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Noise Measurements and Sources of Noise in Primary Schools Located in Vulnerable Areas in Greece: A Cross-Sectional Study

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Abstract

The objective of the research is to record and evaluate the noise conditions prevailing in schools of socio-economically vulnerable areas in the prefecture of Attica in Greece. For this purpose, external and internal noise measurements were carried out in 12 elementary schools, attended by students with low socio-economic profile and a high level of food insecurity, in the prefecture of Attica in Greece. In particular, noise level was recorded in 91 classrooms (both occupied and unoccupied), 12 schoolyards and 9 locations outside school buildings. Additional noise-related school characteristics were recorded through a questionnaire completed by the schools' principals. Views on noise sources per classroom and the extent to which they affect learning processes were recorded in the same questionnaire. All measurements taken of both Unoccupied Ambient Noise Level (UANL) and schoolyard noise level were higher than the WHO recommended maximum levels. Both these measurements were significantly higher than the findings of similar surveys conducted in other studies. The recorded noise level outside the school premises was also quite high compared to the results of other relevant surveys, indicating that the schools which participated in the survey are particularly exposed to environmental noise. According to school principals, simultaneous teaching in other areas of the school is the main source of classroom noise, followed by the students themselves, people talking outside the building, and traffic noise. In conclusion, schools in the socio-economically vulnerable areas of the Attica prefecture in Greece are particularly exposed to noise coming from both the internal and external environments of schools. According to existing literature, this is very likely to negatively impact the effectiveness of the educational process, as well as the health of the teachers.

Keywords: Noise; Primary school; Education; Questionnaire; Greece

Introduction

Grade school is the cornerstone educational institution for children and adolescents. In addition, almost 75% of a typical school day is comprised of listening activities [1]. During the educational process, however, pupils and teachers are exposed to noise whose source may be from inside or from outside the classroom and/or the school. Furthermore, contemporary teaching methods that are founded on cooperative norms burden the educational process with additional noise [2].

It is well known that exposure to environmental and occupational noises is associated with impaired hearing, sleep disorders, cardiovascular disease, mental disorders, annoyance, interventions in communication, social relationship problems, and reduced work performance [3-5]. Additionally, there is a vast amount of literature linking increased noise levels with a series of effects on students during the educational process. These include, but are not limited to, decreased ability to recognize and comprehend verbal communication, inability to concentrate, decreased memory, and low school performance [6-8]. Long-term consequences include negative effects in pre-reading and reading abilities of children, which might be irreversible [8]. Children are more susceptible to the negative effects of elevated noise in school performance, which is attributed to factors related to the maturing of the hearing process, as well as to the fact that basic cognitive functions, like attention and memory, are less automated and more prone to disturbances [8,9]. Furthermore, teachers working in noisy classrooms are forced to constantly raise their voices in order to be heard and understood. This can be associated with vocal fatigue and other vocal dysfunctions [10].

Taking research findings into account, the World Health Organization (WHO) and other state institutions worldwide have adopted guidelines on setting noise limits of classrooms and other areas of the school in order to ensure the utmost efficiency of the educational process, as well as the vocal health of teachers [6].

In the present study, noise levels recorded in primary public schools located in areas of low socio-economic status (SES) within the prefecture of Attica, Greece.

In particular the aims of the study are:

Recording of the noise conditions prevailing in schools of socio-economically vulnerable areas in the prefecture of Attica in Greece.

Evaluation of the recorded noise measurements through comparison with the guidelines set by WHO. Identification of the main noise sources which affect school classrooms through a survey addressed to school principals.

Materials and Methods

Study design

Recording, measurement, assessment, and analysis of noise levels in classrooms took place in public elementary schools located in the prefecture of Attica. These schools were enrolled in the DIATROFI program during the 2016-2017 school year. DIATROFI supports pupils of public schools that reside in socio-economically vulnerable areas of Greece and helps contribute to the reduction of food insecurity and obesity levels among school children. In particular, the program provides food-aid through the distribution of a free, nutritious, and daily meal to all students in participating schools, while at the same time promoting healthy eating through educational material and activities geared toward both students and their families. The DIATROFI Program has been implemented by the Institute of Preventive Medicine Environmental and Occupational Health, Prolepsis, since 2012, and it is executed under the auspices of the Ministry of Education, Research and Religious Affairs. The selection of schools participating in the program is based on food insecurity scores at the school level and along other socio-economic criteria.

The current study was conducted in 12 schools participating in the program, which were selected in order to cover a wide range of different noise settings, which is represented by the number of enrolled students and the age of the buildings. In total, noise measurements were conducted in 91 classrooms of all grades, 12 school yards, and outdoors at 9 schools.

Noise measurements

Recording, measurement, assessment, and analysis of noise levels in classrooms took place in public elementary schools. Noise measurements were conducted by specialized personnel of the Hellenic Institute for Occupational Health and Safety (HIOHS) with the use of a Bruel and Kjaer 2231 Sound Level Meter. Measurements were taken in May 2017, recording noise levels of empty classrooms, occupied classrooms during teaching, schoolyards, and outside of the school premises. Measurements were conducted during school operation times and were completed within one working day for each school. Each measurement was taken over a period of five minutes. A five minute noise sample in school environments is considered to be satisfactory, even for occupied classrooms [11,12]. For each condition/location (unoccupied/occupied classroom, school yard, outside of school premises), the following measurements were recorded: the A-weighted equivalent continuous sound level (LAeq), the A-weighted noise level just exceeded for 10% of the measurement period (LA10), the A-weighted noise level just exceeded for 90% of the measurement period (LA90), and the A-weighted maximum and minimum sound levels (LAmax and LAmin respectively). An approximation of Signal to Noise Ratio (SNR) was calculated as Lesson Noise-Occupied Background Noise Level (OBNL) [13]. Depending on whether the measurement referred to an unoccupied or occupied classroom, we use the descriptions Unoccupied Ambient Noise Level (UANL LAeq including noise from other teaching areas of the school), Occupied Background Noise Level (OBNL LAeq90, occupied classroom), Lesson Noise, etc. All terms were derived from Shield et al. [14]. As, to our knowledge, there is no universally accepted and standardized method for recording noise level in schools [7,15], the procedure in the present study was selected in order to obtain the best possible capture of the noise conditions prevailing in Greek classrooms.

Unoccupied classrooms noise measurement

Measurements were taken in an empty classroom, while pupils were having class elsewhere, and during normal school operation (thus, other school facilities were in normal use, not during break time) as suggested by Shield and Dockrell [7]. Doors of the classrooms were kept closed when measurements were being taken. However, ventilation and cooling needs require, most of the time, the windows to be kept open. Therefore, it was chosen for the windows to be in their usual state according to the wishes of teachers and students. In the vast majority of recorded classrooms, the windows were kept open. The sound level meter was mounted on a special base (tripod 1.55 cm height) at the front of the room and at least a meter away from the walls and the door. In addition to sound levels, the volumes of the classrooms (in m^3) were also recorded.

Noise measurements during class

For each classroom, noise measurements were taken when the classroom was in use and at a separate time in the same classroom when empty. During the measurements of both the occupied and unoccupied classrooms, the doors were kept closed and the windows were left in their usual positions, as previously described. The sound meter was located at a point in the room that caused the least possible obstruction in the teaching process, at least a meter away from the nearest wall and away from the teacher's direct sound field.

Noise measurements in the schoolyard

In the schoolyard of the schools, measurements were taken during class time (not during break time). Regardless, there were always students present in the schoolyard, who did physical education in the presence of a trainer.

Outdoors noise measurements

Outdoor measurements took place adjacent to the school building side that was determined to have the highest burden of environmental noises. The estimation was an outcome of the researcher's observation.

Criteria for evaluation of recorded noise measurements

Measurements conducted are compared with the World Health Organization's (WHO) guidelines for maximum noise levels in schools [3]. These guidelines suggest a maximum of 35 dB for UANL (Laeq dB) in the classroom and a maximum of 55 dB for outdoor playgrounds. The UANL(Laeq dB) level of 35 dB (A) LAeq is established assuming a level of 55 dB (A) for a teacher's voice at a one meter distance combined with the need for a signal to noise ratio of at least 15 dB. The maximum noise level of 55 dB (A) in outdoor playgrounds was chosen to be the same as those for outdoor residential areas in the daytime, in order to prevent noise annoyance [6].

Taking into account the developmental differences that have been identified to the extent that noise affects learning, some researchers propose separate noise and SNR limits, both changing per age group of students [2,16,17]. In the context of the present study, the measured sound/noise was also compared with the acoustic recommendations for primary school classrooms proposed by Mealings (Table 1) [2].

Age Group	Rating	UANL(LAeq dB)	OBNL(LA90 dB)	SNR
6-7 years	Good	<28	< 45	+20 dB
	OK	28-35	45-50	+15 to +20 dB
	Bad	>35	>50	<+15
8-9 years	Good	<35	<47	>+18
	OK	35-40	47-53	+12 to +18
	Bad	>40	>53	<+12
10-11 years	Good	<39	<50	>+15
	OK	39-40	50-56	+9 to +15
	Bad	>40	>56	<+9
12+ years	Good	<40	<50	>+15
	OK	40-45	50-56	+9 to +15
	Bad	>45	>56	<+9
Overall	**Good**	**<30 dBA**	**<50 dBA**	**>+15 dB**
	OK	**30-40 dBA**	**50-55 dBA**	**+10 to +15 dB**
	Bad	**> 40 dBA**	**>55 dBA**	**<+10 dB**

Table 1: Overall acoustic evaluation of classrooms by age of students according to Mealings 2016.

School principal's questionnaire

Characteristics of the schools and classrooms that are possibly associated with noise levels were recorded through a questionnaire that was filled in by the schools' principals. Such characteristics included whether the school was close to an avenue/central road, whether the classroom had windows facing such a road, whether the classroom was prefabricated, etc.

In the same questionnaires, the principals' opinions concerning the degree at which several noise sources affect the educational process were recorded, separately for each classroom. Noise sources that were assessed included pupils themselves, car and train traffic, noises originating from people outside the school compound and noises originating from teaching in other classrooms. These sources were assessed with a 5-grade scale, where 1 indicated an effect on the educational process as "not at all" and 5 as "to a great degree".

Limitations of the Study

Despite the important role it plays in the acoustics of the classrooms, the reverberation time was not recorded in the context of the present study, while the Signal to Noise Ratio (SNR) index was estimated as already described (i.e. Lesson noise-OBNL) [13]. In addition, the fact that the activities of teachers and students were not recorded during the measurement of the lesson noise constitutes another limitation of the study.

Results

Noise measurements

Table 2 shows the basic characteristics of the schools included in the sample. Total number of students ranges from 90 to 306 and the average number of students per classroom from 11 to 21. Half (6) of the schools are located in a distance of less than 100 meters from a main road, while four are closer than 100 meters to a traffic light. Only two schools were located close to an airport.

School	Area	No. of students	Average No of students per classroom	Age of the building	Distance of main road less than 100 m (Yes-No)	Distance of traffic lights less than 100 m (Yes-No)	Close to Airport (Yes-No)	No of classrooms measured
1	Athens Center	123	21	121	Y	Y	N	6
2	Athens Center	92	15	86	N	N	N	6
3	Ano Liosia	190	19	33	Y	N	N	7

4	Athens Center	90	15	33	N	N	N	7
5	Aspropirgos (Industrial area)	193	19	14	N	N	Y	7
6	Athens Center	175	NA	15	Y	Y	N	9
7	Athens Center	164	21	88	Y	Y	N	7
8	Aspropirgos (Industrial area)	306	21	28	N	N	N	9
9	Aspropirgos	293	NA	NA	N	N	Y	10
10	Zefiri	226	19	28	Y	N	N	8
11	Athens Center	95	11	68	Y	Y	N	7
12	Asprorirgos (Industrial area)	201	17	28	N	N	N	8

Table 2: Characteristics of schools surveyed.

Average recorded noise measurements per school are presented in Table 3. Because measurements were taken in May and no schools (except for school 11) had air-conditioning in operation, windows were often left open during the recording of noise level. School 11, despite being close to a main road with a significant amount of external noise (71.7 LAeq dB), exhibited the lowest average UANL (52.6 LAeq dB). It should be noted that in Greece, and especially in the prefecture of Attica, classroom windows are open most of the time throughout the school year for ventilation purposes.

School	UANL(LAeq dB)	OBNL(LA90 dB)	Lesson Noise LAeq dB (occupied)	SNR (Estimated)	School Yard Noise (LAeq dB)	School Yard Backround Noise (LA90 dB)	External Noise Level LAeq dB
1	56.2 (5.4)	56.3 (3.4)	71.3 (3.4)	14.9 (4.2)	70.9	59	68.7
2	54.5 (2.4)	54.8 (7.9)	66.3 (8)	11.5 (2.3)	80.9	72	69.5
3	56.2 (6.3)	58.6 (5.7)	75 (4.7)	16.4 (3.4)	71.9	57	NA
4	59.4 (6)	55.2 (8.6)	70.5 (8.6)	15.1 (2.1)	77.4	62.5	65.6
5	56.6 (8.9)	53.9 (6.9)	69 (5.9)	15.1 (2.1)	74	60	63.9
6	58.1 (5.1)	54.3 (4.1)	69.3 (4.5)	15.1 (4.5)	62.8	53	70.3
7	58 (2.3)	55.8 (6.3)	69.2 (5.9)	13.4 (2.5)	78	70.5	72.2
8	59.4 (3.6)	60.6 (5)	75.5 (5.6)	15 (3.3)	83	70	NA
9	58.3 (5.4)	56.1 (6.6)	69.7 (7.3)	13.7 (2.1)	84.5	78	62.4
10	55.2 (4.2)	55.9 (6.8)	70.4 (9.4)	14.5 (3.8)	84.5	66	61.2
11	52.6 (2.6)	54.9 (8.5)	67.4 (11)	12.5 (5.2)	84.4	79	71.7
12	57.9 (6.3)	51.2 (3.6)	67.1 (5.8)	15.9 (3.8)	71	60	NA

Mean (all classrooms)	57 (5.2)	55.7 (6.2)	70.1 (7.1)	14.5 (3.5)	77.1 (6.6)	65.6 (8)	66.6 (3.9)

Table 3: Average Noise Level Measurements per school surveyed and standard deviation (sd).

All (100%) measurements of both UANL and school yards were higher than the WHO recommended maximum levels. School yard background noise was of acceptable levels in only one school. According to the overall criteria set by Mealings (2016) [2], all (100%) classrooms were classified as "Bad" concerning UANL and OBNL, while 45 classrooms (52.3%) were classified as "OK" and the remaining 41 (47.7%) classified as "Bad" for SNR. When the assessment is broken down by student age and the respective relevant classification, UANL is still "Bad" for all classrooms in all age groups (Table 4). However, there is a significant association between age group and both OBNL (p=0.001) and SNR (p=0.003). Specifically, classrooms of older pupils are more often classified as "Good" or "OK" for OBNL. For SNR, while no classrooms are classified as "Good", the proportion of "Bad" in classrooms of younger pupils is considerably higher than that of older pupils.

Age Group	Rating	UANL(LAeq dB)		OBNL(LAeq90 dB)		SNR	
		Number of Classrooms	%	Number of Classrooms	%	Number of Classrooms	%
6-7 years	Good	0		0		0	
	OK	0		3	12.5	6	25
	Bad	24	100	21	87.5	18	75
8-9 years	Good	0		2	6.7	0	
	OK	0		11	36.7	21	70
	Bad	30	100	17	56.7	9	30
10-11 years	Good	0		6	18.8	0	
	OK	0		15	46.9	19	59.4
	Bad	32	100	11	34.4	13	40.6
	p-value	1		0.001		0.003	

Table 4: Acoustic evaluation of surveyed classrooms (excluding computer labs) according to criteria set by Mealings 2016.

Table 5 shows the average noise measurements in classrooms with characteristics that could potentially affect the level of noise recorded. It is evident that both the presence of a window facing a main road and a prefabricated (prefab) classroom are associated with higher average noise measurements. OBNL and Lesson Noise were both significantly higher in classrooms with a window to a main road (p=0.04 and p=0.03 respectively). Finally, a significant correlation has been identified between UANL and Lesson noise (ρ=0.28, p=0.01) (Figure 1).

The main findings of the study are presented in comparison with the findings of studies carried out in other countries in Table 6.

	UANL(LAeq dB)	OBNL(LAeq90 dB)	Lesson Noise LAeq dB (occupied)	SNR (Estimated)
Classrooms with window towards avenue or main road	58.2	58.1	73.1	15
(st. dev.)	(4.4)	(5.5)	(5.3)	(4.1)
Classrooms with no window towards avenue or main road	56.7	55	69.4	14.3
(st. dev.)	(5.4)	(6.3)	(7.3)	(3.4)
Prefab classrooms	58.2	56.7	72	15.4
(st. dev.)	(5.3)	(6.6)	(7.3)	(3.4)
Non Prefab classrooms	56.7	55.4	69.6	14.2
(st. dev.)	(5.2)	(6.2)	(7)	(3.5)

All Classrooms	57	55.7	70.1	14.5
(st. dev.)	(5.2)	(6.2)	(7.1)	(3.5)

Table 5: Average Accoustic Measurments by type of classrooms.

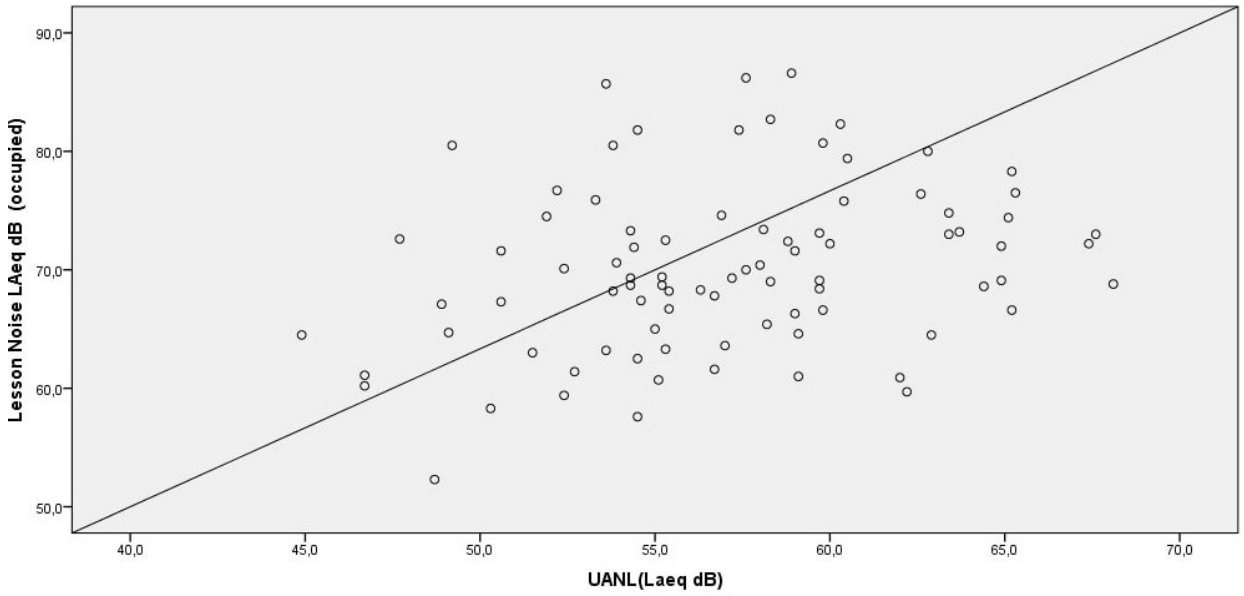

Figure 1: Scatter diagram showing the relationship between lesson noise and unoccupied ambient noise level.

	Measurements in Athens	Measurements in London [7]	Measurements in Edinburgh [19]	Measurements in Brazil [18]
External noise measurements	61.2 – 72.2 LAeq dB 66.6 (Mean)	31 - 78 LAeq dB 57.4 (Mean)		
Classroom noise measurement Unoccupied Background Noise Level (UBNL)	44.9 – 68.1 LAeq dB 57 (Mean)	47 LAeq dB (Mean)	Classrooms with no acoustical treatment (mean): 55.5 LAeq dB Classrooms with acoustical treatment (mean): 46.5 LAeq dB	51.5-70.5 LAeq dB

Table 6: Comparison of noise measurements with findings from similar studies in other countries.

School principal questionnaires

The main source of noise in the classrooms that participated in the study was the teaching taking place elsewhere in the school, with principals stating that this type of noise affects, in a "great"/"very great" degree, 40.7% of the classrooms. The next reported sources of noise were from the students within the classrooms themselves (16.3%), followed by people talking outside the building (10%) and traffic noises (9.3%) (Figure 2).

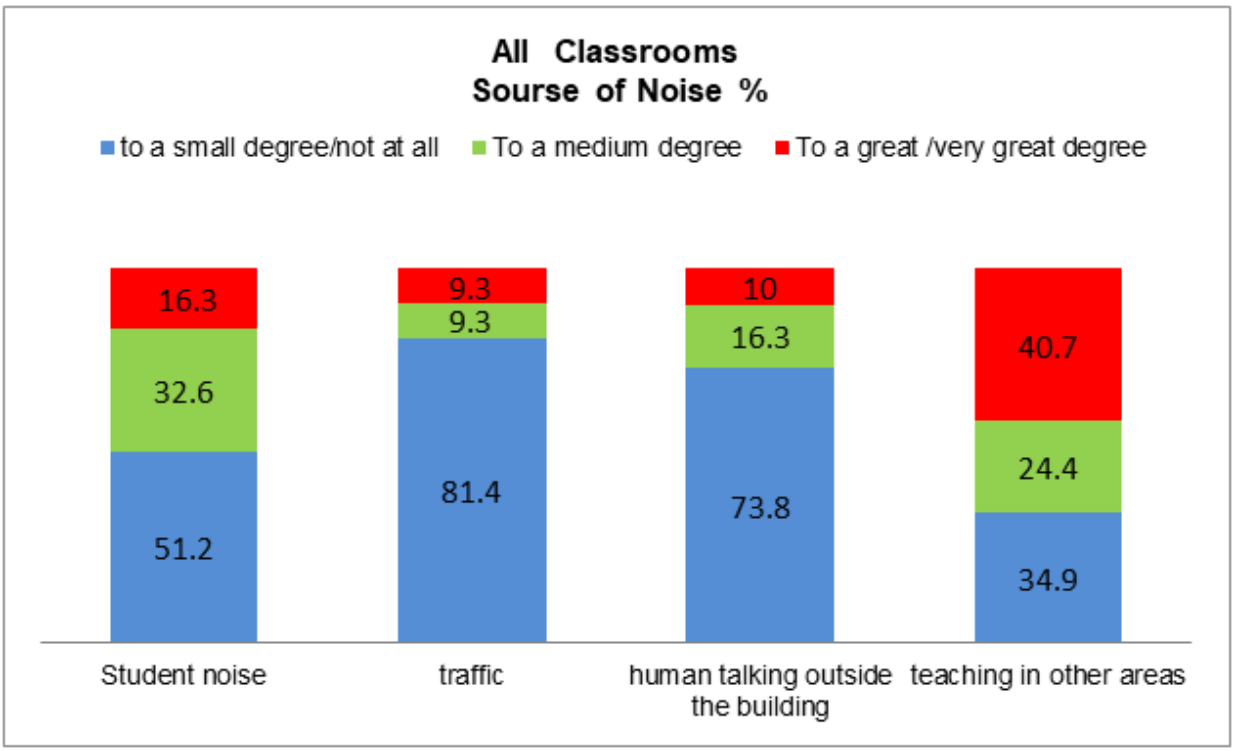

Figure 2: Extent to which various noise sources affect educational process in classrooms according to principal opinions. Percentages of classrooms.

Of particular interest is the fact that both prefab classrooms and classrooms with a window facing an avenue or a main road were more overburdened by the different forms of noise than average (Figure 3 and Figure 4). Specifically, 27.8% of both these categories of classrooms were influenced to a "large" or "very large" extent by car traffic; whereas, as mentioned above, the proportion for all classrooms participating in the survey was only 9.3%. Noise coming from people speaking outside the school building does not seem to significantly affect classrooms with a window at a main road, while teaching in other areas of the school was judged to affect teaching to a "great"/ "very great" degree in 100% of prefab halls and in 44.4% of classrooms with a window on an avenue or main road. In both prefab and window-classrooms, students themselves seem to be a particularly important source of noise, since they seem to affect teaching, to a "large" or "very large" extent, in about half of these classrooms.

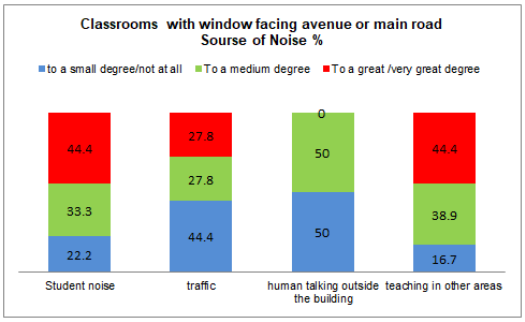

Figure 3: Extent to which various noise sources affect educational process in classrooms with window towards avenue or main road, according to principal opinions. Percentages of classrooms.

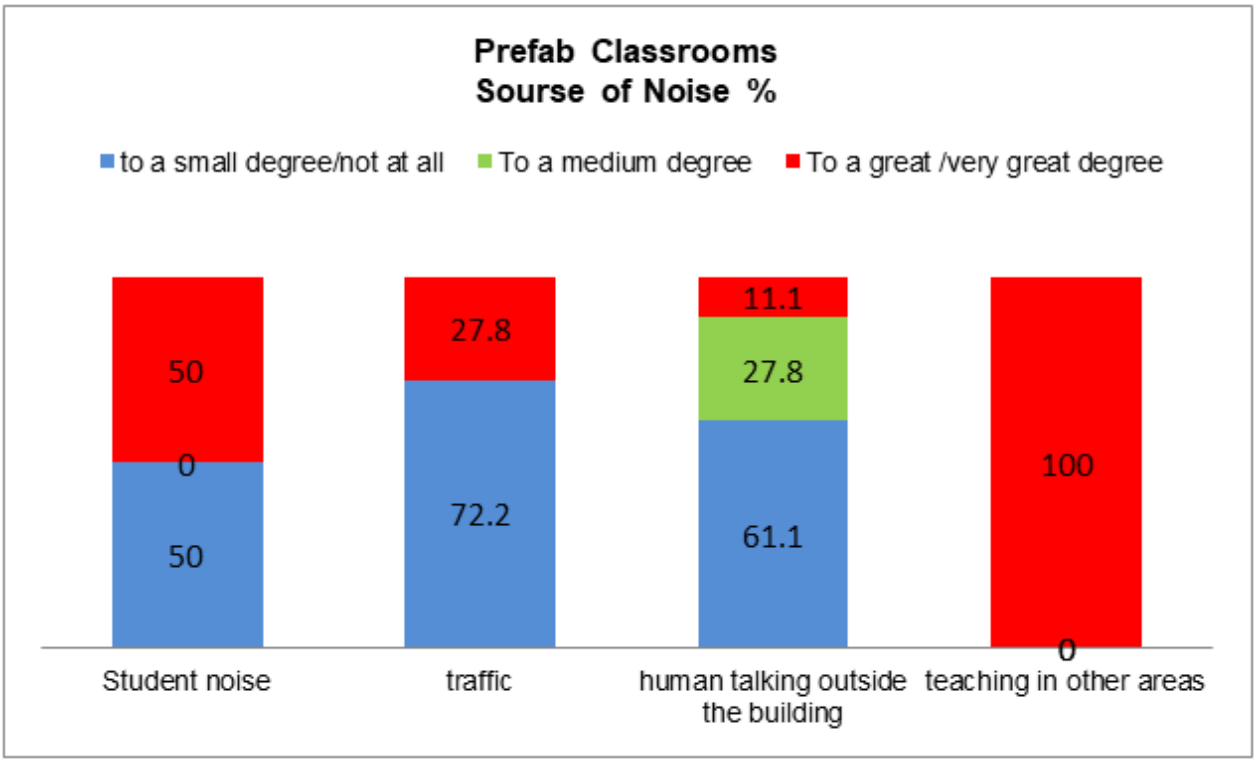

Figure 4: Extent to which various noise sources affect educational process in prefab classrooms, according to principal opinions. Percentages of classrooms.

Discussion

As demonstrated by the results, the schools involved in the study are particularly burdened by noise in both classrooms and courtyards. Additionally, particularly high noise levels were captured outside the school buildings.

In particular, the recorded noise level outside the school premises is quite high compared to what was recorded in London for primary and secondary school premises [7,14]. Specifically, the average external noise level in the 9 surveyed schools in Attica was 66.6 LAeq dB, while in London the corresponding measurement for primary schools was 57.4 LAeq and for secondary schools 52.07 LAeq dB. According to the above finding, the schools that participated in the survey are particularly exposed to environmental noise. Noise measurements of both UANL and school yards in all classrooms exceed WHO guidelines for maximum levels. In particular, all (100%) measurements of both were higher than the WHO recommended maximum levels. According to the overall criteria set by Mealings [2], in an attempt to bring together acoustic standards and recommendations as well as noise levels measured in classrooms across the world, all (100%) classrooms were classified as "Bad" concerning UANL and OBNL. 45 classrooms (52.3%) were classified as "OK" for SNR, with the remaining 41 (47.7%) being termed "Bad" for the same measure. In addition, by differentiating the acoustic environment that pupils of different ages require because of developmental differences, the proportion of acceptable (but not ideal) classrooms, in terms of both OBNL and SNR, increases with the age of students. Although, UANL measurements are still "Bad" for all classrooms. In the majority of similar surveys conducted in different parts of the world, however, the noise levels recorded in the classrooms most of the time exceed the proposed limits. In our case, both the average level of Lesson Noise (70.1 LAeqdB) and the OBNL (55.7) are quite close to what is recorded in similar research done in different parts of the world. For example, in a study conducted in London [7], the average OBNL recorded was 54.1 LAeq90 dB, while lesson noise was 72.1 LAeq dB. What appears to be particularly elevated for enclosed classrooms, in the case of our schools, is UANL (57 LAeq dB), with a corresponding measurement in the Shield and Dockrell survey of 47 LAeq dB. Similar UANL levels were recorded in Brazil [18] with a UANL level of 51.5-70.5 LAeq dB. Also, in Edinburgh in 1998, a mean UANL of 55.5 LAeq dB was measured in classrooms that had not undergone acoustic improvements, while, in classrooms that had, the UANL was 46.5 [19] (For a review, see Mealings [2]).

Meanwhile, the significant correlation that has been identified between UANL and Lesson noise (ρ=0.28, p=0.01) is a possible manifestation of the Lombard effect, as noisier empty classrooms seem to be noisier during lesson time as well (Figure 1). In particular, the "Lombard effect" describes the speaker's tension to increase their voice level when background noise exists. More specifically as it pertains to classrooms, as the background noise level increases, the voice intensities of both the teacher and the students participating in lesson activities tend to increase too. This is a result of an effort to improve the audibility and communication potential. Meanwhile, students who, for any reason, talk to each other about issues irrelevant to the lesson, have to speak louder in order to be heard by their seatmate, charging the auditory environment of the classroom even more. [20].

The regression line fitted (y=48.81+0.37x) suggests that the expected value of lesson noise in a classroom with UANL of 35 dB (WHO limit) is 61.8 LAeq dB, significantly lower than the recorded average lesson noise level 70.1 LAeq dB. It should be noted that all the above acoustic guidelines refer to children without any specific needs. In cases of children with hearing impairments or language delays, proposed limits are even more challenging.

Concerning classroom characteristics, both the presence of a window facing a main road or an avenue and of a prefab classroom produce higher average noise measurements. Both OBNL and Lesson noise were significantly higher in classrooms with a window to a main road or an avenue (p=0.04 and p=0.03 respectively).

According to school principals, teaching in other areas of the school is the main source of noise in the classrooms that participated in the study, followed by students within the classrooms themselves, people talking outside the building, and traffic. Traffic noise and noise from teaching in other areas affect, to a higher degree, both classrooms with windows facing an avenue or a main road and prefab classrooms. Teaching that takes place in other areas affects, to a “large” or “very large” degree, all prefab classrooms. Of particular interest is the fact that, in both prefab classrooms and classrooms with window facing avenue or main road, students themselves become a particularly important source of noise, as they seem to affect teaching to a “large” or “very large” extent, in about half of these classrooms. This finding, combined with the fact that these classrooms are more exposed and burdened by other environmental noises, is another possible confirmation of the Lombard effect.

In conclusion, the noise levels recorded in both schoolyards of schools and classrooms are considerably higher than the proposed limits of WHO and of other national guidelines across the world. The particularly high level of UABL noise recorded in all classrooms can be attributed to poor sound insulation-especially in the prefab classrooms-in conjunction with the fact that windows in the majority of the classrooms were open for cooling and ventilation purposes during measurement. It is a worthwhile finding that the lowest average UANL level (52.6 LAeq dB) was recorded in a school whose classrooms had air conditioning, and, therefore, the windows were closed during measurement. According to school principals, the most important source of noise for the classrooms is teaching in other areas of the school. Traffic becomes an important source of noise in both prefab classrooms and classrooms with windows on avenue or main road. At the same time, higher average noise measurements were recorded in the classrooms with these specific characteristics, as “students themselves” appeared to become a serious source of noise. This finding could be attributed to Lombard effect as, in addition, a significant correlation between lesson noise and UANL has been identified at total classrooms level.

Nowadays, it is extremely difficult for school buildings in Greece to be properly maintained or to adapt to changes occurring in their external environment through intervention, due to economic crisis and budget constraints. Most of the buildings remain as they were several decades ago, while the environment in which they are located changes drastically.

However, the serious impact of noise on the health of both students and teachers as well as on the education and cognitive development of students, must be taken seriously into consideration in order to determine the necessary interventions to implement for improving the acoustic environment of schools. Particularly for the socio-economically vulnerable areas of the country, the unfavorable listening conditions captured in primary schools should be considered in the context of a holistic approach that takes into account the accumulation of other risk factors in noise-exposed children.

Here are some suggestions for interventions that seem appropriate to schools that participated in the study:

Replacement of all prefabricated classrooms/schools, which has remained in function for many years due to budget restrictions, although they only should have been used as a temporary solution.

Examine the possibility of changing the ventilation/air conditioning mode (not through open windows) and installing low noise ventilation/air conditioning devices. In this case, the change of windows to double glazing should also be considered for better sound insulation.

For schools located on or near main roads, that cannot be moved in the context of current financial circumstances, consideration should be given to the possibility of restructuring car circulation during school operation. Installations of noise barriers and/or tree planting are some alternative solutions. Reorganization of the school premises, so that the classrooms are located in the "quiet parts" of the premises, could be another possible solution.

Regarding the interventions that should be made inside the classrooms, it is known that the basic principles of sound architecture necessitate that every space has its own requirements and therefore needs special design. Some materials, for example, are ideal for absorbing low frequency noise, such as traffic noise. Other materials are better at absorbing noise of higher frequency, such as children's voices. In general, it is common practice for sound absorbers to be placed on the ceiling of classrooms, while sound diffusers are placed on the walls. Enriching the furniture of the classroom is another common intervention in schools that improves acoustics.

Roughly speaking, the average cost for the acoustical treatment of classrooms including internal interventions, installation of ventilation/air conditioning systems, and change of windows to double glazing is 10% of the cost of building a new school—or approximately 100 € per square meter.

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