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EXTREME ACOUSTICS IN EXTREME LEARNING CONDITIONS: AN OPEN PLAN HOSPITAL SCHOOL

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ABSTRACT
This paper describes the acoustic survey carried out in a hospital school as part of the London South Bank University open plan classroom acoustics research project. The overall project aims to investigate compliance of open plan learning spaces with current acoustic standards, legislation and guidance by addressing classroom organisation and management in addition to the acoustic design of the classroom. Acoustic survey work includes collection of noise data and room acoustic parameters (reverberation time, speech transmission index etc).

The hospital school provides classroom-based education for children who are mostly in-patients. A large proportion of children have special educational needs, including children with English as an additional language.

The school has an open plan layout and is situated within a large glass fronted atrium. The design results in very poor conditions for speaking and listening in any classroom situation and the specialist pupil profile of the school exacerbates the situation. The specialist pupil profile of the school exacerbates the situation. This case study illustrates implications of extreme acoustic conditions in a school where extreme and difficult learning conditions are already part of daily life for teachers and children. The need for a performance standard for schools of this nature is addressed.

UK STANDARDS AND GUIDANCE

Building Bulletin 93: Acoustic design of schools
Design advice on school acoustics has long been available in the form of Department for Education and Skills Building Bulletins, but since 2003 schools in England and Wales have been included within the Building Regulations and as such are subject to the acoustic performance standards set out in Building Bulletin 93 (BB93)[1]. This document aims to facilitate good speech intelligibility and prevent interference from noise in other areas of the school. These include criteria for ambient noise level, reverberation time and sound insulation, appropriate to enclosed classrooms.

Speech intelligibility in open plan classrooms cannot be assured from the usual criteria, due to the complex layout of the room and the extent of multiple activities. Therefore in addition, BB93[1] requires the speech transmission index (STI) in the classroom to be assessed between teacher and student, and student to student, based on a specific open plan layout and activity plan. BB93 Acoustic criteria are summarised in Table 1. It should be noted that at the time the hospital used in the case study was built, schools were not subject to the Building Regulations and therefore the BB93 criteria were not adopted as design targets.

Table 1: BB93 acoustic criteria for classrooms

Type of space	Ambient noise level* $L_{Aeq, 30min}$ (dB)	Mid frequency reverberation time** T_{mf} (seconds)	STI in open plan teaching and study spaces***
Nursery school playrooms	≤ 35	≤ 0.6	-
Primary school classroom or classbase	≤ 35	≤ 0.6	-
Secondary school classroom or classbase	≤ 35	≤ 0.8	-
Open plan teaching area	≤ 40	≤ 0.8	> 0.6 ('Good')
Classrooms designed specifically for use by hearing impaired students	≤ 30	≤ 0.4	-

* This criterion relates to unoccupied classrooms during normal teaching hours. Noise sources include external sources and building services noise but excludes noise from teaching activities and equipment within the school.
** This criterion relates to unoccupied and unfurnished rooms. T_{mf} is the average of the reverberation times in the 500 - 2 kHz octave bands.
***Raised voice (66.5 dBA at 1m) assumed for teacher

Building Bulletin 96: Meeting the educational needs of children and young people in hospital
BB96[2] provides guidance on education accommodation in hospital settings including basic design guidance for acoustics. The specific organisation of hospital schools is considered as follows[2]:

> *'Acoustic parameters used for mainstream schools may not necessarily be applicable to hospital facilities. In particular, group sizes are normally smaller and a teacher is rarely positioned at the front of the room, addressing the group. The room acoustics should be designed to suit the needs to individuals and small groups working alongside each other'.*

BB96 also notes that design teams should take account of pupils with hearing difficulties. This includes not only children with permanent hearing impairments but also those with mild hearing loss or temporary hearing impairments. Pupils with 'hearing difficulties' could also be extended to other groups who are more at risk to the effects of poor classroom acoustics including inexperienced or immature listeners (young children), children with English as an additional language, and children with other special educational needs.

THE LEARNING ENVIRONMENT

Physical environment

A view of the learning environment is presented in figure 1. The school is part of a children's hospital which opened in London in October 2005. The four-storey glass 'conservatory', or atrium, forms the 'social heart' of the building and is used by the public to gain access to the wards. The atrium houses the gallery and performance space, a café and the hospital school. It is open to the ground floor entrance/reception via lightwells and lift shafts.

The school itself contains three open plan classbases (nursery, primary, secondary), an office area, and an enclosed kitchen and storeroom pod. The school is partitioned off from the rest of the atrium by 1.8 m high screens (covered with acoustically absorbent material). Internal spaces are defined by 2.2 m high storage units plus the walls of the pod. Other temporary furniture (cupboards/filing cabinets) has also been used to define space.

The classbase and administration areas have no ceilings and are open to the atrium, allowing atrium noise to transmit very easily to the teaching areas. The dominant source of noise in the school is reverberant speech from the café and gallery area adjacent to the classrooms, members of the public accessing the wards from the lifts and bridges, and general circulation on the ground floor and lower levels. Reflections from the hard surfaces in the atrium reinforce these sources of sound resulting in a high reverberant noise level in the classrooms. Furthermore, intrusive speech from adjacent classrooms creates additional conflicting noise sources. This combination of high noise levels and excessive reverberation presents a particularly challenging acoustic environment for speaking and listening.

Teaching environment

A small number of children attend the school. Children are taught either in small groups (observed teacher-to-pupil ratio 1:3 or less) or individually. Communication distances between the teacher and pupil are usually short (between 1 and 3 metres). Teaching activities in primary and secondary classrooms are coordinated and the classes will often join together for group activities in the afternoon. The pupil profile includes groups considered as vulnerable listeners (see above).

Figure 1: View of hospital school

MEASUREMENT PROCEDURE

The majority of measurements were carried out in the primary and secondary classbases. Ambient ($L_{Aeq,\ 5min}$) and intrusive ($L_{Aeq,\ 2min}$) noise levels were measured in the centre of unoccupied classrooms using a Larson and Davis 824 hand held sound level meter. Activities taking place in the classrooms and the atrium were recorded during measurements. The noise level due to study activities within the main classbase was not considered as its contribution was negligible compared to intrusive noise levels (assuming the children in the main classbase would be quiet and listening to the teacher).

For the primary classroom noise measurements, the dominant source of intrusive noise came from an event in the atrium with around 30 adults/children involved in discussion. The adjacent secondary classroom had around 10 children and teachers taking part in a drama session which also involved discussion.

Intrusive noise level measurements in the secondary classroom were carried out on a much quieter day without a specific event taking place in the atrium. In the adjacent primary classroom, approximately 5 children/adults were involved in a teaching activity. The nursery area was occupied by 4 children/adults.

The STI assessment was carried out for teacher-to-student communication only, for three positions in the classroom (within 1.5 – 4 m of the source) in accordance with BS 60268-16[3] and BB93[1]. WinMLS (a PC based acoustic measurement system with a professional soundcard) was used to generate a maximum length sequence (MLS) test signal, played though a head-sized loudspeaker positioned in the teacher's normal speaking position in the classroom. A correction was applied to the measurements to account for the effective signal-to-noise ratio at each listening position using the measured intrusive noise levels. A more detailed description of the measurement procedure is given in reference [5].

Reverberation time was measured in unoccupied classrooms at three receiver positions with two source positions in accordance with ISO 3382[4] using an omni-directional loudspeaker. The impulse response was measured using a log-sine sweep excitation signal on the WinMLS analyser. Measurements were limited to a single classroom to avoid disturbance caused to patients in the adjacent wards. Octave band measurements were used to calculate the mid-frequency decay time, T_{mf} at each receiver position using both T_{20} and T_{30} parameters. The early decay time (EDT) was also measured.

RESULTS AND DISCUSSION

Noise levels

Ambient noise levels ranged from 56 to 59 dB $L_{Aeq,5min}$ with general atrium noise present. Noise levels were highest in the nursery as this was more exposed to the atrium space. The noise level increased from 56 to 61 dB when a specific event occurred in the atrium (piano recital). The sample measurements are clearly far in excess of the BB93 requirement for both open plan teaching areas (40 dB) and classbases (35 dB).

Intrusive noise levels were dominated by the ambient noise level arising from noise sources outside the school (eg atrium noise) The average, standard deviation and range of the measured intrusive noise levels (adjacent classbases occupied) are presented in Table 2. Noise levels in the secondary classroom were significantly quieter since no specific event was taking place in the atrium.

Table 2: Intrusive noise levels

Classroom	Number of samples (n)	Intrusive noise level, $L_{Aeq,2min}$ (dB)		
		Mean	σ	Range
Primary	15	59	0.8	58-60
Secondary	21	54	1.6	52-58

Reverberation time

The average mid frequency reverberation time, T_{mf}, given by the T_{30} parameter and measured over the six positions in the secondary classroom was 3.75 seconds. The reverberation time given by the T_{20} parameter was significantly lower (T_{mf} = 2.88 seconds), suggesting the presence of a double decay due to the classroom space being coupled to the large atrium space. The average measured mid-frequency early decay time EDT_{mf} was 0.4 seconds which is much shorter and further demonstrates the double decay effect (shown in figure 2). EDT gives a better indication of the subjective impression of reverberance in a room. It also correlates better with speech transmission index.

BB93 criteria relate to the reverberation time rather than EDT, and conditions are far in excess of the maximum standard of 0.8 seconds T_{mf} for secondary classbases/open plan teaching areas. Reverberation times would be even higher if measurements were carried out without furniture in place (as required by BB93).

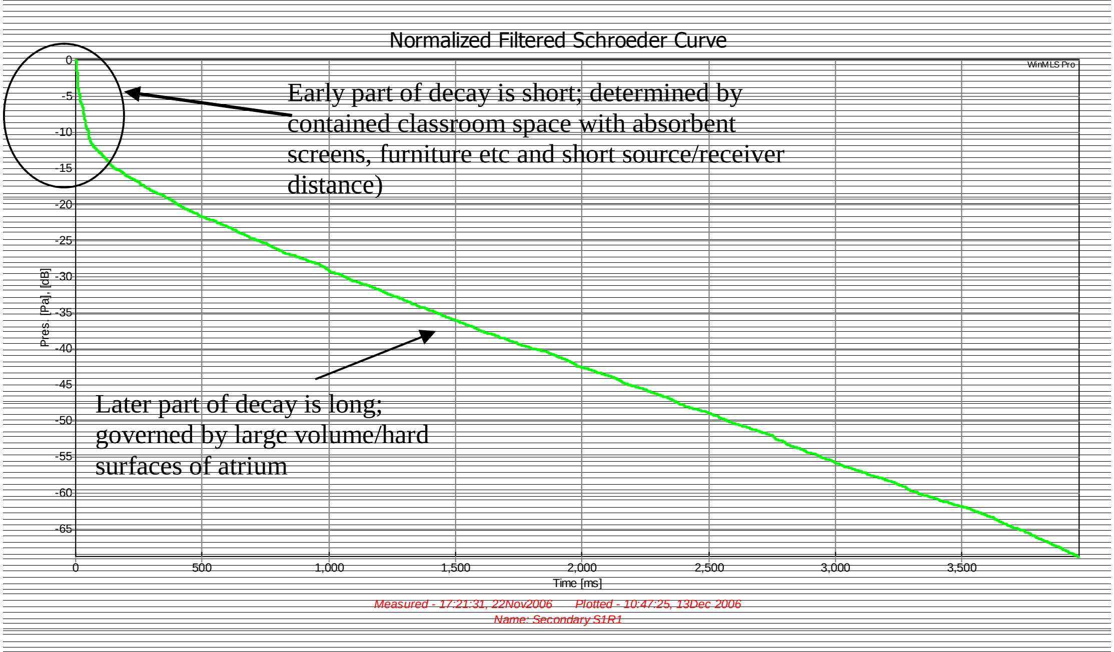

Figure 2: Schroeder integrated decay curve (average of all S/R positions at 1 kHz)

The speech-to-noise ratio, rather than reverberation, appears to be the dominant factor governing STI in this situation (see following section).

Speech Transmission Index (STI)

The STI calculated for each noise sample for ‘raised’ vocal effort is presented in Table 3 in terms of the average, standard deviation and range of STI values obtained at each receiver position. Results indicate that when there is an event taking place in the atrium (primary classroom), the STI achieved is ‘Fair’ which does not meet the BB93 criterion.

When there is not an event taking place in the atrium (secondary classroom), the STI achieved in positions 1 and 2 is ‘Good’ which meets the BB93 criterion. However in position 3 (3.4 m from the source position), the average STI did not meet the criterion. Therefore even in relatively quiet noise conditions, communication would be limited to around 2 m to ensure that BB93 standards are achieved.

Furthermore, an enhanced minimum STI criterion may be appropriate for this type of accommodation given the increased likelihood of vulnerable listeners in the pupil profile. Although beyond the scope of this paper, the additional needs for specialist groups are discussed in references (6) and (7).

The A-weighted speech-to-noise ratios, S/N(A) calculated for each noise sample for ‘raised’ vocal effort are also presented in Table 4 (mean and range). According to ISO 9921[8], a signal to noise ratio of >7.5 dB(A) is necessary to achieve ‘Good’ levels of speech intelligibility for normal listeners. Even though reverberation times were extremely long, the BB93 criterion for STI was achieved at speech-to-noise ratios of 6 dB and upwards due to the relatively short early decay time achieve in the classroom. This demonstrates the ability to compensate for poorer speech-to-noise ratios with shorter early decay times.

Table 3: Measured Speech Transmission Index (STI)

Classroom	Position (distance) from source (m)	Number of noise samples, n	STI Average	STI σ	STI Range	S/N(A) Average & Range
Secondary	1 (1.5)	21	0.67	0.02	0.62-0.70	11 (8-13)
	2 (2.1)	21	0.65	0.02	0.60-0.68	9 (6-12)
	3 (3.4)	21	0.58	0.03	0.53-0.70	7 (4-10)
Primary	1 (2.8)	15	0.49	0.02	0.45-0.52	3 (2-4)
	2 (3.3)	15	0.49	0.02	0.45-0.52	3 (1-4)
	3 (3.8)	15	0.45	0.02	0.42-0.49	2 (1-4)

CONCLUSION

It has been shown that STI levels in the space were more directly affected by EDT (which was relatively short) than the T_{60} reverberation time (which was long). However, the long reverberation time (T) led to increased levels of reverberant *noise*, which decreased the signal-to-noise ratio resulting in poor speech intelligibility (especially when an event was taking place in the atrium).

Acoustic conditions in the open plan hospital school were shown to be very poor, even though communication distances are quite short due to the one-to-one or small group teaching style. Lack of control over atrium noise levels means that BB93[1] criteria cannot be guaranteed even at these short communication distances. This study raises the issue of provision of school accommodation for a specialist user group which is not specifically dealt with in BB93[1]. Although open plan facilities provide a level of flexibility that may be desirable in such a school, designers and end users should be made aware of the detrimental acoustic conditions which could arise as a result of the design.

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