An Experimental Study To Investigate Speech Intelligibility And Sound Quality In Elementary Schools

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Summary
The aim of this study was to investigate the relationship between the acoustic quality of a classroom and speech intelligibility in a primary school that is located directly under a flight path in the Küçükçekmece district of Istanbul. Different methodological approaches, including surveys, intelligibility tests, and measurements were performed within the scope of the research.
Third- and seventh-year students were given 60 real words and 60 non-words to write down under three different acoustic conditions in a classroom: the current condition with reverberation time and noise; an improved condition, in which suspended ceiling material with high ceiling noise absorption and PVC flooring were applied to lower the reverberation time but not the noise; and a second improved condition with better noise-isolated windows and an application of glass-wool based coated cloth wall panels which, together with the first improved condition, lowered the noise level.
Concurrent outer noise measurements and reverberation time measurements were done in addition to the intelligibility tests. The results revealed that the current acoustic conditions are far behind the comfort levels described in standards and that the improvements strikingly increased the intelligibility of speech and acoustic quality of the internal environment.
Keywords: Speech intelligibility, Sound quality, Elementary school buildings, Classroom acoustics

1. Introduction

Recently, whether acoustic conditions in the majority of education institutions make education difficult has been a much-debated topic. Since having a good instructor does not necessarily mean a good education will be received, the importance of the topics of acoustics and noise should not be ignored [1].
The topic of acoustic comfort should also be concerned within the physical conditions required at schools where education and training are provided. The instructor's practice of talking softly in the classroom and each student's ability to hear the instructor clearly have been seen as some of the factors that increase students' success. The topic has been studied, and after a determination of the current condition, a classroom was analyzed. After the two types of acoustic improvement were made, at different times, the results of the students' performance were compared with those from the current classroom condition with the aim of drawing attention to the problem.
A school located directly under a flight path and further subjected to traffic noise was selected, and the intelligibility test was administered to third- and seventh-year students representing two different age groups receiving education in the same classroom, due to the difference between their sensitivities and vulnerabilities within the scope of the study. The intelligibility of 60 real words and 60 non-words was evaluated through the test.
Concurrent environmental noise measurements were taken during the application of the intelligibility tests, and the number of planes that passed through during the lesson was noted. The time of effect during the passing of a plane was recorded by approximation.
Improvements to volume acoustics were implemented in two stages. The first improvement was the application of a suspended ceiling and floor, while the second was changing the wall and the application of cloth coated acoustic wall panels. The intelligibility test was repeated immediately after each improvement with the two age groups, and differences between the intelligibility percentages demonstrated by the students were calculated each time. The internal and external noise measurements were taken after each improvement, and the differences were analyzed by comparing the latest and current conditions of the classroom.

2. Methodology

2.1. Selection of the School

Twelve primary and secondary schools located in Küçükçekmece, Istanbul, and under a direct flight path were visited, and Penyelüks Hasan Gürel (PHG) School was selected for the study because it has the highest exposure to noise for various reasons.

The school is one of the oldest schools in the Küçükçekmece district. It provides education to approximately 500 primary and secondary level students. The biggest disadvantage of the school, which provides mandatory education for the first eight years, is its location under a direct flight path and noise from nearby traffic crossroads.
The short distance between the airport and the school (see Figure 1) can be seen in photos of the school and photos taken from the school garden during the airplane departures. Indoor and outdoor photos of the school are shown in Figures 2.

Figure 1: Aerial photo of the airport and PHG School.

Figure 2: Indoor and outdoor photos of PHG School.

2.2. Parameters Affecting the Classroom Acoustics

There are three important parameters that affect the classroom acoustics. These can be listed as the following:

a) Reverberation time (T)
b) Signal-noise ratio (S/N)
c) Background noise

a) Reverberation time (T): The "reverberation time" parameter, one of the most important parameters of volume acoustics, which was first described by W.C. Sabine between 1895 and 1900, is defined as the time required for a sound to decrease 60 dB (one millionth of the initial energy) from its starting value. The general formula of reverberation time is given below [2]:

$$RT: 0.161\ V / A, \text{ s.} \qquad (1)$$

T: Reverberation time, s.
V: Volume of the room, m^3
A: Total acoustic absorption area, m^2 (sabin)

The most apparent cause of long reverberation time is "large places with a high ceiling and the selection of end materials used in those places from hard surface materials." While the reverberation time for classrooms ranges from 0.4 sec to 0.8 sec in most cases, it should be less than 0.4 sec in classrooms for children with hearing impairment [7].

b) Signal-noise ratio, (S/N): The key point of speech intelligibility is the signal-noise ratio. This is a comparison of the instructor's speech (signal) with any undesired background voice that occurs in the classroom (noise). It demonstrates the difference between pressure levels of signal and noise. When signal and noise change, SNR changes through the room as well. SNR is typically at its lowest level at the back of the classroom, near the walls, or at points close to a source of noise like a vent where the volume of the instructor's voice decreases to the lowest value. The signal-noise ratio is a simple comparison that is made to estimate how intelligible the speech in a room is [4].

c) Background noise: This is also known as ground or ambient noise and is defined as "the residual noise in an environment after particular noises examined in a given time and condition are extracted" according to the ISO 1996 standards. Since the noise levels are dB units, a logarithmic calculation operation is executed. If the background noise levels are higher than the limits determined in the regulations, Leq (background) dBA + 3 or Leq (background) dBC + 5 is considered the highest acceptable noise level (limit) [5]. The background noise level is designed as 35 dBA (NC 30) in small classrooms and course rooms and 30 dBA (NC 25) in bigger meeting rooms. This difference is related to the fact that higher volume loss is observed in larger areas.

2.3. Criteria, Standard and Regulation

For areas around education facilities, acceptable noise levels are determined by national and international standards. Table 1 shows the standards for the acceptable limits of internal environment noise levels used in different countries and their related values, according to the Registration of Evaluation and Management of Environmental Noise.
The results of this study are compared with the values in Table 1.

Table 1: The acceptable standard values by country [6].

Country	Publication	Reverberation Time (s)	Background Noise Level
Australia/ New Zealand	Standard,AS/N ZS 2107:2000	0,4-0,5	35-45 (max)
Belgium	Standard, '87	0,7-1 (200m3)	30-45 dBA
France	Decree,'95	0,4-0,8	38 dBA
Germany	Std,'80 and 83	0,3/0,45/0,5	30 dBA
Italy	Std, UNI 8199 '75	max.1(200m3)	36 dBA
Netherlands		max.1(200m3)	35 dBA
Portugal	Decree,'02	0,6-0,8(200m3)	35 dBA
Sweden	Std, '01	0,5-0,6	26-40 dBA
Turkey	Regulation, '08	<0,6/0,8	35 dBA (windows closed) 45 dBA (windows open) 35 dBA (Leq, 30 min)
UK	Std, BB93	<0,4	30 dBA (Leq, 30 min, for hearing impaired
USA	ANSI S12.60-2010	0,6-0,7	35-40 dBA

2.4 Measurements

Reverberation time and background noise level measurements were performed in order to determine the acoustic conditions inside the Year 3 and 7 classroom where students and instructors are exposed to noise is appropriate.

The measurements were done with a Bruel & Kjaer 2260 sound level meter; the measurement data were transferred to a computer via the acoustic software program Bruel & Kjaer Noise Explorer Type 7815 and analyzed as required (Figure 3).

The measurements of reverberation time and background noise in the classroom are important in determining the change between the current condition of the classroom and the condition after the first improvement, which was the application of an acoustic stone wool suspended ceiling with a PVC floor, and the second improvement, which was the application of cloth coated panels to the walls.

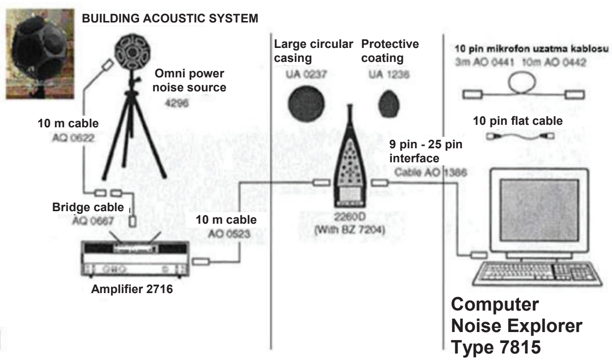

Figure 3: Measurement apparatus.

3. Evaluation of Acoustic Conditions

In this section, the results of the analysis of the current condition and after the acoustic improvements are evaluated.

3.1. Evaluation of the Current Condition

The aim of the analysis of the current condition is to assess the condition before any acoustic improvement was done in the classroom, compare it with the condition after the first improvement, and report the data regarding whether standards are met or not.

For the current condition analysis, photos of the classroom were taken under the first condition, the intelligibility test was administered to the third- and seventh-year students representing different age categories, who use the classroom on the same day but at different times, and the volume acoustics for the current condition were measured.

The measurements of reverberation time and background noise made in the classroom with an area of 48 m² and volume of 139 m³ were much higher than the desired values, and a two-stage improvement was decided. Measurement value levels higher than the standards were found to be correlated with low results on the intelligibility test for the students receiving education in the classroom (Figure 4).

Figure 4: Photo of the classroom in the current condition.

3.1.1. Reverberation time (T) measurement in the current condition

The classroom with a volume of approximately 140 m³, in which reverberation time in the current condition was measured, was furnished. The reverberation time was 1.83 sec on average without any improvements carried out. This value is expected to decrease when the students are in the classroom, but it is clear that it will not drop to 0.6 sec as required by the standards. This situation makes the communication between the students and the instructor poorer and negatively affects the students' concentration. The graph of reverberation measurement of the classroom's current condition is shown in Figure 5.

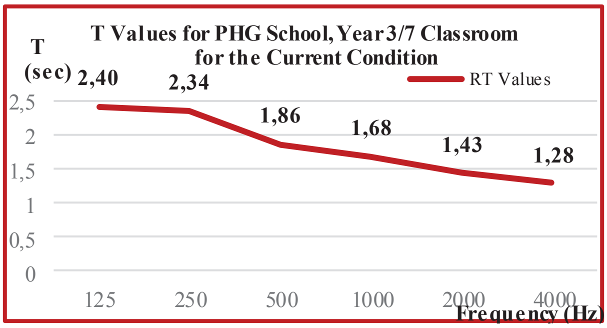

Figure 5: T values for the current condition.

3.1.2. Background noise measurement in the current condition

The A-weighted equivalent value of background noise level (dBA) is 48.7, as shown in Figure 6. Background noise measurements were taken with the classroom windows closed, whereas the results obtained from the current condition were found to exceed the standard values.

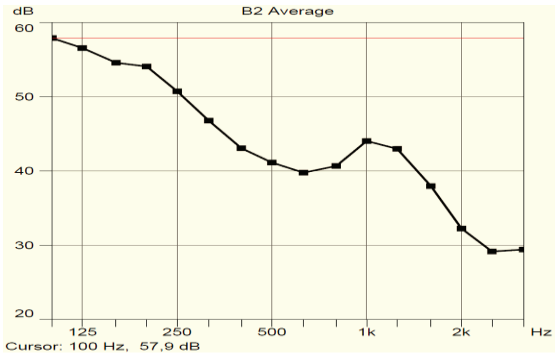

Figure 6: The background noise level values for the current condition.

3.2 Status Assessment After the First Acoustic Improvement

After the noise level of the current internal environment of the Year 3/7 classroom was measured, the reverberation time and reflectivity surfaces in the setting were decreased using materials with high absorption. Within the scope of the improvement work, a Bolero type acoustic rockwool suspended ceiling made by OWA Suspended Ceiling Company with an NRC value of 0.85 was applied to the ceiling area of approximately 50 m2.
The top of the tiled floor material was evened with surface coving mortar and then covered with a Supreme model PVC floor made by Tarkett PVC Floor Company. The noise of impacts like dropping and friction were expected to decrease with this application. Photos of the classroom showing the ceiling and floor materials, respectively, after the first improvement work are shown in Figure 7.

Figure 7: The ceiling and floor materials used in the first improvement.

3.2.1 Reverberation time (T) measurement after the first acoustic improvement

The measurement of reverberation time after the suspended ceiling and floor cover changed after the first acoustic improvement was made in the empty classroom. The height of the ceiling decreased to 267 cm from 287 cm with the suspended floor application, and accordingly, the new volume of the classroom decreased to approximately 130 m³. The measurement graph of reverberation time after the first improvement in the furnished classroom without students is shown in Figure 8; the average reverberation time increased to 0.89 sec.

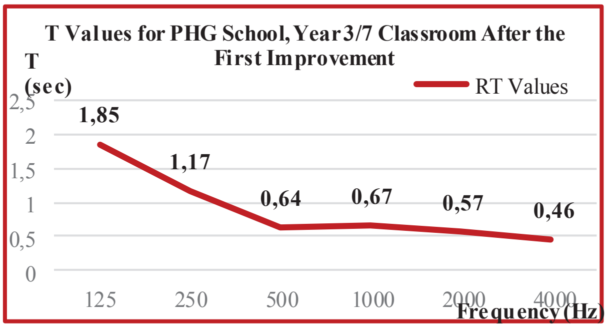

Figure 8: T values after the first acoustic improvement.

3.2.2 Background noise measurement after the first acoustic improvement

The background noise level of 48.7 dBA in the current condition was lowered to 44.0 dBA after the first acoustic improvement; see the dBA values of noise levels shown in Figure 9.
The background noise level measurements were taken with the windows closed. However, it is clear that the results are still high when assessed within the standards.

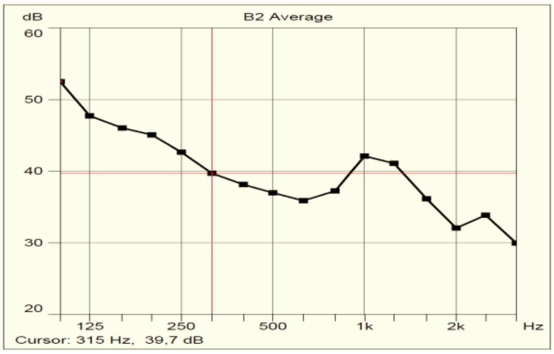

Figure 9: The background noise level values after the first acoustic improvement.

3.3 Status Assessment After the Second Acoustic Improvement

The joinery system was completely removed in the second improvement; a PVC joinery by Saray Aluminium Company was integrated to the wall as an equivalent without changing the appearance of the wall, and all the measurements and intelligibility tests were repeated.

Four acoustic panels with a cloth coated surface and glass-wool based interior sized 120 cm × 300 cm with a thickness of 4 cm were mounted to the two adjacent walls. This application allowed us to apply a material with a high absorption level in the setting and to use panels just like boards.

Figure 10: Photo of the classroom after the second acoustic improvement

3.3.1 Reverberation time (T) measurement after the second acoustic improvement

As the second improvement, the PVC joinery of the wall was changed to be equivalent with the current wall. The reverberation time was measured in the empty classroom after the four cloth coated panels (120 cm × 300 cm, 4 cm thick) had been mounted to the wall. The measurement of reverberation time following the first improvement was performed in a furnished classroom with a volume of approximately 130 m³ and height of 267 cm. The results are shown in Figure 11. The average reverberation time for the values obtained after the second acoustic improvement increased to 0.75 sec.

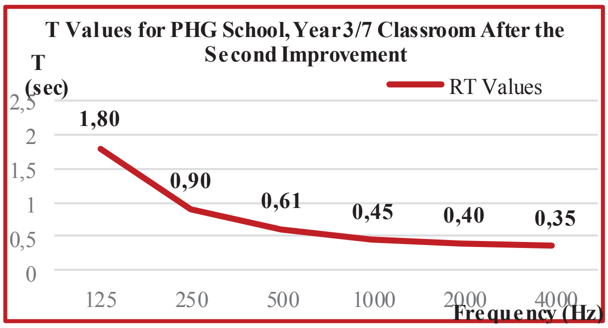

Figure 11: T values after the second acoustic improvement

3.3.2 Background noise measurement after the second acoustic improvement

All the measurements were repeated after the second improvement, and the background noise levels were rechecked after the application of the suspended ceiling and floor. The background noise level of 48.7 dBA identified in the current condition decreased to 32.0 dBA according to the dBA values of noise levels shown in Figure 12 after the wall system was changed through the second improvement. Measurements were taken with the windows closed.

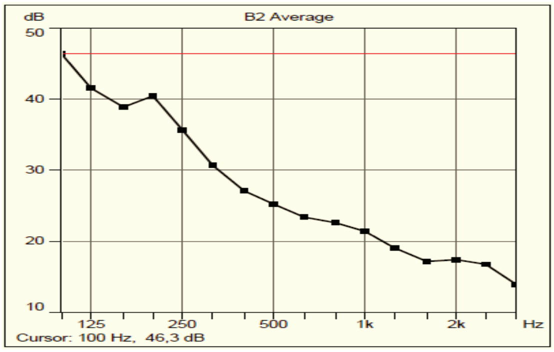

Figure 12: The background noise level values after the second acoustic improvement.

3.4 Intelligibility Test Findings

During the analysis of the current condition, the students were expected to write down the words on their papers that they understood from the 60 real words and 60 non-words, which were spoken just once.

The same test was used in the current condition and the two improvement conditions. The results are illustrated in Figure 13.

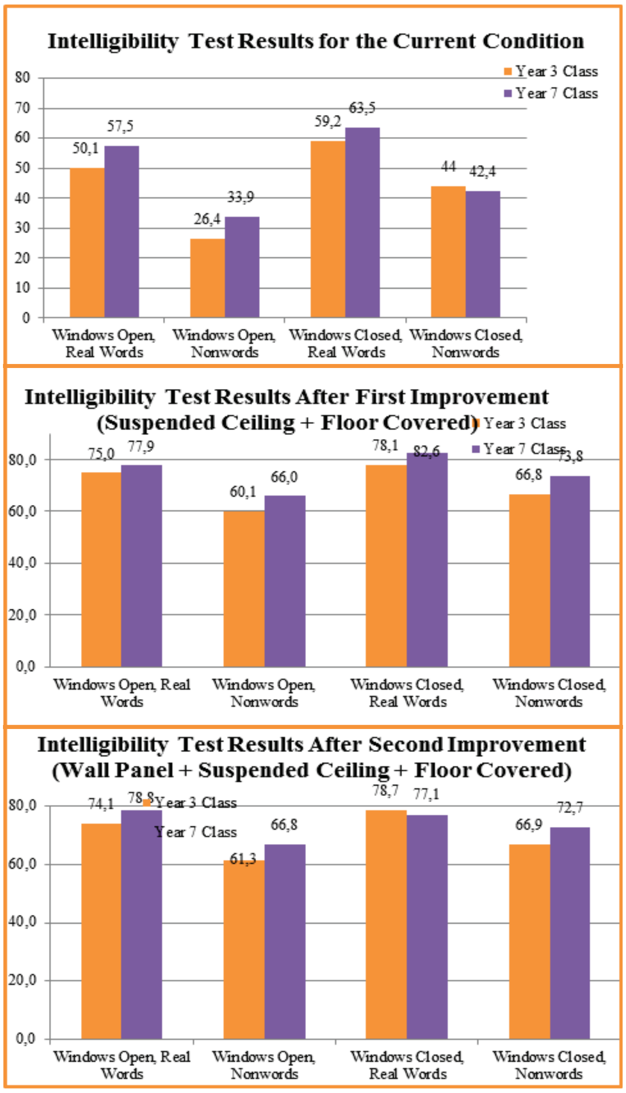

Figure 13: Comparison of the intelligibility test results (%).

4. Conclusions

Third-and seventh-year students who are educated in the same classroom were provided 60 real words and 60 non-words under the current classroom condition and after each improvement within the scope of the study performed at Penyelüks Hasan Gürel School in the Küçükçekmece district. It was observed that as the acoustic conditions of the classroom were improved, and the students' success in understanding the words increased with the improvements. The positive difference between the current condition and the last condition in particular (i.e., after the second improvement) shows that the acoustic conditions of classrooms are very important for learning.
When the measurements from the current condition and the first and second stage analyses were compared, it was revealed that the improvement of acoustic conditions increased the intelligibility of speech in the classroom and the results of measurement were within the limits of the existing standards.

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