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Optimizing acoustic conditions for two lecture rooms in Faculty of Agriculture, Cairo University

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Abstract This paper analyses the acoustic conditions inside two lecture rooms in faculty of agriculture, Cairo University, based on field measurements and simulation technique. Ambient noise and reverberation time were measured in the unoccupied rooms. The measurement results were utilized for validating the results of CATT software that was used to estimate occupied reverberation time, STI and C^{50}. These parameters were analysed in comparison with rooms' properties, optimal reverberation time and maximum acceptable noise for learning spaces. The results demonstrated that acoustic design of the first room is far from the recommended values, whereas the second room includes many defects. For optimizing the rooms' performance, acoustic treatments were proposed and explored. Results clarified that reducing the excessive reverberation to the optimal value, either by increasing room absorption or decreasing room volume, significantly optimizes speech intelligibility. The results also clarified that reforming the ceiling eliminated the shadow and increased the early reflections.

1. Introduction

Low energy of early arriving speech, high ambient noise (L) and excessive reverberation time (T) are common defects in speech rooms [1]. These defects impede the learning process as the spoken words become unclear and incomprehensible [2]. The satisfactory acoustic conditions in lecture rooms should achieve effective speech-to-noise ratio (SNR) that is the ratio between effective signals to the effective noise in decibel [3]. Speech intelligibility (SI) increases proportionally with increase of SNR; achievement of an optimal reverberation time (T_{Opt}) comes in the second importance after achieving suitable L [4]. Although reverberation time gives lesser indication about room suitability for speech than other relevant parameters such as clarity (C_{50}), sound strength and speech transmission Index (STI) [5,6], there is no useful alternate for controlling the reverberation [3], which determines early decay time, early to-late sound index, and total sound-pressure level with volume [7]. In other words, excessive T decreases SI either in noisy or in quiet conditions [2], whereas low T reduces the desirable energy of early reflections and speech intelligibility accordingly [2]. In addition to L and T, STI is the most important single indicator that combines between S/N and room acoustic [4]. Difficult speech communication is considered a common issue in many lecture rooms in

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Egyptian university. For example, numerous auditoria in Faculty of Engineering, Ain Shams University are suffering from poor speech intelligibility due to excessive T and L [11]. Hence, the purpose of this paper was to analyse the acoustic conditions in two lecture rooms in Faculty of agriculture at Cairo University based on field measurements and simulation technique; it also includes proposed treatments to optimize their acoustic defects. The selected proposals will be applied in the future maintenance plan of these rooms. The Faculty of agriculture was established in 1889. It contains eighteen departments and huge numbers of lecture rooms. The examined rooms are Room 108 and Seminars room, the smallest typical room and the most important room in the faculty respectively. Room 108 is located in the ground floor of a new building (El Saman building) that consists of three stories. Seminars room is located in the ground floor of the general library building. The two buildings directly overlook a crowded street, approximately 20 m away from shared taxi stop and 180 m away from Giza square.

2. Literature review

The benefit of the early-arriving reflections has attracted many researchers. Bradly et al. for example [5] carried out speech intelligibility tests on normal and impaired listeners inside an anechoic room, using eight channels electro-acoustic system to generate the sound fields. The tests were performed with various speech-to-noise ratios (S/N) and constant noise level. The results clarified that the improvement in speech intelligibility scores, due to the increase in direct speech energy, is similar to the improvement resulting from the increase in early reflections energy. The research also included measuring early reflection benefit (ERB) in five different unoccupied rooms. The results showed that effect of increasing ERB was very close to the effect of increasing the direct sound level about 9 dB. Moreover, the effect of room design on early reflection strengths was explored using ODEN simulation software. The result confirmed that the first priority of room acoustic design is to increase the total energy of direct speech and early reflections, and the second priority is to achieve optimal reverberation time by minimizing the late reflections. Ellison and Germain [8] confirmed the importance of early reflections on speech intelligibility as well. They explored the effect of an active acoustic system on speech intelligibility in a School. The results showed that the system was able to increase the ERB while keeping the reverberation time within optimal value.

The most applicable solution for optimizing speech intelligibility in lectures room is the suitable selection for the properties of internal surfaces [6]. For example, different arrangements of the same absorptive material can change the values of acoustic parameters up to 50% [9], whereas diffusive surfaces increase the quality of room acoustic due to its indirect effect on room absorption. Pavlović and Petrović [9] studied the effect of diffusivity in a specifically designed physical model on room acoustic parameters. Impulse response of the model at eighteen various combinations of flat and diffuse inner surfaces were measured at 1/3 octave band frequencies, and the surface diffusivity index of the model proposals varied from 0 to 1. The result showed that the measured T resulted from using diffuse surfaces was lesser than T resulted from Sabine equation, whereas C_{50} and D_{80} constantly increased as a function of surface diffusivity index. Currently, room acoustics softwares such as ODEON, CATT and EASE are considered feasible tools for exploring the room acoustic parameters; according to DiMarino et al. [10] "*The combination of such computer model studies and a limited number of validation measurements in real rooms is a cost effective approach for developing better information for designing better classrooms*". For instance, Elkhateeb [6] used ODEON software to verify the acoustic suitability for his proposed interior design of new lecture room in the Faculty of Law, Ain Shams University. The considered acoustic parameters were T, $D_{80,}$ STI and L. After the room construction, the same parameters were measured using MILSA system and compared to the estimated parameters during design phase. The results clarified that room design successfully achieved a satisfactory level of SI though L was high for the usage of natural ventilation.

3. Methodology

To attain the purpose of this research, architectural features of the rooms were surveyed. Room shape analysis based on geometric acoustic was investigated as well; as shown in Table 1, the pattern of sound rays' distribution was classified into four zones [11]. The acoustic conditions in the rooms under consideration were explored through four acoustic parameters: T, L, C_{50} and STI. Ambient noise level and Reverberation time in unoccupied rooms were first measured at octave band centre frequencies; the measurements followed ISO1996-2 [12] and ISO3382-2 [13]. Brüel&Kjer Sound analyser type 2260 in combination with Omni-directional sound type 4296 was the measuring device. Air temperature and relative humidity were recorded during the measurements by thermo-hygrometer device. Otherwise, reverberation time in occupied room (T_{Ocatt}), C_{50} and STI were estimated using CATT acoustic software. The 3D-model of each room was drawn using AutoCAD software. The absorption coefficients of materials surfaces were defined in the Geometry file as in reality; seating area of the listeners was simulated as wooden rectangular block in the unoccupied case and as audience on wooden chairs block in the occupied case. The measured parameters in the unoccupied rooms were utilized to validate CATT model outputs. The unoccupied reverberation time obtained from field measurements (T_M) and that obtained using CATT (T_{Catt}) were compared as shown in Fig. 1. The difference

Table 1 Zones categories based on acoustic quality [11].

Zones categories	Indication	Zone description
Good	(blue)	Areas that receive direct and first Order early reflections only
Medium	(red)	Areas that receive direct, early and late reflections from rear walls
Hard	(green)	Areas that receive direct and late reflections from rear walls
Shadow	(black)	Areas that do not receive reflections due to unstudied arrangement of walls and/or ceiling