Room mode analysis for classrooms: a case study in the College of Engineering

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Abstract. Noise can affect students through both auditory and non-auditory effects, which can compromise concentration, and learning and communication abilities. According to a previous study done by the same author in the College of Engineering, Al-Mustansiriya University, it was observed that 39.5% of the students suffered because of the noise in the classrooms. They felt discomfort, hearing difficulty, need to raise speech sound, tinnitus, lack of focusing, nausea, and headache. Therefore, the room mode was calculated for different classrooms size in various departments to evaluate their sound quality and compare the results with standards. Acoustic parameters, namely background noise and reverberation time, were also measured and analyzed. The room mode analysis showed that most of the frequencies are focused around the transition range of frequency, causing maximum and minimum peaks in frequency response of 20 dB or greater. Therefore, the sound quality in the classrooms is not appropriate for education. Background noise levels and reverberation time are higher than the values established by the standards. Thus, it is recommended that an appropriate acoustical environment in the classrooms should be developed for the benefit of students and teachers.

1. Introduction

Noise can affect students through both auditory and non-auditory effects. It can affect concentration, learning ability, communication, and continuity with teachers [1-5]. In university classrooms, the main concern is that inadequate acoustical conditions can result in poor verbal communication, which can lead to reduced learning efficiency. Moreover, these conditions can lead to fatigue, stress, and health problems (headaches, sore throats) amongst lectures, who are forced to compensate for poor acoustical conditions by raising their voices [2].

In the current case study research analyzed a schoolroom in an old university edifice that was the subject of instructor’s complainants regarding the poor acoustic situation, which included elevated noise intensity and poor speech clarity. Its design is representative of numerous schoolrooms in the old edifice of primary and secondary schools. The edifice was primarily constructed with no central HVAC system. For that, many window type and/or split type air-conditioners were fixed, and they are extremely noisy [6].

An effective learning process in a classroom requires good acoustic quality for a good speech intelligibility. In this context, room mode analysis can be used to evaluate the sound quality of classrooms. Room modes are the result of the reflection of sounds on diverse surfaces in the schoolroom with wide frequency bands. This phenomenon has been researched in detail over the years, especially in rooms where speech and music are important sound sources. Moreover, the interference of the human voice frequency and resonance frequencies that appear in the rooms and their effect on each other have also been studied [7-13].

Furthermore, the acoustical conditions in a classroom depend on three main factors: room geometry (size and shape), sound absorptive properties of the internal room surfaces, and the number of students attending the schoolroom. All these factors affect speech and background noise levels, as well as
reverberation time [2]. Standards such as the ANSI S12 and DIN4109 establish that the highest surrounding noise should not go over than 35dBA, and the reverberation time for classrooms should range from 0.4 to 0.6 s [14,15]. If the measurements are not within the standards, they can cause a discontinuity between the teacher and students because if sound reflation takes long time, antepenultima are disguised and there is a weakening of speech clarity and quality. If the sound reflation takes short time, the speech loses characters and also presents lower quality [16]. These conditions lead to poor learning outcomes.

For this research, the goal is to appreciate the acoustic circumference of the schoolroom by using background noise, room geometry analysis, and reflection sound time.

2. Study Area

The classroom descriptions are summarized in Table 1. All classrooms have rectangular shapes. Three classrooms in each department building were measured. All of them are similar in construction material (concrete and plastered bricks) but have different dimensions and sizes.

| Department building  | Length (m) | Width (m) | High (m) | Capacity (n. of students) |
|----------------------|------------|-----------|----------|--------------------------|
| Environmental        | 9.3        | 4.7       | 3.3      | 40                       |
| Material             | 7.7        | 5.7       | 3.3      | 48                       |
| Civil                | 7.7        | 5.9       | 3.3      | 40                       |
| Electrical           | 7.7        | 5.6       | 3.5      | 30                       |
| Mechanical           | 8.7        | 5.8       | 3.3      | 48                       |
| Computer & Software  | 8.7        | 5.7       | 3.8      | 42                       |

According to a previous study done by the same author in the College of Engineering, “The sources of noise in these classrooms were classified as indoor and outdoor. Indoor noise comes from air conditioner devices, whereas outdoor noise comes from the students' voices when they gather in the squares, electric diesel generators, horn vehicles, traffic, and parking lots near the campus” [17].

3. Measurement Methodology

To evaluate the sound quality of classrooms and check if they comply with the standard criteria for education and learning purposes, a room mode analysis was performed with additional information, namely background noise level and reverberation time (RT_{60}). The obtained data can provide information about sound quality.

3.1 Room Mode Analysis

Room modes are the sum of all different repercussions in a room when this room subject to excitement by noisy sound sources like HVAC systems and loud speakers. Three kinds of room modes are existing, axial, tangential, and oblique. Frequencies affected by room dimension results modal mode activity which in turn leads to peaks and nulls (dips) in the range of frequency response. [16]

Sound waves may meet in phase or out of phase. a peak is produced in response results when waves meet in phase. On the other hand, a dip or null response results when waves meet out of phase. In the
latter case, waves are canceling each other. In the 20 to 200 Hz region, most rooms have their fundamental resonances, each amplitude has to do with one or more measurements of the space or its splitter. Such resonances influence a sound system’s low and mid-frequency response in the space and are one of the biggest obstacles for correct reproduction of audio. Space modes are produced when a sound wave moves, for instance, along two different edges, the walls on the left and right or the floor and ceiling. Room modes are the main reason for under-transition rate acoustic deformation. They cause maximums and minimums in the 20 dB or higher frequency response. Room modes were calculated by using Equation (1) \[16,18\] and drawn by using the Room Mode Calculator software [19].

\[
All \text{ } Modes = \frac{C}{2\sqrt{L^2 + W^2 + H^2}} \quad (1)
\]

Where:

\[C = \text{speed of sound (344 m/sec)};\]
\[L, W \text{ and } H = \text{room dimension (length, width, and height respectively) (meters)}; \text{ and}\]
\[P, Q \text{ and } R = \text{Integer numbers (0,1,2,3,…)}\]

Room mode depends on the Bolt area, which is the ratio between the dimensions of the room (length, width, and height). This ratio shows the approximate sound distribution across the frequency spectrum, and it is used to enhance room acoustics [20].

3.2 Background Noise and Reverberation Time

Background noise is the ambient sound at a given location and time. Its level is measured in unoccupied spaces when the specific noise is suppressed [21]. Reverberation Time (RT) is the time it takes to degrade a loud sound to an inaudible rate after interrupting the origin. It can also define as “the difference between the sound and inaudible levels of -60 dB”. It is normally evaluated for the sound decline from -5 to -35 dB (RT\textsubscript{60}) and multiplied by a factor of 2 for RT\textsubscript{60} compliance.

Background noise was measured according to the ISO1996-1 [24]. Reverberation time RT\textsubscript{60} was measured according to the ISO 3382 [22] and by using the Sound and Vibration Analyzer 957 (sound level meter).

4. Results and Discussion

4.1 Room Mode Analysis

The room mode was analyzed by using the Harman online analysis and Amroc (room mode calculator) online. ‘Figures 1 to 6’ show all modes (axial, tangential, and oblique), and the transition frequencies for these classrooms were calculated as 120 Hz, 120 Hz, 118 Hz, 117 Hz, 112 Hz, and 105 Hz, respectively. From the figures it can be seen that most frequencies are clustered around the region of change, creating spikes and falls in the 20 dB and lower frequency response.[18]. An even sound wave distribution in the room depends on the Bolt Area [11]. The Bolt Area for the classrooms is shown in ‘Figures 7 to 12’. The ratio within the Bolt area should produce appropriate low-
frequency room performance with respect to axial frequency distribution. [11]. However, it can be noticed that only two departments have the correct ratio for length, width, and height. According to the room mode analysis, the sound quality is not good for education in all classrooms despite the two departments with a relatively good bolt area.

![Figure 1. Room mode analysis for classrooms in the Env. Eng. Dep.](image1)

![Figure 2. Room mode analysis for classrooms in the Mat. Eng. Dep.](image2)

![Figure 3. Room mode analysis for classrooms in the Civil Eng. Dep.](image3)

![Figure 4. Room mode analysis for classrooms in the Elec. Eng. Dep.](image4)

![Figure 5. Room mode analysis for classrooms in the Mech. Eng. Dep.](image5)

![Figure 6. Room mode analysis for classrooms in the Comp. Eng. Dep.](image6)
4.2 Background Noise and Reverberation Time

Background noise rates have been assessed in all areas of unoccupied schoolrooms. The results ranged from 50 to 60 dBA, that is lower than the appropriate 35 dBA background noise [14,15].

Reverberation time measured for audible frequencies in the classrooms of the buildings of the Environmental, Material, Civil, Electrical, Mechanical, and Computer & Software Engineering departments were 4.9, 4.4, 5.1, 4.6, 4.3, and 6.8 sec, respectively. However, the typical reverberation time according to the DIN 18041 [25] is 0.52 sec, and according to the ISO 3382 [22], RT$_{60}$ should be 0.4-0.6 sec.
The room mode analysis, background noise level, and measurements of the reverberation period of this work confirmed the results obtained in a previous study performed in the College of Engineering [17]. This previous study reported that 39.5% of the students were negatively affected by the noise in the classrooms. They reported pain, hearing trouble while talking they had to raise their voices, lack of concentration, migraine, tinnitus, and vomiting. Moreover, high background noise and high reverberation may significantly impair the comprehensibility of words as they can mask significant, lower-level consonants, particularly for English, the key language used in the engineering classes. [11]

5. Conclusions
The room mode analysis, and the measured background noise level and reverberation time were used to evaluate the sound quality of classrooms. The measurement results indicate that classrooms have poor sound quality that causes annoyance, discomfort, anxiety, and distress to the students, in addition to the lack of clarity of speech and consequent difficulty to understand it.
To obtain the ideal acoustical conditions in the classroom, further studies should include the distance between the listener and the teacher, and the teachers’ voice levels. Based on that, the maximum safe voice level for teachers can be determined, thus minimizing the risk of voice impairment while providing adequate speech intelligibility for listeners.

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