Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

WHEN BB93 JUST ISN'T GOOD ENOUGH - SCHOOL ACOUSTICS DESIGN FOR EXCELLENCE.

A James BSc FIOA   Adrian James Acoustics Ltd, Norwich, UK
D Canning MIOA   Consultant Educational Audiologist, St Albans, UK

1 INTRODUCTION

Recent British papers on school acoustics have tended to concentrate on the mandatory requirements set out in the Department for Education and Skills Building Bulletin 93 [1], compliance with which is (theoretically at least) mandatory under Building Regulations in England and Wales. BB93 contains much useful guidance on good acoustic design, but the majority of users refer only to the minimum standards set out in Section 1 of the document. The net result is that some schools are built to lower standards than we would previously have considered.

This paper considers some cases where higher standards might apply. These include mainstream classrooms ; rooms for children with varying degrees of deafness, autism and multiple disability ; and dining halls. It does not consider rooms for music or drama, which were addressed in a previous paper [2].

2 BACKGROUND

Since the introduction of BB93, the authors have been involved to a greater or lesser extent in more than 250 schools of all types. A significant minority of these projects were referred to us following complaints about acoustics or noise in existing schools. Such complaints have included :

- Poor acoustics of halls for assembly, drama and / or music
- Noise transmission between music rooms, and from music rooms to other areas
- High reverberant noise levels in dining halls
- Over-reverberant classrooms
- Noise from mechanical ventilation systems
- Noise from external sources (particularly aircraft noise)
- Interference between teaching groups in open-plan and group teaching areas
- Unsuitability of facilities for hearing-impaired students, sometimes leading to applications for transfer to another school

Investigation of these complaints has often, but not always, revealed that the areas in question did not comply with BB93. It is very rare to receive a complaint about acoustics which we do not consider justified – in general, teachers seem to have very low expectations of acoustics, and the absence of complaint is by no means an indication that good or even adequate acoustic standards have been achieved. Even so, it is perhaps instructive to consider those subjects on which we have never received complaints in schools which comply with BB93 :

- Rain noise
- Noise from corridors to classrooms
- Acoustics of music practice rooms, whether with parallel or non-parallel walls
- Under-reverberant (acoustically "dead") classrooms
- Impact noise transmission through floors

3 CLASSROOM ACOUSTICS AND DESIGN FOR CHILDREN WITH SPECIAL HEARING REQUIREMENTS

One of the most hotly-debated questions when BB93 was first written was whether there should be a lower limit for reverberation time in classrooms. It was felt that to set a mandatory lower limit would cause problems with smaller classrooms and would possibly create conflicts with the requirement for shorter reverberation times in classrooms intended for use by hearing-impaired pupils. Hence the only mandatory requirement is that mid-frequency reverberation time Tmf, defined as the average of the RTs in the 500, 1000 and 2000 Hz octave bands, should not exceed 0.8 seconds in secondary school classrooms, 0.6 seconds in primary school classrooms, and 0.4 seconds in classrooms intended for use by hearing-impaired pupils.

What is frequently overlooked, however, is the additional guidance in Section 4 of BB93. This discusses the need for early reflected sound in rooms used for speech and illustrates ways of achieving this by locating acoustic absorption at the edges of the ceiling or at high level on the walls while leaving the centre of the ceiling reflective. This is of course common practice in boardrooms and meeting rooms, but in classrooms cost constraints almost invariably result in the use of uniformly absorbent ceiling tiles. This generally complies with the mandatory requirements, although the lack of diffusion in unfurnished rooms can lead to problems with flutter echoes or room modes artificially increasing the Tmf when commissioning.

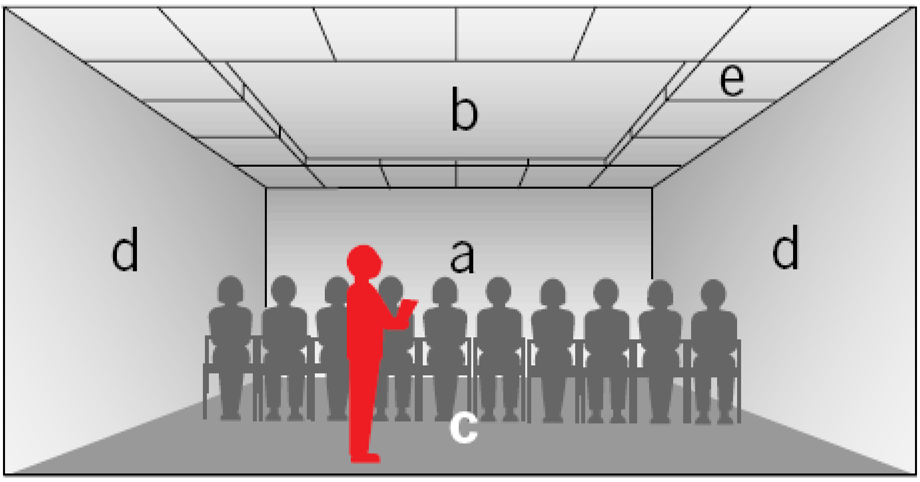


Figure 1 – Guidance on possible classroom design, from BB93 Section 4.
Areas a, c and e are acoustically absorptive, b and d are reflective.

There is no shortage of recent literature on the acoustics of classrooms [e.g. 3,4]. These generally concentrate on large classrooms (typically 50 – 70 m^2) , and the maximization of speech intelligibility from a teacher addressing up to 30 pupils in the traditional formal teaching layout. This does not, however, take account of the increasing need to accommodate children with special needs and disabilities, including hearing impairment, in mainstream schools. Children with hearing aids and cochlear implants are often very sensitive to noise, including reverberant noise – in this context we can consider anything other than the direct sound from the speaker, and very early reflections, to be noise. For this reason BB93 adopted the recommended standards of the British Association of Teachers of the Deaf [5], including a maximum of 0.4 seconds Tmf in classrooms designed for use by hearing-impaired pupils. It is of course arguable that, under the Disability Discrimination Act, all classrooms should be designed to this standard, although in practice it is generally done on an “as-required” basis. In most large classrooms, this requires fairly large areas of acoustic absorption on the walls as well as on the ceilings, with implications for robustness and maintenance as well as cost.

Section 6 of BB93 includes a much more detailed discussion of acoustic design for pupils with special hearing requirements, and like the rest of BB93, is required reading for anyone seeking to implement Section 1 of that document.

Another aspect not often considered in studies of classroom acoustics is the different style of teaching for children with special needs, including hearing impairment. Typically this involves several small groups, each with perhaps 2-4 children at a table with a teacher. The typical source-to-receiver distance in this case will rarely exceed 2 metres, so there is little need for (or likelihood of) early reflections from room surfaces to assist direct sound. There will, however, often be several such groups in a single classroom so that the main requirement is for reduction of speech levels from adjacent groups. In special hearing-impaired units this may be assisted by the use of acoustically absorbent part-height screens. This is not an option in rooms for children with Acoustic Spectrum Disorder or multiple learning disabilities, so the only option is to reduce the reverberation time of the room as far as possible.

4 ACOUSTIC DESIGN FOR AUTISTIC SPECTRUM DISORDER

Building Bulletin 102 [6] *"Designing for disabled children and children with special educational needs"* provides some qualitative outline advice for the acoustics of spaces for teaching children with special educational needs. BB102 suggests that spaces designed for ASD students should have *"good acoustics, avoiding sudden/background noise"*. It does not, however, quantify this rather vague recommendation, instead referring back to the numerical criteria set out in BB93, which does not include any design criteria schools designed specifically for use by students with ASD. We have therefore recently been appointed to develop an acoustic brief for a new school for autistic children.

To this end we visited three schools catering for ASD pupils, interviewed staff and, where possible, took acoustic measurements within the school buildings. This resulted in a limited set of measurements and interviews, but they included input from specialist teachers, educational officers at the National Autistic Society and from the head teachers of established ASD schools, and the consistency of the replies to our questions at different schools provided some reassurance that a larger sample would probably not change our conclusions. We therefore used the information gathered to develop numerical criteria for the different types of spaces.

We had initially expected that autistic children would be very sensitive to unexpected and unpredictable noises such as road traffic, aircraft and doors slamming, and we had prepared our client for the need to provide additional sound insulation to reduce such noises, with mechanical ventilation both to replace the use of opening windows and to provide broadband masking noise. These expectations were proved almost entirely wrong. The study was only completed very recently and will be written up more fully in a later publication, but our conclusions to date are as follows :

- **Airborne noise from outside the building** - We found no evidence, either objective or anecdotal, that noise levels in classrooms due to road or air traffic should be lower than in mainstream schools. We therefore adopted the BB93 criterion, 35 dB $L_{Aeq,\ 30\ min}$, albeit without the BB101 relaxation to 40 dB for naturally ventilated rooms.

- **Rain noise** - Again, we found no evidence that children with ASD are more sensitive to rain noise than other children. We therefore proposed adoption of the BREEAM Education 2008 criterion for rain noise in mainstream schools.

- **Noise from plant, services and equipment** - There was consistent evidence that continuous noise from plant can be very disturbing to some children with ASD, especially if the noise contains tones, regular impulses or other distinguishing characteristics. We therefore proposed that plant noise should not exceed NR25 when measured in octave or one-third octave bands in terms of $L_{eq,\ 30\ min}$ in any teaching room, and should contain no audible or measurable tonal, impulsive or repetitive components. In terms of noise level, this is slightly more stringent than the 35 dB L_{Aeq} criterion in BB93. The purpose of the above criterion is to be very much more specific in the spectrum and type of noise, so as to avoid the characteristics which can cause distress to autistic children.

- **Internal Sound insulation** - We found no evidence to suggest that higher standards of sound insulation are required between spaces for ASD students than those required for mainstream teaching spaces under BB93. Problems were reported where a dining hall was open to circulation areas, and we recommended that such areas should be designed as complete rooms. In principle, open plan design in ASD schools is discouraged for reasons other than acoustics, although we would expect it to cause acoustic issues as well.

- **Room acoustics in classrooms** - *e*xcessively reverberant acoustics were reported as problematic in several areas. Even in schools where all classrooms complied with the BB93 requirements, staff identified the less reverberant classrooms as being particularly good. We therefore proposed a slightly more stringent criterion for reverberation times. In classbases and group rooms not designed for use by hearing-impaired pupils, we recommended that the Tmf should be less than 0.5 seconds, increasing to not more than 0.7 seconds in the 250 Hz octave band and not more than 1.0 seconds in the 125 Hz octave band. The low-frequency increases are not desirable but it is questionable whether shorter low-frequency values are reliably achievable, given that these are large classrooms with small occupancies (typically 8-10 pupils) and that room finishes have to be very robust, which precludes the use of panel absorbers and of dry-lined walls which provide the bulk of low-frequency absorption in most cases.

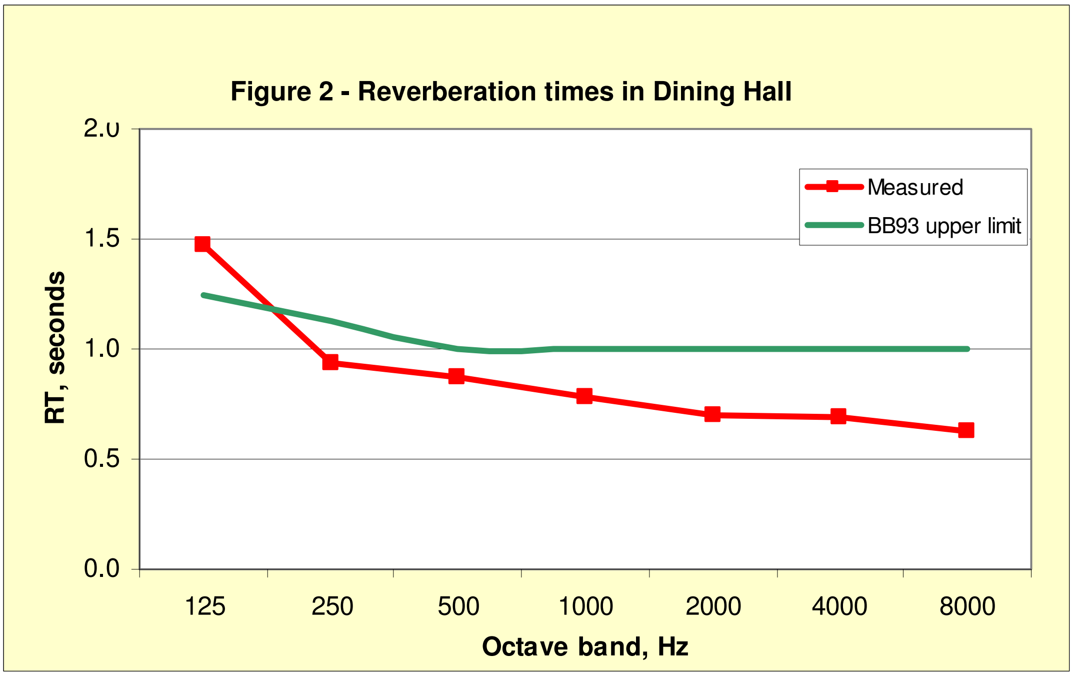
  For practical purposes, and to overcome the technical issues of room modes and flutter echoes in unfurnished spaces, we proposed that these limits should apply to rooms measured either empty or containing such furnishings and contents as the client deems a minimum requirement for teaching in the space. This is a departure from the recommendation on commissioning in BB93, but one which we feel could usefully be adopted more widely to allow for commissioning in rooms with realistic amounts of diffusion and hence reducing the cost of over-design to ensure successful commissioning in unrealistic conditions. Ultimately we are interested in the acoustics that the children will experience rather than that of the empty, unfurnished rooms.

- **Room acoustics in other spaces** - Where excessive reverberation was cited as a problem in dining halls and sports halls, we found that the rooms in question did not comply with the BB93 requirements. BB93 recommends, but does not require, certain criteria for room acoustics in non-teaching spaces used by students (e.g. common rooms) and we considered that these should be required, rather than recommended, in ASD schools.

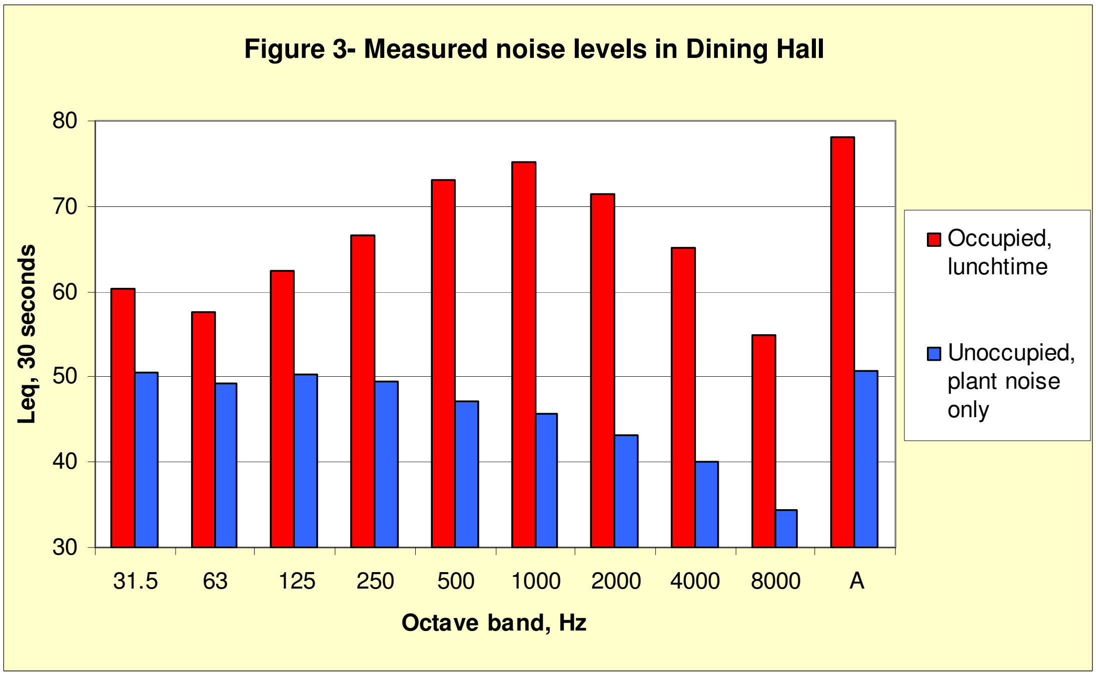
- **Circulation spaces and corridors** - There was consistent anecdotal evidence that noise and over-reverberant conditions could be problematic in corridors and circulation spaces. BB93 contains a complex set of requirements for such spaces, most easily summarised as requiring Type C acoustic ceiling finishes in corridors. Type C denotes moderate acoustic absorption (e.g. some types of perforated plasterboard) but is not inherently cheaper than more effective absorbers such as Types A and B, which are typically faced mineral fibre or perforated metal products. We therefore recommend that corridors and circulation spaces should require at least Type B, and preferably Type A, ceilings. We also recommend carpets in corridors to reduce footfall noise. Where this was impracticable we recommended the use of soft or cushioned floor finishes (e.g. cushioned vinyl) rather than hard floor finishes.

5 DINING HALLS – REVERBERANT NOISE LEVELS

We recently encountered an interesting case of very high speech noise levels in a secondary school dining hall in Essex. Figure 2 shows the measured RTs in the Dining Hall as averaged over all microphone positions. The maximum allowable RT set out in BB93 is also shown for comparison.



The results show a Tmf of approximately 0.8 seconds, which is within the upper limit of 1.0 second set out in BB93, and in fact also complies with the limit of 0.8 seconds previously set in BB87 and its predecessor BB51At first sight therefore we would not expect reverberant noise to be a problem in this room. Figure 3, however, shows ambient noise levels measured in the hall at lunchtime:



.

Subjectively, the Dining Hall was certainly noisy when in use and speech communication was difficult. However, our measurements indicate that the room is not excessively reverberant. Part of the reason is that the ceiling height (and hence the volume of the room) is quite small for the number of people using it so that in spite of the fairly low RT, the reverberant noise level is relatively high. For a source of a given sound power in a room, the resulting reverberant noise level increases with reverberation time and decreases with room volume.

Very elementary acoustic theory states that in a room with a diffuse reverberant field, if the source sound power remains constant, the reverberant sound pressure level Lp at a given frequency is a direct function of the sound power level Lw and reverberation time T at that frequency, and of the room volume V:

$$Lp = Lw + 10 \text{ Log } (T/V) + 14 \text{ dB} \quad [1]$$

Hence Lp should increase by 3 dB for each doubling of RT and should also decrease by 3 dB with each doubling of room volume – or for a given floor area, for each doubling of room height. The reverberation time itself is, however, a function of room volume :

$$T = 0.161 \; V / A \quad [2]$$

where A is the total amount of acoustic absorption in the room. For this reason, the reverberation time for a given use of a room should ideally always be considered both as a function of the use of the room and of its volume. For example, a small music practice room with a reverberation time of 0.8 seconds, as allowed under BB93, would experience high reverberant noise levels compared with a larger room with the same RT (a matter which becomes relevant when considering the risk of damage to hearing among music teachers and students).

BB93's predecessor, BB87, dealt with this issue by listing a range of preferred room dimensions (including ceiling heights) for each type of room. This was possible because BB87 was considered to be more of a guideline than a regulatory document. BB93 deals with this at a very basic level by setting lower RT criteria for primary school classrooms, which tend to be smaller than those in secondary schools, but did not go further than this without introducing a level of complexity which is incompatible with the setting of minimum regulatory standards. Fortunately, in most cases this is not necessary because most rooms in new schools tend to be of fairly standard dimensions for a given room type. In this case, however, the height of the dining hall is relatively low compared with other rooms of the same floor area, and the net result is that the reverberant noise level is higher than we would expect from other dining halls of the same RT.

This alone does not account for the very high reverberant noise level. We have compared the results of our measurements with other dining halls at schools in Reading and Ealing, where we were called in to investigate problems, and the results can be summarised as follows:

	Essex	***Ealing***	***Reading***
Floor area, m^2	205	228	225
Average height, m	3.4	3.0	6.0
Volume, m^3	704	684	1350
Mid-frequency RT, (Tmf) seconds	0.8	1.5	3.4
10 Log (T/V) *(see Equation 1)*	-29.4	-26.5	-26
Reverberant noise level, dB LAeq	78	80	68

All three dining halls had similar floor areas and occupancies. If the source sound power (the amount of noise generated by the occupants) is approximately the same in each case, from Equation 1 we would expect the reverberant level at the Essex school to be about 2-3 dB lower than at Ealing, and this is in fact the case. We would also, however expect the reverberant level at the Reading school to be about the same as at Ealing whereas it was in fact more than 10 dB lower than at either Ealing or Essex. A possible explanation is that at Ealing and Essex, noise levels quickly reach the point at which the Lombard Reflex is triggered, such that the occupants adjust their vocal effort to the ambient noise level. At Reading the acoustics were unpleasant but because of the very large volume of the room, ambient noise levels did not become high enough to trigger this effect.

The Lombard Reflex is a psycho-acoustic effect dependent on many interrelated variables, including the dimensions and acoustics of the space, the number of people in the space, the seating density or distance between talkers and listeners, and the dynamics and characteristics of the occupants. Because of this, it is not possible to predict accurately the room acoustic conditions in which the Lombard effect will occur. It is not necessarily triggered by the reverberant noise level alone ; the trigger may be the intelligibility of speech from adjacent, unwanted, sources, which would be a more complex function depending on direct and early reflected sound from other conversations near to the speaker, as well as the reverberant level of unintelligible “babble” from conversations further away.

There have been a number of studies of Lombard effect in eating establishments. Hodgson, Steiniger and Ravazi [7] conclude that there is no simple relationship between room acoustics and the onset of Lombard Effect. Their study is based on eating establishments frequented by adults and we might expect that with children, the Lombard effect would set in more quickly as children may be less inhibited about raising their voices. As far as we are aware (and we have not at this stage undertaken a formal literature search) there has been no definitive study of Lombard effect in school dining halls.

During the writing of this paper the authors have begun investigations of another, quite similar, school dining hall which again complies with the reverberation time criteria in BB93 while having an unusually low ceiling. There have been complaints of very high noise occupied noise levels but at the time of writing we have not been able to measure these. It does seem, however, that the simple BB93 approach of setting an RT without reference to room dimensions is not always sufficient.

6 REFERENCES

1. Department for Education and Skills, Building Bulletin 93 "Acoustic Design of Schools". http://www.teachernet.gov.uk/acoustics

2. A James, A Thompson, I Rees "School music rooms – designing beyond BB93" Proc IoA, Vol 27, Part 2 (2005)

3 J Bradley "A new look at acoustical criteria for classrooms", Proc Internoise 2009

4 J Whitlock and G Dodd, "Recent New Zealand initiatives towards understanding classroom acoustics" Proc Internoise 2009

5 "Classroom Acoustics – recommended standards" BATOD, 2001. http://www.batod.org.uk

6 Building Bulletin 102 "Designing for disabled children and children with special educational needs - Guidance for mainstream and special schools". Department for Children, Schools and Families. http://www.partnershipsfor schools.org.uk/documents/design/BB102.pdf

7 M Hodgson, G Steiniger and Z Razavi ""Measurement and prediction of speech and noise levels and the Lombard Effect in eating establishments" J.Acoust. Soc. Am. 121 (4) 2007.