Evaluation of Acoustical Suitability of Lecture Rooms with Respect to the Quality of the Sound Reinforcement System and the Level of Background Noise

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Introduction

In order to evaluate acoustical suitability of certain lecture rooms located on the Faculty of EE and Computing in Zagreb, Croatia, a questionnaire was given to the students who take their classes in those particular rooms. The first part of the investigation was intended to be focused on the quality of sound reinforcement system located in two largest lecture halls that was to be replaced with a new one of significantly better quality. The intention was to examine whether this change will be reflected in the grades of acoustical suitability of these lecture halls as given by the students. However, since the installation of the new sound reinforcement system in these halls has not been completed at the time this paper was written, this particular problem remains to be addressed in future work. The second part of this examination deals with two smaller lecture rooms of identical size and acoustic treatment, but with significantly different levels of background noise due to their location in the Faculty building. The source of this background noise is the outdoor traffic noise due to the fact that the Faculty building is situated very near one of the streets with the heaviest traffic in Zagreb. The overall noise levels have been measured in both rooms, as well as speech intelligibility. The results of these measurements are interpreted with respect to the subjective grades given by the students.

General issues

The problem that inspired this work in the first place is how to maintain acoustical suitability of lecture rooms facing the street with respect to traffic noise. Due to relatively high levels of this noise, it has become very difficult to give lectures in these rooms with no sound reinforcement system as a support. Unfortunately, the Faculty building is situated very near one of the busiest city streets, as shown in Figure 1. The street itself has three lanes in each direction and a two-way tram line in the middle, altogether representing a major noise source. In the past, the noise emitted from this street was tolerable regarding the quality of lecturing due to lighter traffic and the non-existence of the crossroad shown in Figure 1. However, since this crossroad was built a few years ago and the traffic load has increased, the noise has become a severe compromising factor to the quality of lecturing in these rooms. In addition, a tram stop has been built in close proximity of the building, thereby adding a new dimension to the problem. As a consequence, the windows on these rooms have to be shut if reasonably low noise levels in the rooms are to be maintained. As you can imagine, this does not represent a problem in winter, but severely compromises comfort in the summer as there is no air-conditioning installed in these rooms. The solution to this problem to be implemented in the future includes three parts: improving the sound insulation of the existing windows or installing new ones, thereby reducing the levels of outdoor noise, installing the sound reinforcement systems appropriate for lecture rooms of given size and acoustic treatment and, finally, installing the air-conditioning systems

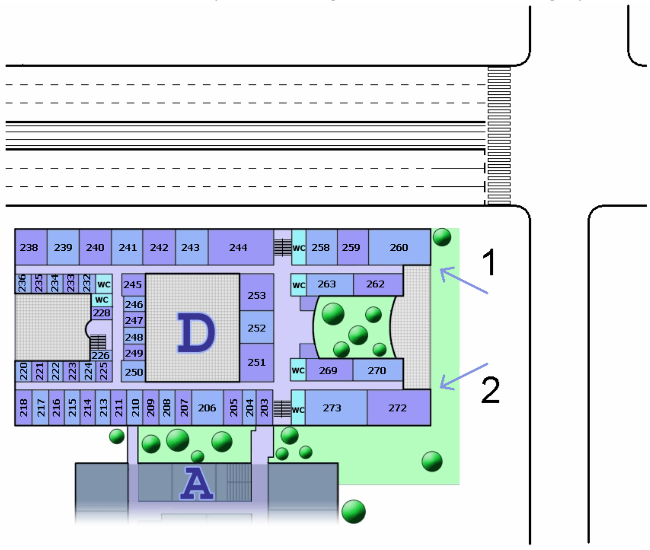

Figure 1. The position of the examined lecture rooms within the building and with respect to the street as the noise source

in the rooms to eliminate the need for opening the windows.

Objective measurements and subjective evaluations

The goal of this paper is to evaluate the quality of two lecture rooms with respect to acoustic conditions in those rooms that are influenced by the existence of a major source of traffic noise in close proximity. For this reason, two lecture rooms of the same size and acoustic treatment were chosen, each being the mirror image of the other regarding their location within the Faculty building. The chosen rooms are, however, very different regarding their exposure to traffic noise. The positions of both lecture rooms are shown in Figure 1. It is clear that room 1 is exposed to high levels of traffic noise emitted from the street, being only 10 meters away from the nearest car lane. To make things worse, all windows in room 1 are facing the street. On the other hand, room 2 is positioned almost 50 metres away from the street and the majority of its windows are looking in the direction opposite to the street. Therefore, it is expected that the level of traffic noise emitted from the street will be significantly lower in room 2 than in room 1 and that this will be reflected in the overall quality of lecturing in these rooms.

In order to obtain objective measures of acoustic conditions in both rooms, the initial step was to divide the audience areas in both rooms into nine sectors, as shown in Figure 2.

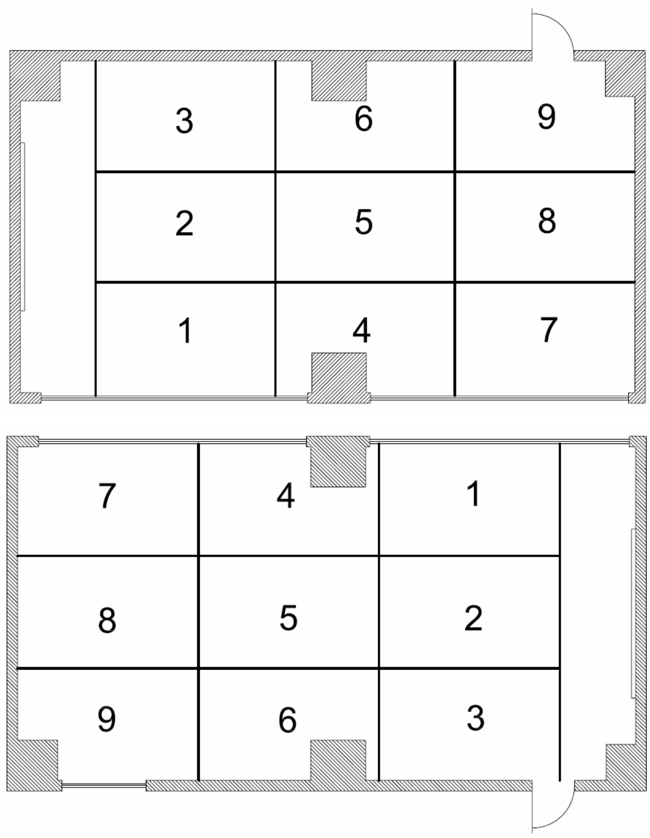

Figure 2. Audience areas in room 1 (above) and room 2 (below) were divided into nine sectors in for detailed objective measurements

The division described and shown above was made in order to gain a more detailed insight to the problem. Total noise level was measured in each sector and then averaged over all sectors in each room. Additionally, speech intelligibility was measured in each sector using an artificial head and torso simulator fed with pink noise having a level of 74 dB at a distance of 30 cm from the mouth. The measurements were made for both opened and closed windows. The results are shown in Tables 1 and 2.

Room 1		
Sector	ALCons (%)	
	Windows closed	Windows open
1	11,71	10,74
2	8,39	16,08
3	10,82	20,38
4	15,52	13,89
5	12,46	32,70
6	10,37	14,82
7	14,71	48,94
8	15,88	17,19
9	16,55	36,92
Average	**12,93**	**23,52**
Noise level (dBA)	**47,5**	**59,0**

Table 1: Noise level and speech intelligibility measured in room 1

Room 2		
Sector	ALCons (%)	
	Windows closed	Windows open
1	12,44	11,04
2	7,62	7,71
3	10,45	9,75
4	14,79	14,47
5	14,87	13,50
6	17,75	13,02
7	15,06	16,53
8	17,55	17,59
9	16,40	14,70
Average	**14,10**	**13,15**
Noise level (dBA)	**37,9**	**44,1**

Table 2: Noise level and speech intelligibility measured in room 2

The data obtained from measurements made in room 1 clearly shows that the acoustic conditions in the room change drastically when the windows are opened, resulting in an increase of noise level by more than 10 dB and decreasing the speech intelligibility to unacceptable values. It should be noted that the measurements of both noise level and speech intelligibility made in room 1 are greatly affected by the time-varying character of traffic noise, resulting in a somewhat unexpected results if observed for each individual sector in the room. Therefore, it was decided that average values of these parameters shall also be presented in order to gain an insight in the overall acoustic situation in the room.

On the other hand, noise levels measured in room 2 are lower than those measured in room 1. Naturally, the increase of noise level in the room as the windows are opened is evident, but even with open windows the noise level is reasonably low. The reason for this is that room 2 is not directly exposed to noise emitted from the street, but rather to the ever present background noise of the city. Furthermore, the values obtained for speech intelligibility suggest that noise levels in room 2 are not high enough to have an influence on speech communication which takes place in the room.

The combined results obtained for both rooms reveal two important findings: first, the outdoor noise does not seem to have an influence on speech intelligibility in the room below a certain noise level threshold, and second, the values describing speech intelligibility suggest that some kind of acoustic treatment is required if the quality of speech communication in both rooms is to be improved. The fact that the walls and the ceiling in both rooms are made of solid concrete with no acoustic treatment whatsoever seems to support the findings stated above.

In order to gain some insight in the students' opinions on the acoustical properties of the lecture rooms of interest, in the second part of this research the students taking classes in these rooms were asked to fill out a simple questionnaire. The questionnaire consisted of the following questions:

1. How much does the noise coming from outdoors bother you during your classes?

(not at all = 0, a little = 1, moderate = 2, very = 3)

2. How well do you understand the lecturer speaking?

(excellent = 0, very good = 1, good = 2, poor = 3)

3. Mark your current position in the room on the floor plan.

The questionnaire was given to students not enrolled in classes covering the field of room acoustics or noise, so the questions and answers were made as simple and straightforward as possible. The first question addressed the problem of noise and the second one was put with the intention to evaluate speech intelligibility in the room. The third and final task in the questionnaire was given in order to place each student in the appropriate sector in the room, which provided the means for a more detailed analysis.

The number of students at the time of subjective evaluation was 58 in room 1 and 38 in room 2. Furthermore, the windows were closed in room 1 and open in room 2. Sectors 7, 8 and 9 in room 2 were not occupied due to a small number of students that were present during the evaluation. The students' answers to each question in the questionnaire were examined separately. However, a summary grade was also calculated simply by adding the grades/answers given by the students to both questions. The summary of the results are given for both rooms in Tables 3 and 4.

Room 1 - windows closed			
Sector	Influence of outdoor noise	Understanding the lecturer	Summary grade
1	1,00	0,78	1,78
2	1,00	0,67	1,50
3	1,11	0,67	1,78
4	1,83	2,00	3,83
5	1,36	1,64	3,00
6	1,50	1,50	3,00
7	1,00	1,25	2,25
8	0,80	1,40	2,20
9	0,50	1,50	2,00
Average	**1,14**	**1,16**	**2,30**

Table 3: Results of subjective evaluation made for room 1

Room 2 - windows open			
Sector	Influence of outdoor noise	Understanding the lecturer	Summary grade
1	0,25	0,63	0,88
2	0,64	0,54	1,18
3	0,00	0,33	0,33
4	0,50	0,00	0,50
5	0,17	0,00	0,17
6	0,71	1,00	1,71
7	-	-	-
8	-	-	-
9	-	-	-
Average	**0,45**	**0,52**	**0,97**

Table 3: Results of subjective evaluation made for room 1

It should be noted that the subjective evaluation made in room 1 is more relevant than the one made in room 2 due to a larger number of participants. The general observation that can be made is that the overall average grades for each room clearly indicate that room 2 is more favourable than room 1 for giving lectures, given the acoustical properties of both rooms. This finding is supported with the results of objective measures given in Tables 1 and 2. A more comprehensive analysis by individual sectors in the room has not proved to be useful in room 2 due to a relatively small number of subjects. In room 1, however, certain conclusions can be made. To be more precise, the subjective grades indicate that the sectors of the room that are the closest to the windows are indeed the least favourable ones to sit in if the lecture is to be listened to with due attention. Furthermore, the noise level measured in room 1 was only 3 dB higher than the one measured in room 2, given the state of the windows in both rooms at the time the subjective evaluations took place. In those same conditions, the objective speech intelligibility was almost the same in both rooms. Nevertheless, the subjective grades given by the students indicate that there is a greater difference in acoustic properties of these rooms than it would be expected by comparing only the objective measures. In our opinion, one of the reasons for this is that the time-varying character of noise is also an important factor along with the presence of noise itself.

Unfortunately, certain problems have arisen while conducting subjective evaluations. Specifically, several students have made a remark that indoor noise may be a problem as significant as the outdoor noise due to the fact that the most of the students have a hard time keeping quiet during the lecture. Most of all, our fear is that the students did not take this research as seriously as we had hoped, although the importance of the research has been emphasized more than once. Therefore, it is a matter of debate whether the answers given by the students truly reflect the acoustic situation in both rooms. The overall averaged grades make a clear distinction between the two rooms, but a larger number of subjects, which was not available at the time this research took place, are required for a more detailed analysis.

Simulations

According to [1] the optimum reverberation time at medium frequencies is RT_{60} = 0,65 s. Using the computer simulation and 3D model, calculated reverberation time for empty classroom was RT_{60} = 1,5 s, that is more than two times higher than recommended time. For half full lecture room the calculated RT_{60} is 1 s, and for full room the reverberation time was equal to 0,75 s. The more interesting acoustical parameter was speech intelligibility. The DIN standard requires that Al_{cons} has to remain under 8% in the whole area of the room. From the results of simulations shown in Fig. 3 it is clear that under described conditions it is not possible to fulfill this requirement.

The reason why we have made simulations was that we wanted to verify the measured results for speech intelligibility. Although it is possible that the measured spatial distribution of values is different than the one revealed by the simulation, the room is small enough to maintain the averaged values of speech intelligibility in the same range.

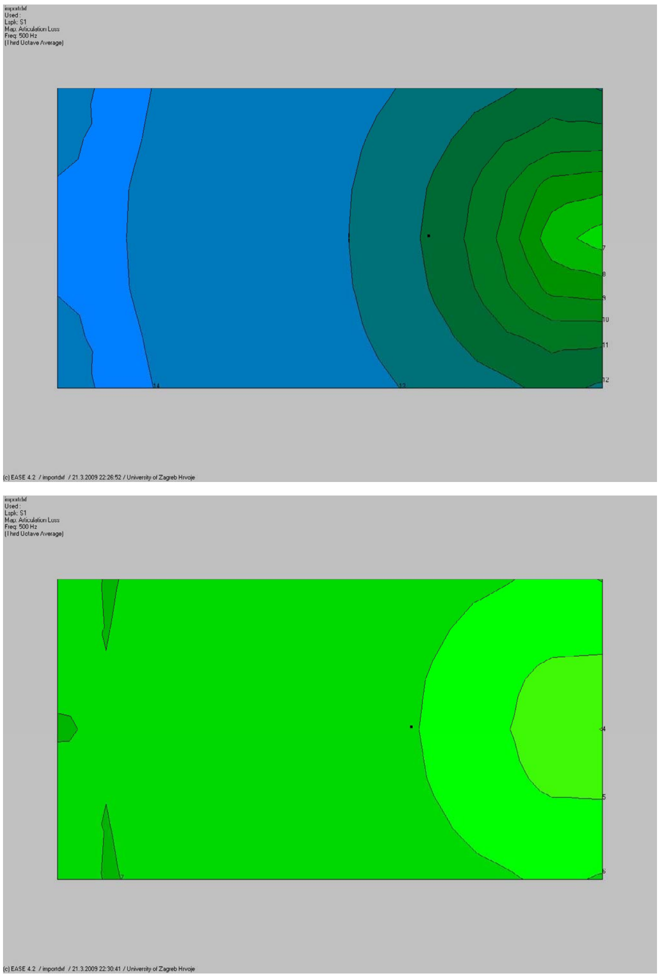

Figure 3. Calculated Al_{cons} values for empty room (above) and fully populated room (below)

Conclusion

Both objective and subjective evaluation confirm that outdoor traffic noise represents a major factor that affects the acoustical quality of lecture rooms inconveniently situated in close proximity of a major city street. As proposed before, there are three possible courses of action that can improve the acoustic properties of such rooms: improving the sound insulation of the windows, eliminating the need for opening the windows by installing air-conditioning devices and installing sound reinforcement systems in these rooms. The fourth course of action has asserted itself as a logical response to relatively poor speech intelligibility in the rooms, that is, to improve the acoustic treatment of these rooms. In our opinion, at least two measures out of these for have to be taken: most importantly, air-conditioning devices have to be installed in order to ensure that the windows facing the street can be closed at all times. As a second measure, any of the remaining three will improve the acoustic situation in these rooms, while a combination of these three measures will provide the best results.

Future work in this field will include further examination of this problem by repeating and extending the evaluation described in this paper to other lecture rooms on our Faculty. Furthermore, the largest lecture halls are currently being equipped with sound reinforcement systems as a part of our efforts to improve the quality of lecturing as much as possible.

References

[1] DIN 18041:2004, Acoustical quality in small to medium-sized rooms, Deutsches Institut für Normung e. V., 2004-05.

[2] ANSI/ASA S12.60-2002, Acoustical Performance Criteria, Design Requirements and Guidelines for Schools, American National Standards Institute, Inc., 2002.

[3] Building Bulettin 93: Acoustic Design of Schools guide, 2003.