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The Acoustics of Learning Environments and Implications in Communication and Learning

Dalianis Sotirios[a]. and Campourakis George[b].

[a,b] Department of Electrical and Computer Engineering, Division of Communications, Electronics and Information Systems, National Technical University of Athens, Heroon Polytechniou 9, 157 80, Athens, Greece

Abstract The acoustic environment of education buildings is related to learning difficulties and this applies to all levels of education, especially to nursery and early learning stages. Although the legislation for noise levels in adult working environments is extensively reviewed there are few references for school environments in relation to noise levels, construction and room acoustics. In this paper we study learning difficulties aspects in relation to noise levels and reverberation time of different learning environments including nursery, early learning stages, primary and secondary education and higher education lecture rooms. The particularity of each environment is analyzed and the effects of room acoustics and noise level are concerned. These elements have implications to students learning process as well to teachers working environment quality. Construction aspects of such environments are discussed.

1. INTRODUCTION

From the experience that was acquired during investigative visits to schools we can say that both teachers and students are suffering from noise in teaching rooms of primary and secondary education as well as in amphitheatres of higher education. In private education the situation remains the same or sometimes worse than public schools. In classes of lower age there are also children with a difficulty in concentrating. This leads to noise pollution in the teaching room as these children tend to create noise for no reason or to gain attention from their classmates which makes teaching practically impossible. Any effort for the people trying to learn under these circumstances most of the time has an affect on their health [1].

This issue cannot be totally covered with the method of investigations. On the other hand the noise pollution issue continues to exist in all levels of education, an issue which has not been properly taken care of by the authorities. There have been various cases of stress to teachers due to noise in teaching rooms [2, 3] and it is clear that there are links with teacher's pronunciation problems or vocal disorders.

According to discoveries of the National Voice and Speech Centre in Iowa, USA teachers with vocal disorders are around 3.1 million. In the same country the main volume of patients with vocal problems is mainly teachers and lecturers. The combination of pronunciation problems and classroom noise pollution places in a disadvantaged state, the children of immigrants and decreases their learning levels. Although noise pollution in education is an international phenomenon the public has not been informed about this [4, 5, 6]. In general we could say that more attention has been given to the societal as well as psycho-societal behavioural types in education rather than the physical factors that have been mostly ignored [7].

2. NURSERY AND DAY-CARE CENTERS

The sense of hearing and the ability of speech have been developing very early in infants. This demands an amount of care. Allen, Whitman, Kistler and Dolan (1988) [8] managed to prove that the ability of infants to define frequencies is developed near the end of their 3rd year of life. Therefore a noisy environment at this age plays an important role in their effectiveness of learning numbers, how to read and mainly speech. Maxwell and Evans (1988) [9] who researched the acoustic environment of a day care center and ended up with the conclusion that bad acoustics created problems for the children as far as their learning skills were concerned. Improving the acoustics led to more effective learning.

References to the effects of noise has on disabled children had been presented by the German Health Ministry [10, 11, 12]. From relevant research in kindergartens it was clear that noise bothered the children. In some kindergartens the noise levels were in the region of L (A)eq 80-85 dB(A) during working hours of the school.

These levels in a working environment for adults are considered by regulation, dangerous and recommend the use of earplugs [13]. Similar observations showed that the age limit used for the calculation of the overall acoustic anxiety of an individual should be minimized including younger primary school ages. Research done in Finland [14] that included the examination of 200 teachers of 25 kindergarten and nursery schools, showed that the vocal disorders that the teachers presented were due to volume of their voice they needed to have to communicate. This of course was a result of bad acoustics. From investigative visitations to such schools in Greece we found that the acoustics of teaching rooms was of lowest priority of needs and in many cases is completely ignored while any relevant legislation referring to building conditions is overlooked by designers and constructors. In the next paragraph primary and secondary education teaching rooms are examined as far as the acoustical treatment of learning environments is concerned.

3. PRIMARY AND SECONDARY EDUCATION

From international bibliography [5] it is shown that in many cases noise has a bad affect on learning environments and the development of learning skills but mostly has a negative influence on speech functions. In the USA (1998) with the support of the Acoustical Society of America a collective of prototypes and instructions for further processing were written to improve a large number of schools with insufficient acoustics. In some publications most teaching rooms had insufficient acoustics [15]. In the relative paper of Picard it is noted that the rates of noise in the rooms exceed the optimum rate by 4 to 38 dB(A).

In Germany the founder of child acousticology (paedaudiology), Loewe, expressed his grievance (1990) for the long reverberation times in the teaching rooms and their general acoustic behavior [16].

Through these complaints arise other questions especially since in Germany there are many prototypes concerning the protection from noise pollution and for the acoustics in rooms that hold many people [17, 18, 19, 20]. The possible explanation could be that some of these took a long time to be approved (for example the DIN 4109 was approved 30 years after its first publishing) and changed along the way. Obviously the teaching rooms were built in between approval and initial publishing time and therefore the rooms do not coincide with the prototypes. That is why in working environments the measurements are 55 dB(A) while in elementary schools in Berlin the measurements were Leq 76 dB(A) (in an 8 hour period). The well known established company Sennheiser did noise measurements in German classrooms and found that in empty rooms the noise level was around 42.5 to 46.6 dB while when the children were inside the noise level was 75 dB (with children 5-6 years of age), 65.3 dB (with children 7-10 years of age) and 64.5 dB (with children 11-16 years of age).

In France, in a similar paper there are measurements of 70 dB(A) while in schools of professional training measurements of 90-100 dB(A) were not rare [6].

In Holland, Houtgast (1981) developed the RASTI method for an objective measurement of intelligibility as a solution to noise pollution in teaching rooms. This method is now being used universally.

During an investigation in New Zealand [21], in 106 rooms and 149 teachers the findings persuaded the researchers that “the acoustical situation in most of the rooms that were examined were disgraceful”. This was logical since the average signal to noise ratio was 6 dB(A).

In Spain Delgado, Perera and Santiago measured the intelligibility in each seat of the rooms that were in their research [22], others [23] had a problem with stress from noise pollution in the region of Valencia. The main finding of these researches was that the teachers believed that the problem was only in their classrooms and the neighbouring ones.

In England [24] measurements as high as 100 dB(A) were found while in 60 elementary schools that were acoustically treated it was found that learning skills had improved.

In Russia [25] levels were over 75 dB(A) Leq in big schools with 1800 and 2200 students. Obviously the students should have been less.

In Czechoslovakia [26] the results that came up were that students that lived in quiet areas could withstand noise more than students from noisy ones. This means that students with higher and longer levels of exposure to noise have problems with their learning skills.

In Poland there is an important activity concerning the research of acoustics in schools. The findings show levels of 86 dB(A) in elementary schools and 79 dB and higher levels of education. The researchers support that the maximum amount of children in a room is 25 so that they can establish better acoustics. When the amount of students increases to over 30

than it is most likely that the overall noise will also increase by 3 dB(A). The average rates in Poland were 80 dB(A), 85 dB(A) in public schools and 72 dB(A) in private ones.
In China [27] a research involving the learning capabilities of students of elementary schools showed that students in quieter classrooms had better grades than those in noise polluted rooms. The rates found were between 42 dB(A) and 55 dB(A), which is very low compared to other countries. These result led to many rooms being improved [28].
In Greece no particular researches have been made that allow any conclusions being made as far as the acoustic treatment of classrooms are concerned. However, investigative measurements done by the authors make officials believe that there are serious noise pollution problems in classrooms all over Greece. That is due to the fact that most of the buildings were not built according to a prototype which would guide builders to create acoustically treated rooms. Finally the findings from measurements in the National Technical University of Athens were accepted as a reason to improve certain amphitheatres.

4. OBSTRUCTION OF SPEECH AND HEARING FUNCTIONS

The basic path of communication in schools is via speech. This means that the size of intelligibility is very important. Already since 1978 the obstruction of distinguishing sounds due to noise has been referred to [25]. The findings of the initial research by Finitzo and Tillman have been confirmed many times and it is obvious now that in a noisy environment students have a problem distinguishing clearly what their teachers are saying. This applies for both the students with good and problematic hearing. The ability of the children to distinguish words was also researched by Geffner, Lucker and Koch (1996) [29]. In this research the distinguishing ability of children at the age of 7 and 12, with and without hearing problems were compared. Children with hearing problems were by rule hyperkinetic and were therefore examined not at school but at a clinic. These two groups of children were exposed to similar noises (speech with meaning, speech without meaning, noise from meeting room). It was observed that in a quiet environment there were not any differences between the two groups. On the other hand under circumstances that involved the addition of noise to that environment, children with hearing problems had difficulties in distinguishing words. This way, older findings by Nober were confirmed [30]. The paper by Spreng had already been written earlier (1994) [31] concerning the obstruction of verbal communication between individuals with normal hearing due to noise pollution. In this paper a number of parameters are examined. These are: the dependency of intelligibility from the level of the interfering noise, the time and frequency characteristics of noise, the reverberation time of the room in which the communication is being achieved, the distance between speaker and listener, the volume of the speech, the additional optical information and the changes in pronunciation and speed of expression of the speech.
A lot of emphasis was especially shown involving the stress of the speaker and listener due to noise which affects mostly very young children as well as older children with hearing problems. This shows how important intelligibility is to communication through speech, a procedure which usually is followed in live transmission of knowledge like in any form or level of education. Intelligibility as a measurement depends on the acoustic parameters of space in which it is measured and the noise that exists in this space. It also depends on the quality of pronunciation of the speaker and the condition of the listeners hearing. In teaching rooms the measurements that need to be changed are mainly the reverberation time and the limitation of exterior sounds.

Not only does noise have a negative affect on learning abilities but also have implications to their psychology and performance as it accelerates tiredness and is a reason for loss of concentrations due to disturbances in the normal sleep cycle [32]. In addition noise can be the reason for bad societal behavior of children. Evans paper (1998) [33] refers to children who are stressed due to noise find it harder to continue with their student duties. These findings are valid both for short term noise exposure (half an hour) and long term (chronic exposure). The fact that the public does not understand the consequences of noise in learning environments of younger populations, proven through a relative research, where the same children were asked to determine the factors that define their personal learning process. Since they were informed about several factors that distracted them from learning and decreased their concentration, children of the lower levels of education supported that noise was more important to them while other children of higher levels of education did not. Very young children connected all reference to noise to the free time they had to play rather than learning time. The overall population supported that as the age increases less believe that noise is a problem compared to other physical factors. The reduced reaction of the population concerning noise pollution is probably the reason that the acoustics of learning environments have not been taken seriously by governments.

5. PRACTICAL MEASURES FOR TEACHING ROOMS WITH GOOD INTELEGIBILITY

In 1993 the Worldwide Health Organisation (WHO) adopted a series of measures for the design of new teaching rooms or the improvement of existing ones based on relative investigations [34, 35, 36]. These measures are:

- Consider a short time reverberation which is < 0.6 s in the frequency region of 125 to 4000 Hz. The octave of 125 Hz is very important for children with diminished hearing due to the fact that they are more sensitive to lower frequencies. This imposes the use of the C curve during the measurement of noise (in combination with the A curve). Children are more sensitive to longer reverberation times than adults are [37]. There are reports that support that even individuals with a loss of hearing at around 10 -15 dB(A) have a rather larger problem with intelligibility than people with normal hearing [4]. Even individuals with normal hearing can go through certain periods where a percentage of their hearing has been lost for example if they have a cold. Therefore it is considered that the reverberation time is better not to exceed 0.4 s. For larger meeting or teaching rooms, a reverberation time smaller than 1s is recommended.

- Background noise should not exceed 30 dB(A) and 50 dB(C). This rate is anticipated on the prototype DIN 4109 but is not always applied. For economic reasons we could accept rates between 35 dB(A) and 40 dB(A). This measure must go through a specialized sound-absorption investigation where all the elements that may have an affect on the inside and outside of the room are examined.

- An installation of a public address system for the lecturer or speaker especially for teaching rooms that will have children with hearing problems.

The volume of an average lecturer is 60 dB(A). To improve the intelligibility when the background noise is 65 dB(A), the lecturer will have to increase his volume to 70-75 dB(A). That is when problems will occur [38] due to the fact that the speaker will have to speak slower and with more and longer pauses between sentences. Also it has been observed that there is less communicative information since the lecturer tends to simplify the way he expresses what he wants to say. The result is an observation of fatigue in both the speaker and the listeners. The listeners are also more likely to turn around and start talking with each other therefore increasing the overall noise and the consequences that have an impact on learning are also increased.

Investigations related to the Lombard syndrome [39] show that children who are learning to speak have a tendency to raise their vocal volume to the same level as the people around them. Adults on the other hand can change the volume of their voice for a better result in their communication with others. What studiers of spaces and rooms have discovered from this is that the basic level of noise should not exceed 35 dB(A) in spaces where intelligibility is important

The problem that a speaker may encounter in a teaching room or space is that although he can hear himself he does not know how the audience is hearing him. The speaker places himself according to his acoustic perception and usually does not take into consideration the intelligibility of the room when the reverberation in the room is very fast. The speaker's only option is to increase the volume of his voice which is not a solution. To cope with this problem Andersson [34] suggests a procedure, which can be applied if the speaker listens to someone speaking in the back of the room. This will help him understand the intelligibility of the room as he is placing himself in the room as a listener. This can also be applied with children. Any type of acoustical improvement to a room will have attributes, while the learning capabilities of the students show better results

The two tables below (Table 1 and Table 2) show the average absorption rate that is needed to reach a reverberation time of 0.4 s for a series of measurements which are found in various rooms with hibht of 3.8 and 2.8 meters. The calculation was done by using Eyring's formula.

Table 1.

The average absorption rate for rooms with a height of 3.8 m

		Length (m)												
Width (m)		**4**	**4,5**	**5**	**5,5**	**6**	**6,5**	**7**	**7,5**	**8**	**8,5**	**9**	**9,5**	**10**
	4	0,23	0,24	0,25	0,25	0,26	0,26	0,27	0,27	0,27	0,28	0,28	0,28	0,28
	4,5	0,24	0,25	0,26	0,26	0,27	0,27	0,28	0,28	0,28	0,29	0,29	0,29	0,29
	5	0,25	0,26	0,26	0,27	0,28	0,28	0,29	0,29	0,29	0,30	0,30	0,30	0,30
	5,5	0,25	0,26	0,27	0,28	0,28	0,29	0,29	0,30	0,30	0,30	0,31	0,31	0,31
	6	0,26	0,27	0,28	0,28	0,29	0,29	0,30	0,30	0,31	0,31	0,31	0,32	0,32
	6,5	0,26	0,27	0,28	0,29	0,29	0,30	0,31	0,31	0,31	0,32	0,32	0,32	0,33
	7	0,27	0,28	0,29	0,29	0,30	0,31	0,31	0,31	0,32	0,32	0,33	0,33	0,33
	7,5	0,27	0,28	0,29	0,30	0,30	0,31	0,31	0,32	0,32	0,33	0,33	0,33	0,34
	8	0,27	0,28	0,29	0,30	0,31	0,31	0,32	0,32	0,33	0,33	0,34	0,34	0,34
	8,5	0,28	0,29	0,30	0,30	0,31	0,32	0,32	0,33	0,33	0,34	0,34	0,34	0,35
	9	0,28	0,29	0,30	0,31	0,31	0,32	0,33	0,33	0,34	0,34	0,34	0,35	0,35
	9,5	0,28	0,29	0,30	0,31	0,32	0,32	0,33	0,33	0,34	0,34	0,35	0,35	0,35
	10	0,28	0,29	0,30	0,31	0,32	0,33	0,33	0,34	0,34	0,35	0,35	0,35	0,36

Table 2.

The average absorption rate for rooms with a height of 2.8 m

		Length (m)												
Width (m)		**4**	**4,5**	**5**	**5,5**	**6**	**6,5**	**7**	**7,5**	**8**	**8,5**	**9**	**9,5**	**10**
	4	0,21	0,22	0,22	0,23	0,23	0,23	0,24	0,24	0,24	0,25	0,25	0,25	0,25
	4,5	0,22	0,22	0,23	0,23	0,24	0,24	0,25	0,25	0,25	0,25	0,26	0,26	0,26
	5	0,22	0,23	0,24	0,24	0,25	0,25	0,25	0,26	0,26	0,26	0,26	0,26	0,27
	5,5	0,23	0,23	0,24	0,25	0,25	0,25	0,26	0,26	0,26	0,27	0,27	0,27	0,27
	6	0,23	0,24	0,25	0,25	0,26	0,26	0,26	0,27	0,27	0,27	0,27	0,28	0,28
	6,5	0,23	0,24	0,25	0,25	0,26	0,26	0,27	0,27	0,27	0,28	0,28	0,28	0,28
	7	0,24	0,25	0,25	0,26	0,26	0,27	0,27	0,28	0,28	0,28	0,28	0,29	0,29
	7,5	0,24	0,25	0,26	0,26	0,27	0,27	0,28	0,28	0,28	0,28	0,29	0,29	0,29
	8	0,24	0,25	0,26	0,26	0,27	0,27	0,28	0,28	0,29	0,29	0,29	0,29	0,30
	8,5	0,25	0,25	0,26	0,27	0,27	0,28	0,28	0,28	0,29	0,29	0,29	0,30	0,30
	9	0,25	0,26	0,26	0,27	0,27	0,28	0,28	0,29	0,29	0,29	0,30	0,30	0,30
	9,5	0,25	0,26	0,26	0,27	0,28	0,28	0,29	0,29	0,29	0,30	0,30	0,30	0,30
	10	0,25	0,26	0,27	0,27	0,28	0,28	0,29	0,29	0,30	0,30	0,30	0,30	0,31

6. CONCLUSIONS

It seems that the principle of the quiet school [40], (the basis of Montessorian educational perception) has returned as a need in contemporary society. This principle is in the «network of quiet schools» [41] that was formulated in 1998 as a part of an effort to limit noise in Europe. To fulfill the mission of the school as an acquisition of knowledge and psycho-societal development, an important requirement was to insure environmental peace. The impact of traffic noise pollution in rooms is an important factor. However it is not only the exterior noise that is very important but also the interior noise that is created inside the room and particularly by people.

Obviously a totally quiet school is not the desired situation but the increase of student freedom leads to the creation of noise. The followers of the encouragement of creativity at school insist that the creation of noisy activities must be included, where the acoustics of teaching rooms will help decrease rather than increase noise levels.

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