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A SURVEY OF ACOUSTICAL STANDARDS IN UK CLASSROOMS AND THEIR EFFECT ON PUPILS AND TEACHERS

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1. THE CHANGING ROLE OF SCHOOL BUILDINGS

In 1870, the British Education Act made primary education available for all children. The importance of providing children with an environment in which they could learn was recognised and a large number of school buildings were constructed to cope with the amount of school age children needing to be educated. However, the pressures upon resources, both human and material, required to cope with this influx of pupils was such that buildings were constructed purely and simply to contain the children and their teachers. School buildings were often modelled in a pattern influenced by the churches they were usually linked to. Solid, practical buildings where a large number of children could be taught at one time were built, usually with high ceilings to accommodate tiered seating. High ceilings, like those in hospitals, were also thought to have the advantage of helping prevent the spread of such diseases as tuberculosis by allowing infected air to rise up away from the rooms' occupants. Lessons were taught in such a way that that the master spoke and the children listened and learned. The classroom environment and personal comfort were rarely considerations.

Time and society progressed and the authoritarian pattern of education mostly moved to a more flexible approach, not only to teaching, but to teaching spaces. The continually rising school population, particularly in urban areas, demanded rapidly constructed buildings, often lightweight with pre-fabricated components. The needs of the newer pedagogy meant the emphasis was upon large multi-use areas, and internal dividing walls decreased to create more flexible, lively teaching spaces. These advancements created opportunities for different teaching methods, but they also brought difficulties of noise and discipline.

More recent changes such as the 1981 Education Act[1] meant that an increased number of pupils with Special Educational Needs have been integrated into mainstream classes. The majority of schools have recognised the benefits of such 'inclusion' and have made provision for the additional needs of these pupils. In some cases this may be the creation of a ramp at the front door for wheelchair access, or by sending teachers on courses to inform them of useful teaching strategies for pupils with particular special needs. The aim of these measures is to eliminate barriers within the school, whether physical or less tangible obstacles, and to teach children in the least restrictive environment.

However, in most schools barriers still exist and affect a large number of pupils. These barriers are poor acoustics and those effected are not just hearing impaired pupils, but all occupants of the room - pupils and teachers. Previously it was thought that high levels of background noise and long reverberation times only caused problems for those children with hearing aids. More recently it has been discovered that, whilst hearing impaired children are those most effected by poor acoustics, the majority of other pupils in the classroom will perform and behave better if the room's environment is conducive to listening and learning[2]. The intelligibility of speech is very susceptible to the effects of poor acoustics and this is often the main reason why teachers report their classrooms as being difficult places in which to teach. However, noise and reverberation have many other detrimental psychological and physiological effects upon the room occupants.

2. CAUSES OF POOR CLASSROOM ACOUSTICS

The aim of the present research project was to establish whether the acoustics in UK classrooms were as bad as they were subjectively reported to be, and if the results supported other findings from around the world. The main causes of poor acoustics in classrooms had previously been identified as overly long reverberation times and excessive levels of background noise. It is unclear which of these is the most detrimental factor with conflicting findings. It has been reported that reverberation time is "the single most important factor determining the acoustical qualities in a room", because it is the "intensity of the direct versus the reflected sound and their times of arrival, which are the most important determiners of speech intelligibility in a room"[3]. Reverberation time was also concluded to have the most effect upon children in classrooms, in a more recent study[4], and this too, was due to the corrupting effect of reverberation upon speech. However, a study by Berg et al[5] concludes that it is background noise which is the biggest problem in classrooms.

Whilst there is much debate as to which of noise or reverberation has the most effect upon room occupants, the majority of classrooms suffer a combination of both problems. Classrooms tend to have a high proportion of reflective surfaces and often have large volumes. In many of the classrooms studied, high ceilings, often with angles or beams incorporated into the design, were a common feature. These properties can cause not only long reverberation times, but peculiarities in the sound field such as 'dead' or 'live' spots. School are also notoriously noisy buildings with noise being generated from within the school as well as often entering from outside. A classroom may be subjected to a wide variety of noise sources, including classroom 'chatter', impact noise from rooms above or sports halls, and often intruding traffic and aircraft noise. Either of the factors alone, reverberation time or background noise, can seriously diminish speech intelligibility. However, when combined the problem is aggravated and the acoustical environment may be the catalyst of a variety of problems for both teachers and pupils. This survey comprised of objective measurements of reverberation times and background noise levels, plus levels of speech intelligibility in classrooms using the Speech Transmission Index (STI). In addition, subjective measurements of speech intelligibility of children using a novel test were conducted.

3. ACOUSTICAL STANDARDS FOR SCHOOLS

The acoustical conditions in classrooms and schools should ideally be taken into account during the early planning stage of a new building. Remedial acoustical treatment is often costly and this work may well be passed over when money is needed in apparently more essential areas. However, architects designing new schools, particularly those which may house pupils with hearing impairments, often find that there is a distinct lack of specific acoustical guidelines to turn to for advice. The Department for Education and Employment Building Bulletin 87 [6] has only been available in the last twelve months, and although the area of standards to aim for is fairly wide, there are few guidelines as to how to achieve these reverberation times and noise levels. The guidelines give information for normally hearing pupils (an RT of 0.5-0.8 seconds and a background noise levels of 30-40dBA), plus a small section of separate advice for hearing impaired pupils (an RT of 0.3-0.6 seconds and a noise level of 20-30dBA). However, most mainstream classes will at some point contain children with hearing impairments, whether permanent or temporarily caused by colds or ear infections, who will benefit greatly from the lower recommended RTs and background noise levels. Indeed, during the course of this investigation, results indicated that in rooms with an RT of 0.5-0.8, the level suggested for normally hearing pupils, a large percentage of speech is still lost, particularly under higher levels of occupied background noise. When the RT is in the region suggested for hearing impaired pupils, an acceptable amount of speech can be understood by all listeners.

The levels recommended by the UK Department for Education are in line with those guidelines from governments and researchers in other countries. The Finnish Ministry of the Environment recommend an RT of 0.6-0.9 seconds and a background noise level of 35dBA in unoccupied classrooms[7]. The American Speech-Language and Hearing Association Position Statement[8] is a little more extensive in its recommendations, citing an RT of 0.4 seconds, a background noise level of 30dBA, plus a Noise Criteria of 20 and a Signal to Noise ratio of +15dB at the listener's ear. However, there are still few recommendations as to how to achieve these figures. There are fewer guidelines for hearing impaired pupils, but they are also similar to those in the UK. Crandell and Smaldino[9] and Barron [10] advise that 0.4 seconds is a suitable RT for hearing impaired pupils with a background noise level of 30-35dBA. The lowest RT for hearing impaired pupils is suggested by Berg et al [5] and is 0.3 seconds. Any lower than this and the room risks becoming too dead and there will not be enough reflected sound to reinforce direct sound.

Despite these guidelines, plus many others, there is still a dearth of advice on how to achieve suitable figures. It is often 'pot luck' for the architect striving to achieve quoted figures, using various calculations and specified product information.

4. UK SCHOOL SURVEY

Although a substantial amount of research has been carried out into the acoustics of classrooms, very little testing has been conducted in realistic conditions. Often measurement are carried out in empty rooms or in simulated classroom environments. In some cases, subjects in acoustical investigations have been adults, because of the increased ease of administering tests when compared to using young children as subjects. Measurements in this project were carried out under realistic conditions, using existing classrooms for occupied and unoccupied tests. Whilst testing occupied classrooms in busy schools introduced factors that were not so easy to control as in a laboratory environment, the resulting findings are far more relevant to classrooms that are used for teaching and learning under these conditions daily.

The schools tested were of a wide variety. The locations ranged from rural schools to schools in very built-up areas. The age of the buildings included very old to schools built in the last few years. The schools were mainly primary schools, but some were special schools whose pupils ranged from nursery to secondary age. Most schools were single storey, but several were two or even three storey. Sixty teaching spaces were tested including libraries, and halls, as well as classrooms. During tests in occupied classrooms, all pupils and staff wore ear defenders when any loud noises were introduced into the room. Apart from in the cases of special needs schools, the subjects involved in this research were primary school children aged five to eleven. The was a fairly equal distribution of sexes and ages. Room occupants also included the typical teaching and auxiliary staff, usually no more than two The rooms tested were separated into three distinct categories: open-plan, cellular and acoustically treated. Classrooms in the 'acoustically treated' category all had some form of specific acoustical treatment incorporated into the design, or added at a later date. This treatment usually consisted of carpets and acoustical ceilings.

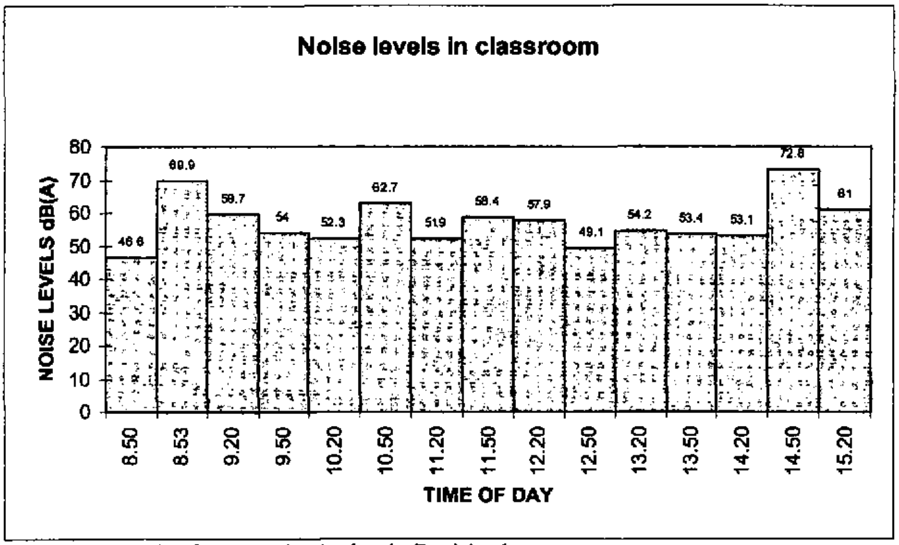

Figure 1. Example of measured noise levels (L_{Aeq}) in classrooms

Objective measurements consisted of the following:

<u>i. Background noise levels</u>. Continuous L_{Aeq} measurements were conducted at 15 minute intervals throughout the school day. The sound level meter was placed at head height in a random listening location in the classroom, to represent the typical noise levels experienced at a child's seated position. All noise produced during the school day was included in the measurements, including the teachers' and pupils' voices. Figure 1. shows the typical noise levels experienced in a classroom throughout a school day. The classroom shown is a cellular classroom and it is typical of rooms of this type with peaks and troughs in noise level. Open-plan classrooms tended to have a more consistent level of noise throughout the day caused by the busy activities around the measured room. Instantaneous background noise level measurements were taken when the classrooms were both empty and occupied. When the room was occupied three different conditions were measured; pupils silent, pupils talking and teaching talking. Each class teacher verified that the noise levels produced were typical for group working conditions where children were permitted to talk in reasonable voices. The

computer analysed the information with an A weighting, which has been shown to be representative of the human ear's listening capabilities. However, this A weighting does not take into account either a child's listening spectrum, which is different to that of an adult, nor that of a child with hearing aids or hearing impairment. results of these measurements are shown in Table 1.

	CELLULAR	OPEN-PLAN	TREATED
PUPILS SILENT	55.5 (min 31.4/ max 67.8)	56.6 (min 49.1/ max 70.3)	46.5 (min33.9/ max 55)
PUPILS WORKING	77.3 (min 51.9/ max 101.1)	72.1 (min 59.8/ max 84.3)	70.1 (min58.9/ max 79)
TEACHER TALKING	69.6 (min 41.8/ max 83.6)	63.6 (min 49.3/ max 74.1)	70.0 (min 59.8/ max 84.9)

Table 1. Measured background noise levels

The background noise levels within the classrooms were found to vary depending on a number of factors such as; The general design and layout of the school, the number and age of room occupants, the location of the school and its classrooms with respect to external noise, various construction methods, varying sound insulation qualities of walls, partitions and floors, noise sources within the room.

ii) Reverberation Time measurements. Reverberation is the persistence of sound in an enclosed space or room after the source of sound has ceased. It is quantified by the time taken for the sound pressure level to decay by 60dB after the sound source has stopped. As the reverberation time increases, the intelligibility of speech in a classroom usually decreases. Reverberation times in this study were measured at 1/3 octave bands between 63 and 4000Hz. The frequencies at either end of this spectrum tend to be outside of the normal speech frequencies, but it was intended to discover if there were any abnormal RTs in these frequencies that may be detrimental to both children and hearing aid users, whose hearing can cover a much more diverse range of frequencies than most normally hearing adults. Reverberation times were tested at six different random locations around each room, and an average time for each frequency was obtained. All frequencies were noted, but 500Hz was selected as the frequency chosen to represent each room's RT as this tends to be the mid-frequency of speech and the one quoted in most acoustical guidelines. Table 2 shows the range of reverberation times measured in this survey.

	CELLULAR	OPEN-PLAN	TREATED
EMPTY	0.7 seconds (min 0.35/max 1.23)	0.6 seconds (min 0.46/max 0.77)	0.4 seconds (min 0.28/max 0.41)
OCCUPIED	0.6 seconds (min 0.36/max 1)	0.4 seconds (min 0.43/0.43max)	0.4 seconds (min 0.28/max 0.45)

Table 2. Measured Reverberation Times at 500Hz

The reverberation times in the classrooms studied varied greatly. As would be expected, the RT was dependant on the volume of the room and the layout and design. Carpets and curtaining were of varying amounts and classroom furniture was of various design. All of these factors can have an effect on the RT of a room, as can the number and size of the room's occupants.

iii) Speech Transmission Index. The STI has been used by various researchers as a guide to speech intelligibility in classrooms[11]. It measures the reduction of a signal which undergoes fluctuations form source to receiver. It takes into account such detrimental factors as reverberation and background noise. The measurement is carried out in seven octave bands (125Hz-8KHz) and the modulated transfer function (MTF) in each band is converted into a single figure between 0 and 1, where 1 indicates that 100% of the syllables in speech will be understood and 0 indicates that no speech would be understood. A score of 0.6 and below is not adequate for rooms used for speech because as much as 40% of speech may still be lost or misunderstood. So, for the purposes of this research, it was considered that only rooms with an STI score of 0.6 or above would be adequate for speech.

STI measurements also enable the Percentage Articulation Loss of Consonants (%Alcons) to be calculated. This measurement is an indication of the quality of speech arriving at a particular point in a room. It is an objective measure of the percent of consonants that will be lost or misunderstood and is an excellent indication of speech intelligibility. The recommended %Alcons for excellent speech in a room is no more than 5%[12]. STI and %ALcon measurements were taken at child ear height at every seating location around the room, both when the classroom was empty and occupied. Each individual location STI and %ALcon score was recorded, plus averages were calculated for each room and these are presented in Table 3.

ROOM AVERAGES	CELLULAR	OPEN-PLAN	TREATED
STI	0.5 (min 0.41/max 0.68)	0.5 (min 0.34/max 0.58)	0.7 (min 0.64/max 0.74)
%ALcons	13.7 (min 4.5/max 36.9)	16.5 (min 9/max 30.5)	4.6 (min 3.2/max 6.1)

Table 3. Average STI and %Alcons scores for occupied classrooms.

As this is ongoing research, only the occupied STI and %ALcon scores have been calculated and are ready for presentation. However, as each STI test was conducted it was observed that the scores for occupied rooms were generally worse than for empty rooms. This is in contrast to a study by Diaz[11] which found that STI scores improved when rooms were occupied due to lower reverberation times. As mentioned earlier, it shall be considered that only classrooms with an average STI score of 0.6 or above and a %Alcons score of less than 5% will be classed as acceptable for children's listening environments. On this scale most of the classrooms tested do not provide an appropriate acoustic measurement, and it can be seen that only acoustically treated classrooms meet this criteria.

5. IMPLICATIONS OF FINDINGS

From the work conducted so far in this study it can be concluded that the majority of classrooms in the UK have poor acoustics. Reverberation times in most classrooms were long and this indicates that much speech in the rooms will be distorted and not always easy to understand. This has implications for all children, but in particular those with hearing loss or with English as a second language. If the RT in a room is long it means that any noise introduced into the room remains in the room for a longer period of time than if the RT were lower. This, combined with the high levels of background noise measured mean that the signal, whether the teacher's voice or other source, will rarely rise high enough over the competing noise to be clearly and comfortably understood. There have already been cases of teachers taking their LEA to court claiming for 'industrial injury' to their voices due to noisy working conditions. Considering the Noise at Work Act 1989 (1st Action Level, 8 hours Leq) regulations cite a maximum level of 85dBA in the workplace, it seems incredible that some teachers and pupils in this study work in noise over 100dB.

Poor acoustics do not only effect speech intelligibility in classrooms. It has been shown that children in noisier schools have higher blood pressure levels and faster heart beats than children in quieter schools[13]. There is little evidence to suggest this causes any harm to children in the short term, but it may well cause damage over a longer period of time. Noise may also affect the performance of pupils and teachers. If noise cannot be suppressed to allow full attention to be paid to the important sounds, children will find attention hard to maintain and memory and learning skills may well be hindered. There is also a proven link between noisy classrooms and pupil misbehaviour[14].

Although it is true that poor acoustics are not the only difficulty faced in school classrooms today, if the listening environment is excellent and noise levels are kept as low as possible it may go a long way to helping alleviate other problems. It is every child's right to an education and every adult's right to work in a comfortable workplace. If we are to expect these people to achieve optimum results, they must surely be provided with an optimum environment

6. REFERENCES

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