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Evaluation of the Acoustic Performance of Classrooms in Algerian Teaching Schools

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Abstract**—**This paper presents the results of an evaluation of acoustic comfort such as background noise and reverberation time in teaching rooms in Height National School of Civil Engineering, Algeria. Four teaching rooms are evaluated: conference room, two classroom and amphitheatre. The acoustic quality of the classrooms has been analyzed based on measurements of sound pressure level inside room and reverberations time. The measurement results show that impulse decays dependent on the position of the microphone inside room and the background noise is with agreement of National Official Journal of Algeria published in July 1993. Therefore there exists a discrepancy between the obtained reverberation time value and recommended reverberation time in some classrooms. Three methods have been proposed to reduce the reverberation time values in such room. We developed a program with FORTRAN 6.0 language based on the absorption acoustic values of the Technical Document Regulation (DTR C3.1.1). The important results of this paper can be used to regulate the construction and execute the acoustic rehabilitations of teaching room in Algeria, especially the classrooms of the pupils in primary and secondary schools.

Keywords**—**Room acoustic, reverberation time, background noise, absorptions materials.

I. INTRODUCTION

IN acoustic room science, reverberation time is one the main used criteria to qualify the sound quality of speech and teaching rooms. Sabine [1] and Eyring [2] models based on the diffuse sound field assumption are wildly used as prediction methods for reverberation time [3].

In diffuse field theory, for a reverberant room with walls of a homogeneous geometrical and acoustic nature and for an omnidirectional sound source, Sabine deduces the reverberation time according to the average absorption coefficient of the walls. However, the Eyring's formula takes on consideration the high absorption coefficients.

Carolina Reich Marcon Passero et al. [4] evaluates several procedures to determine the reverberation time. The resulting data are analyzed statistically to verify their similarity. No statistical difference was found between the values obtained by the two measuring methods. The computer simulation produced accurate data. Their results show that the best formula for calculating RT in the classroom is Eyring's formula.

Arianna Astolfi et al. [5] present a comparison between measured and calculated acoustical parameters in eight high school classrooms. The reverberation time in unoccupied and occupied classroom were compared with analytical and numerical predictions. The results show that the ODEON 6.5 code and the Sabine formula gave the most accurate results for reverberation time in the empty classrooms. When the students are present, the Eyring and Sabine formulas and Hodgson's empirical model resulted to be the most accurate.

S. K. Tang et al. [6] present an investigation on the speech acoustical parameters (C80, RT, D and Ts) in the Hong Kong classrooms having standardized architectural layouts. Their results show that these acoustical parameters are highly correlated. The best result of this paper is that the strong correlations between the acoustical parameters and the regression formulas can help engineer and architects to the estimation of the speech quality of the classrooms in the design stage.

Carl C. Crandell et al. [7] examines different acoustical parameters, such as noise, reverberation, and speaker-listener distance. The results of their finding show that the discussion examines the effects of these parameters on the speech perception abilities of both children with normal hearing and children with hearing loss. The appropriate acoustical criteria are suggested for children in educational settings in this paper.

The American Speech-Language-Hearing Association's (ASHA's) recommended that an appropriate acoustical environment be established in all classrooms and learning spaces. ASHA endorses the ANSI standard and recommends three criteria for classroom acoustics: First, the levels must not exceed 35 dB(A) in unoccupied classroom. Second, the signal-to-noise ratio (the difference between the teacher's voice and the background noise) should be at least +15 dB at the child's ears. Third, the reverberation must not surpass 0.6 seconds in smaller unoccupied classrooms or 0.7 seconds in unoccupied larger rooms.

Chris DiMarino et al. [8] study the acoustical performance of a grand lecture hall using experimental and modeling techniques. Reverberation time, early decay time, clarity and STI were the four acoustical parameters considered. The results show that the room design demonstrated less than ideal reverberation time and early decay times for the proposed room use but above average clarity and STI values.

The main objective of this paper was to evaluate the acoustic comfort in different teaching room and proposed acoustic correction when this comfort is insufficient. To

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determine the range of reverberation times and background noise obtained in teaching rooms, a series of measurements was carried out in four samples of rooms. In order to obtain the acoustic comfort and optimise prescribed absorptions panels surfaces required to decrease reverberation time in such rooms, we developed program on FORTRAN 6.0 language. This program is based on data base of DTR C3.1.1 [9] elaborated by CNERIB center. In our knowledge no published work concerning the acoustical charteristic of teaching room of the primary and secondary schools in Algeria.

The paper is divided into seven sections. After the Introduction (Section I), Overview on national acoustic regulation of building is given in Section II, the material and measurement methodology are presented in Section III. The architectural detailed of rooms and results of measurements are discussed in Section IV. The critical distances are given in Section V. Section VI concerns the acoustic correction method and implementation of the panels is given in Section VII. Finally a conclusion is given in Section VIII.

II. OVERVIEW ON NATIONAL ACOUSTIC REGULATION OF BUILDING

In Algeria, the main document of the acoustic regulation in building is the DTR C3.1.1 (technical document of regulation) entitled: acoustic insulation of the walls against the airborne noise, rules of calculus [9]. This document is elaborated by the national center of research in Building (CNERIB) related to Algerian Ministry of Habitant and Building. In this document, the detailed about the calculus of the acoustic loss factor is given. The recommended reverberations time values for different rooms such as: teaching room, sport room and residential building. The data base of different materials of the construction is tabulated. The special attention is given for the hospital, school and commercial building. It should be noted that this document is not sufficient for acoustic correction inside school and classroom. For this reasons, several research project will be executed in the next years by the CNERB.

In the present study, the rooms measured are all in Kouba, Algeria and are all at the National School of Civil Engineering. Details of the rooms are given in Table I.

TABLE I
DATA FOR THE MEASURED ROOM

Room	Volume (m3)	Seats	Volume/seat (m3)	RT (S)	Critical distance (m)
Conference room	370	60	6.20	0.94	6.27
Class room 1	740	70	10.6	2.92	5.03
Class room 2	190	40	4.75	1.52	3.50
Amphitheatre	1430	300	4.80	0.97	12.14

III. MATERIALS AND METHODOLOGY

A. Materials

The measurement was done with Lutron SL-4013 equipment and software consisting of: Spectra RTA (Fig. 1 (a)); wireless microphone; sound level meter; Pc portable to analyze the results. Fig. 1 (b) shows a Lutron SL-4013 sound level meter used for all the experiments. This equipment was used to capture the spatial decays of the sound pulse generated by popping inflated balloon (Fig. 1 (c)) at expected mouth location of teacher which is about 1.2m above the floor and 1.0m of the vertical centerlines of the green board. The microphone is located at a distance of 1.2m from the floor, corresponding to ear of height of average listeners in typical chairs.

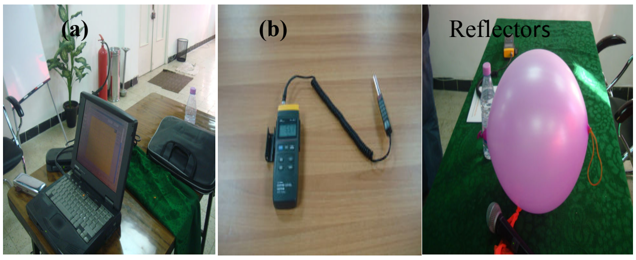

Fig. 1 Materials used for experiment, (a): PC and Spectra software, (b): Sound level meter Lutron SL-4013, (c) balloon

B. Measurements Methodology

The aim of this work was to verify the acoustic quality of classrooms built according to standard designs for school buildings. All the measurements were taken as suggested by ISO 3382-1 [10] and ISO 3382-2 [11] with respect to the position of the sources and receiver in the room. Five sound source and five sound receiver positions were used. The positions were chosen in the main seating area covering the typical range between teachers and students in the room.

Changes were made in the numbers of repetitions and intensity of the signal in order to obtain a more accuracy in measurements. All windows and doors were closed and the air conditioners were switched. The measurements were carried out between 11:00 and 13:00 in the absence of students. All the reverberation times have been measured in octave bands. Additionally, mid-frequency parameters have been calculated as the mean of the 500 Hz and 1 kHz octave band levels.

The measurement results for each receiver position were averaged over two or three measurements.

IV. RESULTS AND DISCUSSIONS

A. Conference Room

1. Succinct Description

The conference room is situated at the first storey of the administrate building. It has capacity of 70 seats and hosts a variety of events, such as, conference courses and presentation of final project by students. The form of the conference is basically trapezoidal and their walls are with brickwork and concrete. The windows are covered with thin curtains. It should be noted that the acoustical performance of furnished room is best than unfurnished one. A photograph of conference room can be seen in Fig. 2.

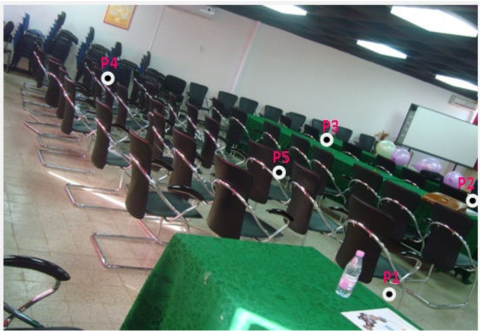

Fig. 2 Conference room with five measurements positions

2. Architectural Layout

The architectural layout of the conference room is presented at Fig. 3. The tables and chairs are presented because it's have significantly effect on the reverberation time. The ceiling and walls are general reflective and non-diffusive. The floor is covered by tile with very low sound absorption coefficient (DTR C3.1.1). [9] The desks and chairs are more closely packed and minimum distances between themes.

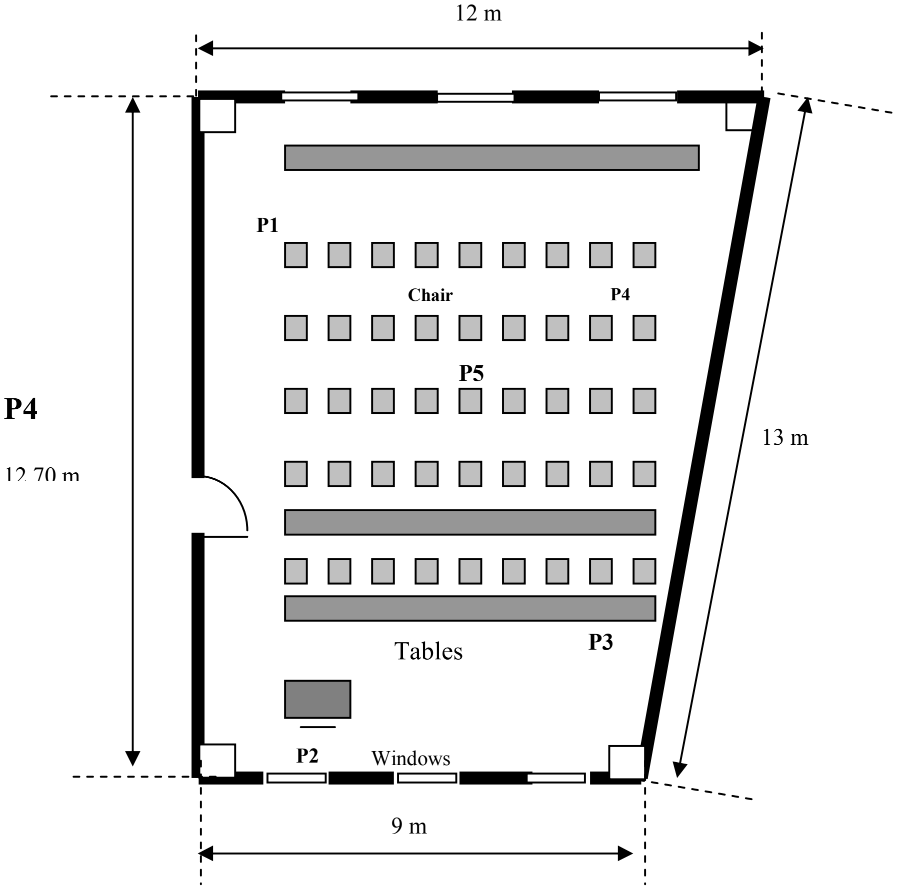

Fig. 3 Architectural layout of the conference room

3. Measurement Results

Room Impulse Decays

As can be seen in Figs. 4-7 the results show the room impulse decays during time for two locations (P1, P2, P3 and P5). All the figures illustrates that the impulse decays time are strongly affected influenced by the positions and frequencies. It should be noted that the maximum pick of the sound level are observed obtained for height frequencies, however it is very small for low frequencies. The fluctuation of the curves after damped presents that the curve achieved the background noise level.

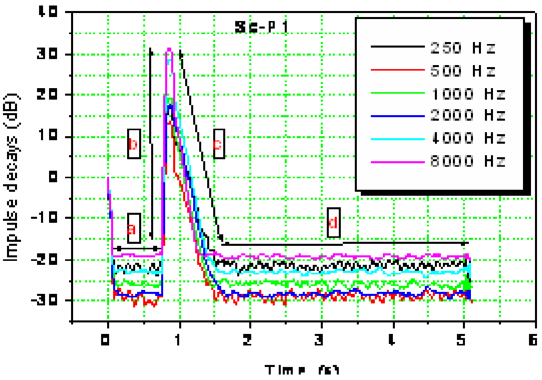

Fig. 4 Impulse decays for the locations P1

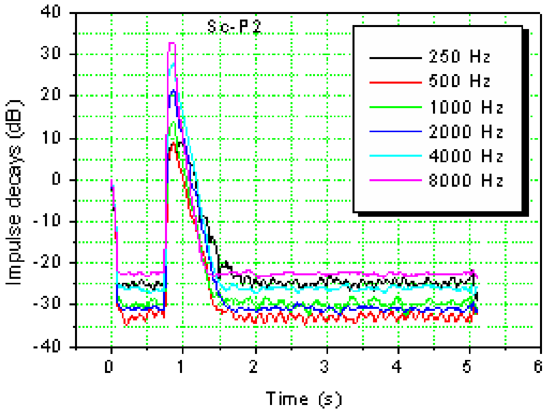

Fig 5 Impulse decays for the locations P2

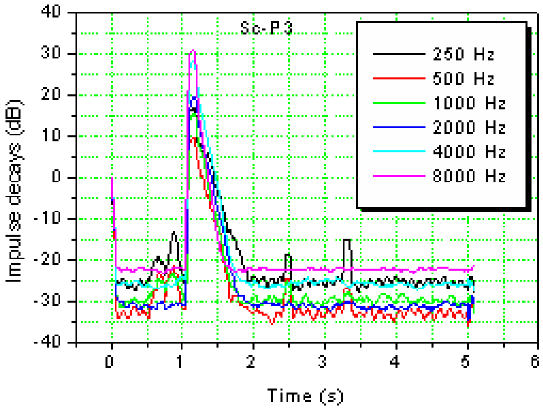

Fig 6 Impulse decays for the locations P3

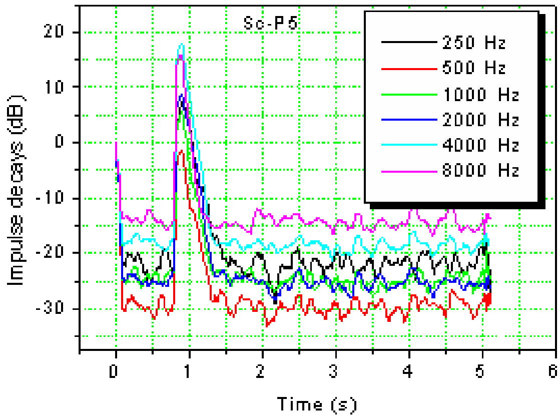

Fig. 7 Impulse decays for the locations P5

Reverberation Time

It will be known that the reverberation phenomena are formed by a number of reflected sounds superposed without discontinuity that add to the direct sound waves and prolong it.

All the measurements have been carried out with a closed curtain. The measured average reverberation time in octave bands at different positions in the conference room are shown in Fig. 8. The maximum reverberation time values are observed for height frequencies, however the minimum values are observed for the low frequencies.

Understanding speech is hindered by the combined effects of excessive noise and reverberation in this classroom, which tends to interfere in the learning process. The combination of noise and reverberation exerts a stronger negative effect on speech recognition than the sum of their separate effect [12].

Apart from the room surface sound absorption, it is supposed that the chairs and tables inside the conference room tend to scatter sound. The reverberation time values have small effect on position in low frequency. We can conclude that the reverberation time of this room is closely to the recommended values. The famous curve shows that the reverberation time is affected by volume of rooms and this values can be in the small range (0.4-1.2 S). The reverberation time of this room is in range of standardization. This result can be explained by the lot of objects which are affecting directly on acoustic characteristics. The background wall of this room is covered by thin curtain. The chairs are covered with special curtain and also the tables are enclosed with synthetics curtains. The forward floor part is covered with synthetic curtain of surfaces 22m^2; the absorption coefficient of this panel is very high, α≈0.6 for medium frequency.

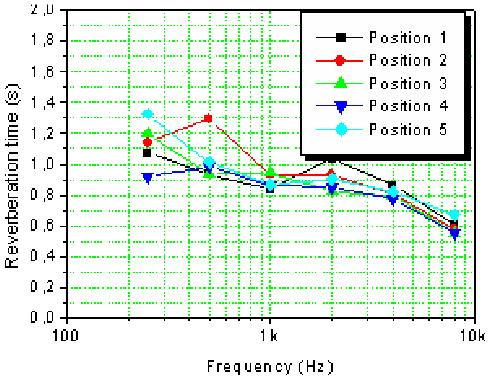

Fig. 8 Reverberation time for the conference room

B. Teaching Room 1

1. Succinct Description

The teaching room 1 has a seating capacity of 70 seats (student) and has been designed for courses. The form of this room is octagonal and the inner surfaces are predominately hard and reflective, such as concrete and brickwork. A photograph of teaching room can be seen in Fig. 9.

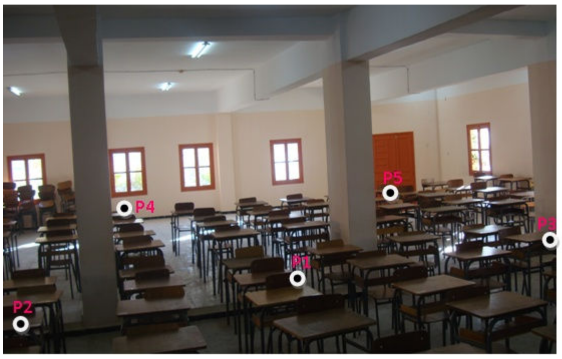

Fig. 9 Teaching room with five measurements positions

2. Architectural Layouts of the Teaching Room 1

The architectural layout and basic furnishing of class room is presented at Fig. 10. The dash lines represent the locations of structural beams. The ceiling and walls are general reflective and non-diffusive, but the basic furniture such as wood and steel will to some extent scatter the sound. The floor is covered by tile with very low sound absorption coefficient (DTR C3.1.1) [9]. The desks and chairs are more closely packed and minimum distances between themes not exceed 1m.

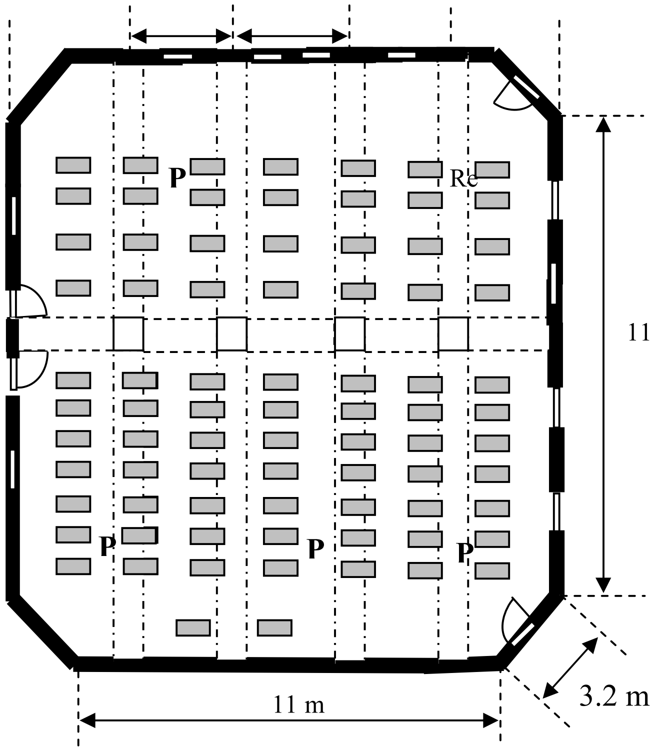

Fig. 10 Architectural layout of the teaching room

3. Measurement Results

Room Impulse Decays

Fig. 11 shows the impulse decay time for point P5 inside the room, the same remarks for the previous room can be deduced. All the curves present pick which the maximum sound level is obtained. The maximum decay can be attained 40 dB in all cases. The extrapolation method is used to define the reverberation time values.

Reverberation Time

Fig. 12 illustrates that reverberation times values are very height for the low frequency and become small for height frequencies.

In this case the reverberation phenomena appeared that is elongated compared from the previous case. When the experiments are taken, it is very easy to listening reflected noise generated by the inflated balloons. This can be explained the highest volume of the room and their chaps. In addition, we can see that no absorptions materials covered the walls.

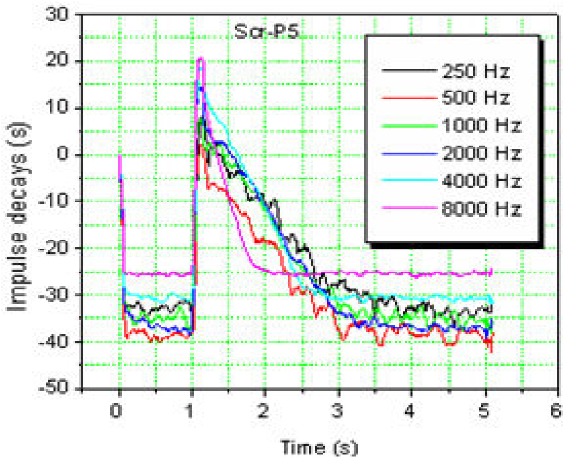

Fig. 11 Impulse decays for the location P5

Theoretically, the reverberation time (RT) is defined as time required for the sound energy density to decay 60 dB after the source has stopped emitting. It depends on the acoustic and geometric characteristics of the room. In DTR C3.1.1 [9] different data base materials and absorption coefficient are listed. There are methods to determine reverberation time based on the wave or geometrical theory. There exist different models based on statistical theory. For each model, air absorption is ignored.

Reverberation varies as a function of frequency and, therefore, may need to be measured at discrete frequencies. Generally, because most materials do not absorb low frequencies well, room reverberation is shorter at higher frequencies and longer in lower frequency [13].

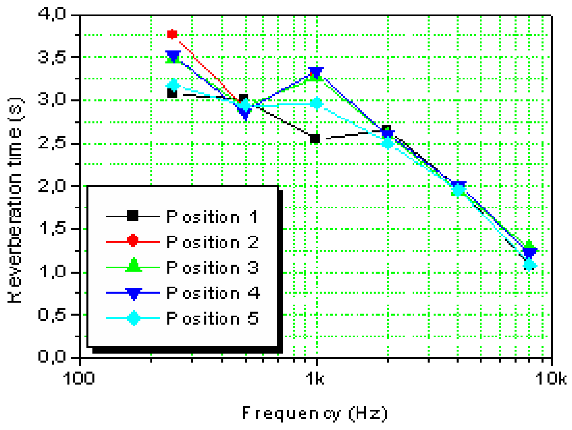

Fig. 12 Reverberation time for the teaching room

C. Teaching Room 2

1. Brief Description

The teaching room 2 has a seating capacity of 40 seats (student) and has been designed for courses. The shape is a parallelepiped rectangle with a height of 3.3m and the interior partitions are hollow brick walls covered with plaster. A photograph of teaching room can be seen in Fig. 13.

2. Architectural Layouts of the Teaching Room 2

Fig. 14 shows the architectural layout of the teaching room

2. The dash lines correspond to the location of structural beams. We can see that, there is not curtains covered the glazed façade, and this case can affect directly on the reverberation time inside room. The curtains of the glazed can eliminate the reflected ray and decrease the reverberation time.

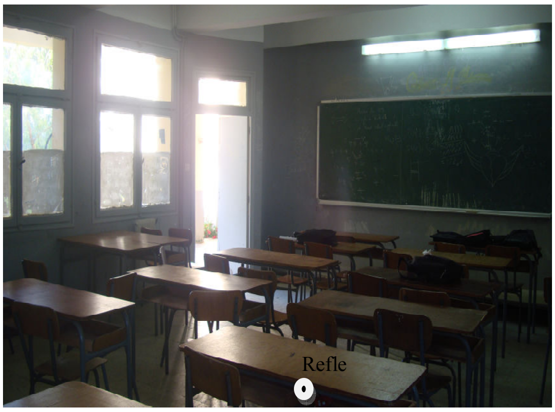

Fig. 13 Teaching room with measurements positions

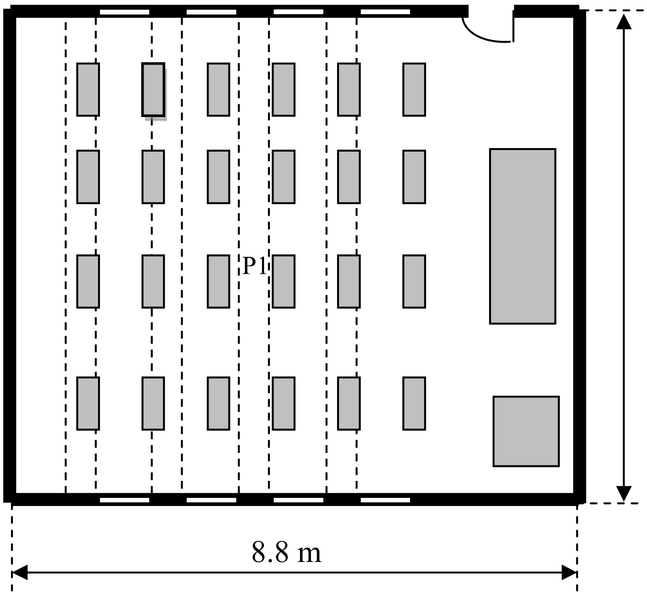

Fig. 14 Architectural layouts of the teaching room 2

3. Measurement Results

Fig. 15 shows the impulse decay time for only one position inside room and for different frequency. All the curves present picks which the maximum sound level is obtained. The maximum decay can be attained 40 dB in all cases. For the frequency Fr=8000 Hz, the decay attain 40 dB(A). The same method is used to define the reverberation time values in this case.

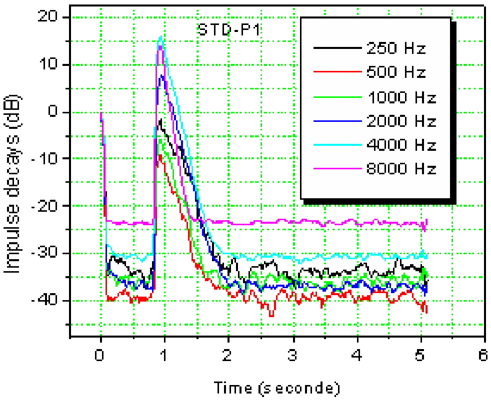

Fig. 15 Impulse decays for the locations P1

In spite of small volume, Fig. 16 shows that the reverberation times values are very height for the low frequency then it become small for height frequencies. It attains 2 second for the disagreeable cases. The student in this room can prepared those courses and discusses the correction of directed exercises. Reverberation can affected directly on the speech intelligibility and reduce the understanding. The standard reverberation time value for the classroom is ranged from 0.6 to 1.2 Second, in Algerian standardization, the reverberation time must be in the range of 0.8 second (DTR C3.1.1) [9] We present in this case that the student in the room affect directly on the reverberation time and reduce it to the prescribed values. But the intelligibility of speech can be reduced significantly. In conclusion, this room needs prescribed acoustic correction and the method for this purposes will be disused later. Reverberation refers to the phenomenon of sound continuing to be present in a room because of sound reflecting of surfaces such as desks or chairs. When sound lingers in a room there is more interference with speech. In a classroom it is important to have a short reverberation time.

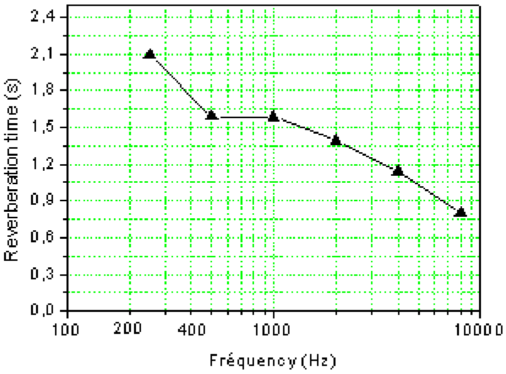

Fig. 16 Reverberation time for the teaching room

D. Amphitheatre

1. Brief Description

The amphitheatre has volume of 1430m^3 and seating capacity of 300 students (seats). The slop of the amphitheatre is 14°. The windows are located at tow lateral side walls. The chairs and tables are with varnished wood with low absorption coefficient (DTR C3.1.1) [9]. The windows represent 15 % of surfaces of the laterals walls (Fig. 17).

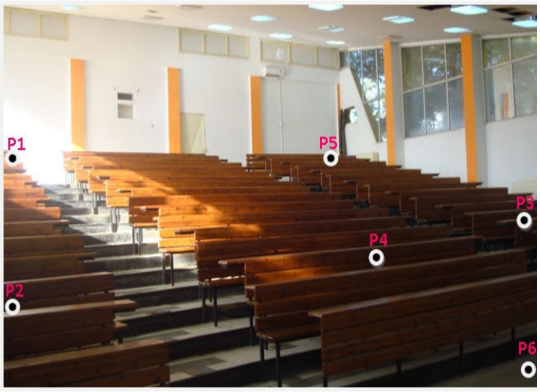

Fig. 17 Amphitheatre with six positions of measurements

2. Architectural Layouts of the Amphitheatre

Fig. 18 shows the architectural layout of amphitheatre. The floor is covered by plastic tiles with low sound absorption coefficient. The walls are predominately hard and reflective, such as concrete and brickwork.

The ceiling is with plaster with absorption coefficient of 0.04 in medium frequency (DTR C3.1.1) [9].

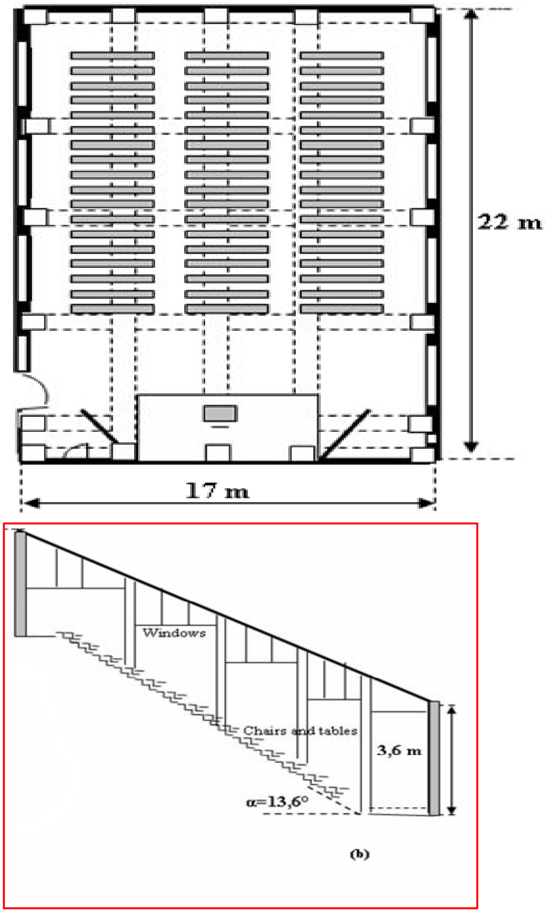

Fig. 18 Architectural layouts of the amphitheatre, (a): Top view, (b): side views

3. Measurement Results

Figs. 19 and 20 show the impulse decay for position P1 and P4. The signals are perturbed for the low frequency. In the same part it is very smoothed for the height frequency. In spite of different positions measurements, the impulse decay in amphitheatre achieved 40 dB in the most of studied cases.

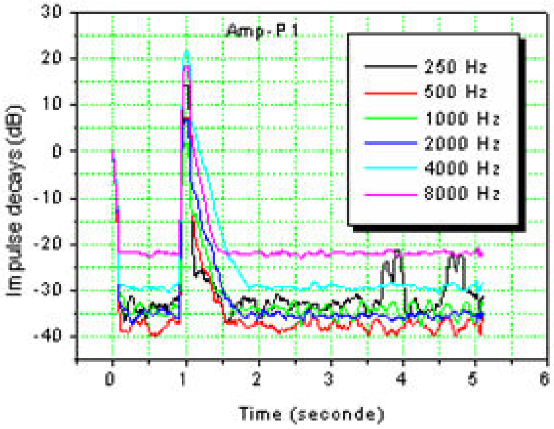

Fig. 19 Impulse decays for the locations P1

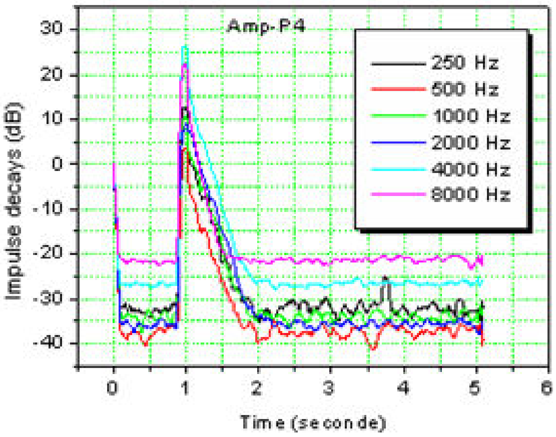

Fig. 20 Impulse decays for the locations P4

Fig. 20 shows the reverberation time in different position inside the amphitheatre. The ceiling and walls are in general reflective and non-diffusive, but the basic furniture (wood and steel type) i.e. table and chairs will to some extent scatter the sound. The floors are covered by tiles with very limited sound absorption capacity (DTR C3.1.1) [9]. The green boards produce some sound absorption.

First diagnosis in amphitheatre is that the teachers and students consider the noise generated and voice of students in neighboring classrooms as the main sources of annoyance inside the classrooms.

V. TEACHER-TO-LISTENER DISTANCES

In this subsection we introduce the important parameter that influences speech perception in the classroom; it is the distance from the teacher to the student.

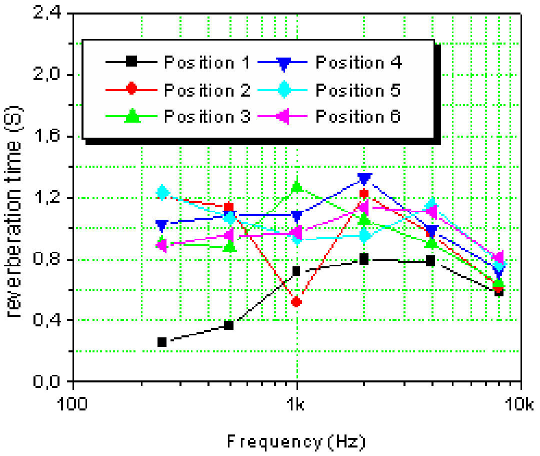

Fig. 20 Reverberation time for the teaching room

When the student is near the teacher, the direct sound wave is dominated in the classroom and the transmission of the sound is effected with minimal interference.

Direct sound pressure follows the principle of the inverse square law, which states that sound level decreases 6 dB for every doubling of distance from the sound source.

As the child moves away from the teacher, the indirect or reverberant field begins to dominate the listening environment [7].

The indirect sound field originates at the “critical distance” of the room. The critical distance of the room refers to the point in the room where the level of the direct sound and the level of the reverberant sound are essentially equal (Fig. 21). Operationally, critical distance (Dc) is defined by the following formula [7]:

$$D_c = 0.20\sqrt{VQ / nRT} \tag{1}$$

where V is the volume of the room in m^3, Q is the directivity factor of the source (the human voice is approximately 2.5), n is the number of sources, and RT is the reverberation time of the enclosure at 1400 Hz.

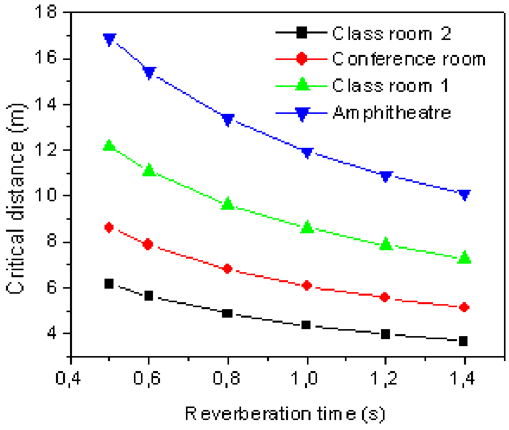

Fig. 21 Effect of reverberation on critical teacher-to-listener distances for different rooms

VI. METHODS FOR ACOUSTIC CORRECTION

In this subsection, we introduce the fundamentals techniques for acoustic correction in teaching rooms studied previously. In addition, we elaborate program with FORTRAN 6.0 language which estimates the values of reverberation time based on data base of DTR C3.1.1 [9]. The numerical results for the suggested acoustic correction will be illustrated later. Generally, there exist three methods for the acoustic absorption

1. Installation of porous and fibrous panels.
2. Installation of resonators.
3. Installation of membranes [12], [14].

In market, the porous panels can be existed in different chaps and colors such as plane or waved. The absorption coefficient of this material increase with same time of frequency, it can attain 0.6 in some cases. The holes insides panels can deflect the rays then scatters those and reduces the reflection to the receiver In Fig. 22, we illustrate the different view of the holes for dimension of 1mm, 100μm and 50μm. The panel with porous material can be distributed inside room perfectly, for this reason the numerical code can estimate the acoustic parameters of the room under study. Finally, the method of correction is founded.

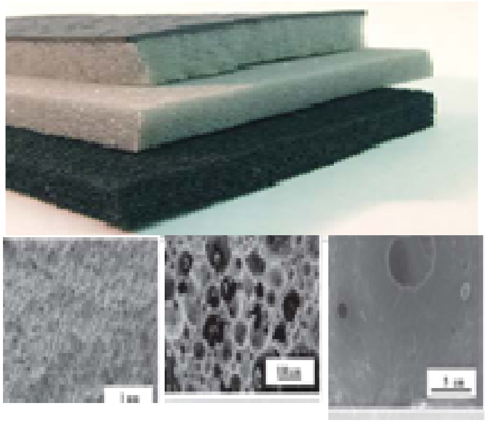

Fig. 22 Different kinds of porous materials

The resonator is old method which is developed by the roman in the church. It is small enclosure of air which is the absorption of the sound waves is height. The resonance frequency of this system dependent on different parameters such as: volume of enclosure, length and diameter of the channel. Nowadays, the detailed architectural can introduce this system with different chaps, in Fig. 23 the resonator is created between tow plate placed on the ceiling of the room.

Fig. 23 Resonator placed on the ceiling

The membranes or reflected panel are mounted near walls with small thickness. The wave deflects the panel and compressed the air between wall and panel. The system plays the same behavior of the resonator when the frequency of the wave approaches to the natural vibration frequency of the membrane. It should be noted that the height absorption of this system situated near the low frequencies. The range of absorption can be increased when the air inside the gap is damped with fibrous or porous panels.

In order to ensure height absorption in large range of frequency, the previously listed method scan be combined together. In this case, the corrected surfaces can be reduced significantly. Fig. 24 shows that the combined methods increase the absorption field inside room [12]. In Fig. 25 we summarize the measurements reverberation time in previous rooms and the recommended reverberation time ranges.

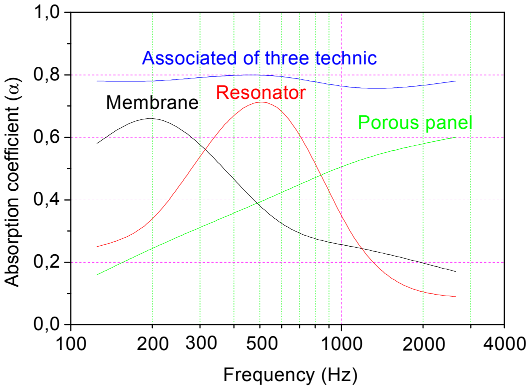

Fig. 24 Effect of porous, resonators and membranes. Increasing the absorption with combined methods

Fig. 26 shows the comparison of the background noise level with recommended noise level by the national office journal. With regard to the level shown in this figure, it can be concluded that the classrooms are less affect each other and the airborne noise are compatible with the values established by the Algerian standard for acoustic comfort in classrooms.

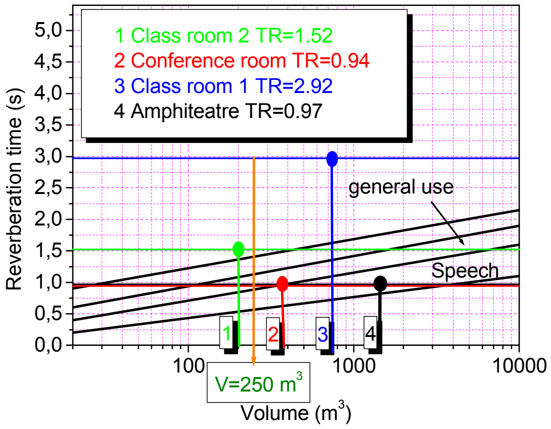

Fig. 25 Optimal reverberation time of different room under study

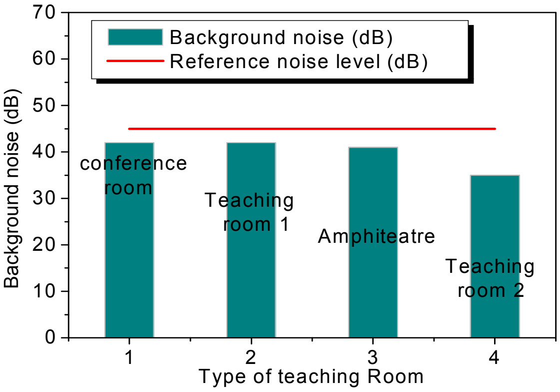

Fig. 26 Background noise compared with recommended noise level

VII. IMPLEMENTATION OF THE PANELS

In this section we present the method of executing the panels and absorption materials in classrooms and amphitheatre.

In this type of room, when the absence of acoustic treatment, the reverberation is too long and there are great possible of reverberation, which generates a bad intelligibility [12]. In this case it is necessary to treats the part of the ceiling located towards the bottom of the room, also, the backward wall and a side wall (see Fig. 27).

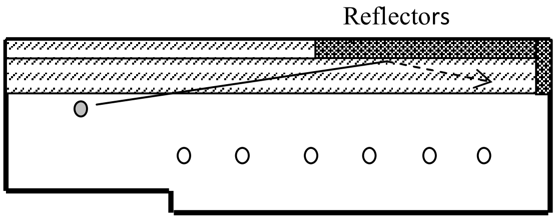

Fig. 27 Classroom with absorption panels

The seat position of the students in steps increases acoustic absorption, which makes that it possible to limit the zones treated with the wall of the bottom and, possibly, at the zone of ceiling furthest away from the lecturer. The bottom, located above the lecturer, is laid out so that the sound waves, in their reflective, are distributed to the bottom of the room.

If the side walls are reflective, it should be not be parallel. If they are parallel, they must be imperatively treated in order to make them diffusing. The solution consists to equipping them with reliefs in order to break their parallelism and to ensure a good homogeneity of the sound field inside classroom.

Fig. 28 shows the amphitheatre with absorbents and reflectors panels, where all the listeners, whatever their place, profit from a good intelligibility. The form of the amphitheatre and, materials disposition has strongly significant on the sound field distribution. Reflectors and absorbent panel can enhance the intelligibility.

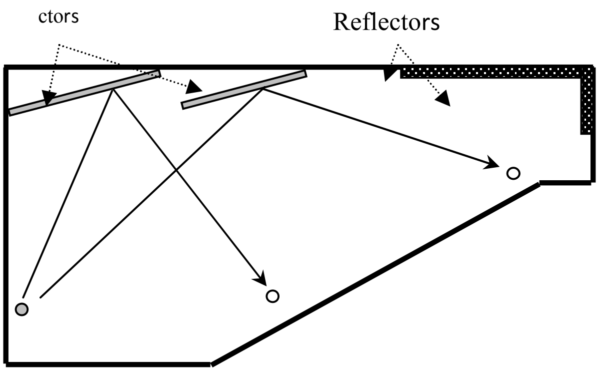

Fig. 28 Amphitheatre with reflector and absorbents panels

VIII. CONCLUSIONS

This work concerns the acoustic characterization of different teaching room in national school of civil engineering, Algeria. Some conclusions are summarized as follows:

1) The National School of Civil Engineering is less affected by outdoor traffic noise and the background noise is less than recommended level prescribed by Algerian standardization.
2) The reverberation times in teaching rooms are excessive than recommended reverberation time, however, the values of this parameter for the conference room and amphitheatre is in good agreement with recommended values. The famous result obtained from this work is that the 50% of teaching rooms in this school needs prescribed rehabilitation of internal walls. No insulation for the airborne is required, because the values measured are in good agreements with the national Algerian Newsletter. The critical distance refers to the point in the room where the level of the direct sound and the level of the reverberant sound are essentially equal were defined.
3) Three methods have been proposed to reduce the reverberation time and the developed program with FORTRAN language can estimates the values of reverberation time based on data base of materials construction listed in national regulation document (DTR C3.1.1).

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