress level, particularly to the teachers, that spend the most part of their working time in these environments.

The cause of this situation consists of several factors, that have been carefully analysed:

The raised level of background noise, due to the sound pollution coming from outside, that is mainly originated by road traffic.

The room sizes, that are lower than the ones prescribed by the law. Physical activities take place in environments originally designed for different purposes, because of the few resources available for the educational sector.

The raised noise levels due to overcrowding. For the above mentioned reasons very often the gyms give hospitality to the pupils of other close schools at the same time.

The poor acoustic absorption, as evidenced by the high reverberation times data. The surfaces of the environments are very reflective, because of the lacking in interventions for improving the acoustic quality.

The noise levels at which teachers and students are exposed to, are lower compared with the limits ratified by the law; nevertheless they determine a very high psychological disease; moreover the teachers show problems with their vocal cords, because of the vocal effort they perform to make their voice more intelligible; this effort has no significant effect on the speech communication.

In this paper we present the results of acoustic quality assessment, performed in a school gym in Rome, and a proposal to improve the acoustic comfort that can be carried out quickly and a relatively low cost.

1. Introduction

The aim of this study is to improve acoustic characteristics of a high school gym in Rome.

In order to ensure safety and comfort of the users (teachers and students), a gym must have specific characteristics. People who use the gym must be able to perform their physical activity in a suitable environment in order to benefit from their exercise.

In Italy this matter is regulated by DM 18-12-1975 under the title of “Updated technical standards on school buildings, including minimum requirements for the performance of educational activities, construction and town-planning standards to be complied with in school buildings”.

Point 5.1 contains the definition of acoustic standards for school environments, with particular reference to the requirements of acceptability of different acoustic parameters (airborne sound insulation of building elements, level of stamping noise, noise of toilets and fixed installation, absorption coefficient, reverberation time).

Another regulation on this matter is laid down in “Ministerial Circular of May 22nd, 1967” titled “Assessment and commissioning criteria of acoustic requirements in school buildings”.

This document provides specific sound insulation standards. In school gyms the reverberation time should not exceed 2.2 seconds.
In the school gym that we examined for this paper, we investigated the acoustic quality, namely the "acoustic comfort". In the classrooms used for teaching activities, acoustic optimization is necessary for verbal communication understanding and for better student learning results [1].
However, in a gym this level is usually lower because for a class to be effective students only need to understand verbal communication. An unsuitable environment in terms of acoustic parameters may have negative effects on speech understanding and affect attention and behaviour, making students restless.
It should be noted that based on Legislative Decree 81/2008, in spaces used for physical exercise noise is rarely a direct risk for health and safety of workers given the substantial lack of noise sources. Noise in the school environment is usually a disturbing agent for teachers and students and a cause of physical and mental stress. Additionally, with increasing noise the speaker (the teacher)tends automatically to raise their vocal effort (**Lombard effect**) [2]. Many teachers suffer from more or less serious voice disorders. With respect to the acoustic properties of the environment, reverberation is extremely important because it is responsible for the so-called "sound tail" [3].
This study shows the results of our measurements in the above mentioned school gym.
We have specifically taken into account the noise exposure of gym users and the reverberation time of the environment. As a result of our analysis, we propose remedial intervention to improve the acoustic properties of the gym.

2. Methods

2.1 Equipment

Measurement systems used for this work are in compliance with the specifications of Class 1 standards reported in EN 60651/1994 and EN 60804/1994.
For the acoustic measurements we used the post-processing software N&W version 2.5 (Spectra).
The "measurement chain" used for noise detection is indicated below:

- 4 Channels Analyser; Manufacturer: F&V; Model: TeTrA 8440. Acoustic measurements in accordance with Standard IEC 61672-1, class 1.
- Amplifier PCB Piezotronic; Model: PCB 426E0.
- Microphone BSWA; Model: MP201.
- Calibrator L&D; Model: CAL 200.

For the measurements of reverberation we used the following:

- Sound source of dodecahedral type, with omnidirectional emission ("Look Line" system) for measurements with the interrupted noise method and Sweep-Sine method
- Clapper device for measurements with the integrated impulse response method

2.2 Monitored environments

Noise measurements were carried out in a gym located in the basement of a secondary school in the city of Rome. The school is located in a high urban traffic area. Figure 1 contains the gym plan.

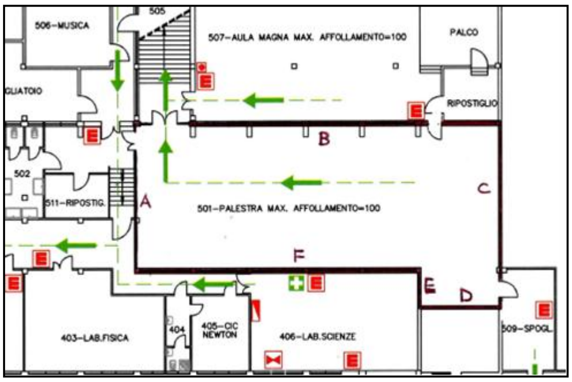


Figure 1. Gym plan

The gym area is basically a rectangle (m.23x9) with a small-size recess with two service rooms (dressing room and playroom). The gym height is m.4.98. Room measurements (surface and volume) are indicated below:

Side A	Side B	Side C
44.92 sqm	114.54 sqm	54.63 sqm

Side D	Side E	Side F
23.90 sqm	12.95 sqm	90.64 sqm

Floor	Ceiling
216.82 sqm	216.82 sqm
Total surface	Total volume
775.22 sqm	1080.00 m3

For proper allocation of sound absorption coefficients of surface materials, it must be specified that along the B-side there are 6 windows (4.00x1.60) (Photo 1) over a glass door. On side D there is one window of the same size.
On side D, the glass surface is 6.4 sqm, while on the B side the glass surface is 38.4 sqm. If we include the glass door, the surface is approximately 40.0 sqm.
So, the room has a total of 46.4 sqm of glass surface.

Photo1. Inside the gym

3. Results

3.1 Noise exposure

In order to define the “acoustic climate” of the environment, measurements were carried out to assess the level of noise exposure in the gym during teaching activities. The aim of the measurement is the following:

- Verification of compliance with the exposure limits stated in Legislative Decree 81/08;
- Feasibility of improvement of the acoustic properties of the environment.

Therefore, the value of Leq (A) was measured during a gym class, placing 2 microphones in the location where the teacher is usually standing during the lesson; microphones were at a distance of about 2 m. from one another and the measurement had a duration of about 30 minutes. The measurement indicated Leq (A) value varying between 80.8 dB (A) and 82.0; the peak value of the weighted c (ppeak C) is clearly lower than the lower action value established by the law (Art.189 - D.lgs. 81/08: ppeak= 135 dB (C).
During the measurement, 16 students and a teacher were present in the room. As pointed out by the head teacher, the lesson often involves more than one classroom at a time and therefore the number of students may double. As a consequence, exposure levels may be higher. Also the small size of the space must be taken into account, which does not comply with the requirements laid down in D.M. 18/12/1975.
However, it has been shown that exposure to high levels of noise only occurs in a limited period of time, compared to the planned observation period of 8 hours, in accordance with Decree 81/08. Consequently, there is a sort of "dilution" of exposure peaks.
The above measurements indicate that the space is in compliance with the statutory limits and there is a low probability of hearing damage. However, measured values are such as to generate an unfavourable acoustic environment.

3.2 Reverberation time

Measurements were taken of the reverberation time in the gym in order to verify the compliance of this parameter with the requirements in the law (max value 2.2 seconds, as an average related to the frequencies of 250, 500, 1000, 2000 Hz).
The reverberation time is defined as the time required for the sound pressure generated by a source to be reduced to 1/millionth of its value, after the interruption of the source that generated it. In logarithmic terms, this translates into a reduction of the sound pressure by 60 dB. The reverberation time varies as a proportion of the volume of the environment, while it is inversely proportional to the degree of absorption of the environment.
The sound absorption coefficient α is derived from the ratio of the sound energy absorbed and the incident energy; the value of α therefore represents the fraction of sound energy that is absorbed by a material.

The results obtained from the measurements (related to the environment, as required by legislation) are representative of the worst case scenario, while the actual conditions of use (full room), are more favorable than the reverberation times because they have greater sound absorption.
Reference values for the measurement of the reverberation time are provided in standard UNI EN ISO 3382-2: 2008 "Measurement of the acoustic parameters of the environments - Part 2: Reverberation time in ordinary rooms." The standard provides for three different methods of measurement: control method, technical design method and precision method [4].

In this case, it was considered more appropriate to use the technical design method, as specifically recommended for measurements in standard ISO 140 (all parts), which provide references on the reverberation time. This method is used also to verify the performance of the buildings.
The nominal accuracy is supposed to be better than 5% in octave bands and better than 10% in third octave bands (see Appendix A of the standard). The method involves measurements for at least two source positions and required six combinations independent source-microphone, as outlined in Table 1.

Table 1. Minimum No. of measurement positions.

Technical planning method - minimum number of positions and measurements	
Source-microphone combinations	6
Source positions	≥2
Microphone stations	≥2
No. of decays in each position (interrupted noise)	2

Regarding the measurement techniques, three different methods have been used:

- **Interrupted noise method**: method to obtain decay curves by recording the decay of the sound pressure level after exciting an environment with a broadband noise or bandwidth limiting.
- **Integrated impulse response method**: method to obtain decay curves by integrating the inverse of the mean square of the impulse response.
- **Scanning sinusoidal signal method (Sweep Sine)**: this technique (more recently developed) offers an excellent signal/noise ratio. Its allows the execution of measurements in noisy environments, with the use of omnidirectional sound sources at low power [5].

For the measurements related to the first and third method, a sound source of dodecahedral type was used, with omnidirectional emission. For the reproduction of "interrupted noise" the signal consists of pink noise. Moreover, the source has been set so as to have a sufficient dynamic range, with a level of at least 35 dB higher than the background noise. For the "Sine Sweep" method, the signal consists of a sinusoidal scan that embraces the entire spectrum from lower frequencies to higher frequencies.

The second method (integrated impulse response) was achieved by a special "clapper device", made of two wooden board of appropriate size hinged together. The boards are equipped with external handles are clapped to generate a impulse of adequate sound level.
The source was positioned in 3 different points of the environments away from each other; positions were chosen randomly in the environment analyzed, observing the minimum distance required by the standard (the position of the microphone related to the source, the position of the microphone related to the walls, floor and ceiling). For each point source 6 random microphone positions were identified. Source-microphone measurements for each of the 18 pairs were carried out with the 3 methods above.
The measurements made with 3 different techniques have been checked to ensure their accuracy, based on a number of quality indicators:

Filters answer BT > 16:
In the frequency analysis, the use band of the filters in 1/3 octave or 1/1 octave is such that the more the bandwidth is reduced, the more the response time of the filter is increased. In order to verify that the measurement is not affected by the response time of the filters, you should check if the values of T60 measured are higher than those identified by the

curve B*T>16 (B is the bandwidth in Hertz, T is the reverberation time).

Curvature:
In irregular environments (environments that do not correspond to a simple solid figure, such as two communicating rooms), you can also have significantly different reverberation time, if calculated on the T20 rather than T30. When the difference exceeds 10% we can calculate an indicator of curvature, given by:

$$C = 100 \times (T30/T20 - 1).$$

Waste:
The accuracy of the measurement is influenced by a number of factors: the volume of the environment, the distribution of absorption, the interaction of acoustic modes at low frequencies. The "waste" type (standard deviation) is therefore checked based on reverberation measurements acquired at different microphone positions and compared with the expected standard deviation. The quality of the measurement is given by a limited deviation between the actual and the theoretical gap.

Figure 2 shows the procedure used for the measurements, where for each location the 3 methods are applied in sequence (sine sweep, interrupted noise and impulse noise).

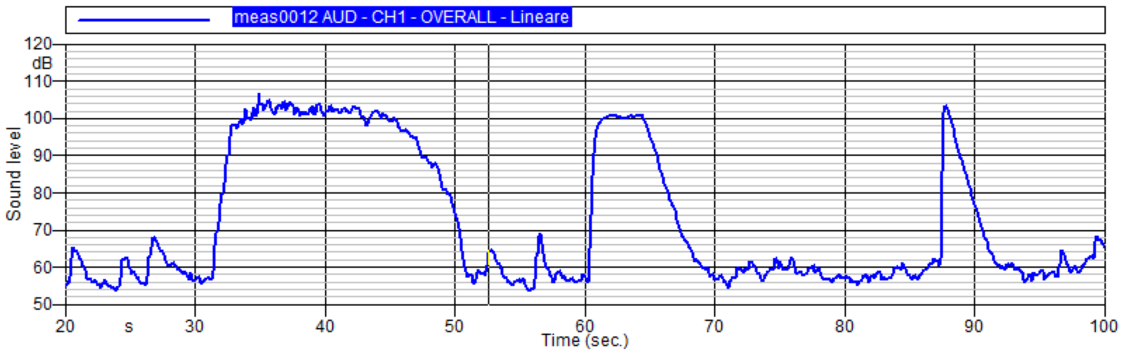
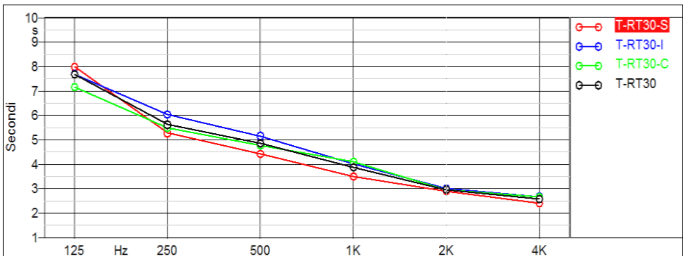


Figure 2. Time History of Sound Measurements

The graph in Figure 3 shows the average values of reverberation times relating to 18 different measurement stations (source-microphone) according to the three different methods of measurement. The red line corresponds to measurements with the Sweep-Sine method; the blue line to the method with the interrupted noise and the green line to the method of impulsive noise. The black line represents the average of the 3 methods. The graph also shows the results obtained from the calculation of quality indices, for the purpose of verifying measurement accuracy. Green indicates a condition of acceptance, while yellow indicates attention condition and the red is an indication of non-acceptance.



Nome	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
T-RT30	7.68	5.62	4.85	3.88	2.96	2.58
T-RT30-S	7.99	5.27	4.43	3.50	2.91	2.41
T-RT30-I	7.70	6.03	5.15	4.03	3.01	2.68
T-RT30-C	7.16	5.49	4.78	4.09	2.96	2.65

BT	952	1399	2393	3873	5920	10320
Curvatura	9	2	5	1	0	-3
Scarto	20	0	0	0	0	0

Figure 3. Time of reverberation and quality indicators

For the purpose of verification of compliance with the Circular of the Ministry of Public Works of 22/05/1967 we have the following results:

T_{60} = 4.33 seconds

The results obtained with the 3 measurement methods show a good correspondence. Quality indices reflect good accuracy and precision of measurements. The reverberation time detected is much higher than the reference values laid down in the Circular of the Ministry of Public Works of 22/05/1967.

3.3 Considerations on the results and proposed intervention measures

In order to optimize the acoustic characteristics of the environment and also to have an appropriate balance between costs and benefits, the most appropriate action is to increase the degree of sound absorption, to bring the reverberation to an acceptable level.

The intervention should consist in the application of absorbent panels on the surfaces of the environment. These sound-absorbing panels should be placed out of the reach of the users of the gym (students and teachers), both for convenience and hygiene. By virtue of the above considerations, a simulation has been carried out based on the assumption of acting exclusively on the ceiling of the environment, located about 5 mt from the ground. To simulate the effects of this environmental remediation the calculation model proposed by Arau has been used, which better simulates the environment that we studied [6].

In particular, the ceiling lining can be made with a specific sound absorbing material with the following properties: sound-absorbing, semi-rigid with polyethylene calibrated closed-cell. Table 2 shows the values of absorption coefficients, even for other surfaces and covered areas.

Table 2. Sound absorption coefficients of gym surfaces

Area (sqm)	**Location**	**Material**	**Sound absorption coefficient α**			
			250	500	1000	2000
295.18	Walls	Plaster on the	0.05	0.06	0.08	0.04
216.82	Floor	Linoleum	0.03	0.03	0.03	0.03
46.4	Windows	Glass	0.25	0.18	0.12	0.07
216.82	Ceiling	Polyethylene	0,5	0,95	1,04	1,1

By entering the data on the different areas and their relative absorption coefficients α on the spreadsheet we obtain a curve of the reverberation time T60 (blue line), which represents a significant improvement compared to the pre-construction situation (red line) (Figure 4).

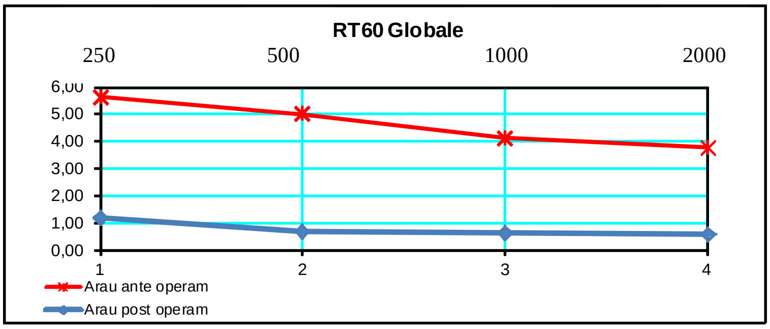


Figure 4. Ante / Post Operam Time of reverberation

In particular, the distribution at different frequencies is as shown in Table 3.

Table 3. Reverberation time post-operam (Arau model)

T_{60} with treated ceiling	Hz	250	500	1000	2000
	Sec.	1.21	0.69	0.63	0.57

Which yields the following average value:
T60 = 0.77 seconds.
This value falls within the limits of legislation, including the Ministerial Circular of May 22, 1967 (2.2 seconds).

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