SCHOOL ACOUSTICS AFTER BB93 - PRACTICAL PROBLEMS AND SOLUTIONS

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1. INTRODUCTION

The revised Approved Document E of the Building Regulations came into force in July 2003. One of the new requirements is that, for the first time, new and refurbished schools have to meet strict standards for noise levels, sound insulation and room acoustics. These standards are set in Section 1 of the Department for Education and Skills (DfES) Building Bulletin 93 "Acoustic Design of Schools". [1] The previous acoustic standards were contained in Building Bulletin 87 "Guidelines for Environmental Design in Schools" [2] and although these formally set out the Recommended Constructional Standards for Schools under the School Premises Regulations, they were widely regarded (and frequently disregarded) as guidelines only.

At the time of writing of this paper the new Approved Document E and the new Building Bulletin 93 have been in force for several months and designs for both new schools and refurbishments are being developed, both under Private Finance Initiative (PFI) schemes and under more traditional procurement methods. This paper reviews some of the issues that have arisen in the interpretation and implementation of the Building Bulletin, highlights some of the changes that have been made as a result of consultation, and revisits some of the questions raised at the Institute of Acoustics seminar of 15th October 2002 [3].

2. COSTS

One of the most often-voiced concerns about BB93 is the cost of implementing the new regulations, and in particular, the implications on Private Finance Initiative (PFI) schemes. The Regulatory Impact Assessment published as part of the BB93 consultation package included some fairly crude estimates of additional costs of improved acoustic standards in schools. The baseline for acoustic standards from which any improvements could be considered was set by the DfES Constructional Standard, Building Bulletin 87.

In fact , as discussed in an earlier paper [4] the improvement in acoustic standards from BB87 to BB93 is not as wide-ranging as has been widely assumed. One of the main areas of concern, the requirement to achieve the specified ambient noise levels and ventilation standards simultaneously, was contained in BB87. Another change, the reduction in permissible ambient noise level in classrooms, has to be offset against the fact that the levels in BB87 included noise from adjacent rooms whereas BB93 considers this separately. The main problem, in fact, seems to be that some contractors and designers who previously ignored BB87 are now having to recognise and achieve the acoustic standards because they are now enforced under the Building Regulations.

At the time of writing of this paper, the DfES was carrying out some more detailed studies of cost implications for various school projects. Our experience to date has been that in most cases where architects were already applying BB87, the added costs of complying with BB93 are not great. We have also been asked to comment on some schemes which would not have complied with BB87 in the first instance, and there the cost uplift has to be considered not from the existing position but from the point at which the design has been amended to meet the standards set out in BB87.

3. PFI SCHEMES

A frequently voiced concern is that PFI developers were not aware either of BB87 or of BB93, and that their budgets for large-scale projects covering many schools have not taken account of the acoustic requirements. It is perhaps worth pointing out this concern has been voiced by acoustics consultants and not by the PFI contractors themselves. The PFI contractors with whom we have worked have not, to date, been aware of and taken account of BB93 in their schemes.

It is reasonable to expect that any organisation letting a contract for any type of building should do so with reference to all relevant guidance, standards and legislation. It is also reasonable to expect that any organisation bidding for such contracts should have the knowledge and expertise to take these into account in their submissions for such work. This is particularly so for contractual undertakings on the scale typical of PFI projects. It is inconceivable to the authors that Schools PFI contractors could have committed themselves to costs without taking account of the DfEE's Constructional Standards for Schools, the Schools Premises Regulations and hence of Building Bulletin 87. The question therefore becomes whether contractors should have known about the draft Building Bulletin 93 and the financial implications of this.

In addition to the consultation exercise carried out for BB93 itself, there was also an earlier and more wide-ranging consultation for the amendments to Approved Document E. Requirement E4 of these Regulations states that all areas in schools should be acoustically suitable for their use, and refers to the DfES Bulletins as setting out the standards for these. It would therefore be as difficult to believe that Contractors did not know about this as it would be to believe that they did not know, for example, about the changes arising from the Disability Discrimination Act.

4. NOISE CRITERIA

To avoid semantic arguments about the correct use of terms such as background, ambient and residual noise, for the purpose of this paper we will simply refer to all design criteria relating to noise from unwanted sources as "Noise criteria". For simplicity, we also refer to levels purely in terms of overall A-weighted levels, dBA.

4.1 The purpose of noise criteria

There is considerable confusion as to the purpose and application of background and ambient noise criteria. Depending on the use of a room we may need to define noise criteria to achieve any of the following subjective criteria :

- Inaudibility – for performance / recording spaces
- Intelligibility – where a good signal-to-noise ratio (including reverberant noise) is required, e.g. in classrooms and open-plan spaces.
- Lack of distraction – where concentration is needed. e.g. in classrooms and open-plan spaces as well as libraries, study areas, examination halls
- "Acoustic comfort" (or lack of stress) – which is a function of absolute noise level

In a classroom, noise levels have to take account of several factors. The least demanding of these is the Signal to Noise ratio. In general, a ratio of 15 dB is regarded as adequate for good speech communication, in classrooms where hearing impaired pupils may be present. A teacher speaking in a normal voice will generally produce a sound pressure level of about 60 dBA at 1 m, and using a raised voice the level is about 67 dBA at 1 m. Given the normal dimensions of a classroom, this suggests that a 15 dB S/N ratio should be achievable over a noise level of about 40 dBA without teachers having to raise their voices.

If this were the only criterion we could achieve it by providing the teacher with a sound system, at much less expense than providing sound insulation for a school in a noisy area. A 15 dB S/N ratio is typically provided by the public address systems in airport concourses where noise levels are typically 70 dBA. No-one has yet suggested that this would be acceptable for teaching, so there must be some other noise criterion to be applied.

In fact we are designing not only so that pupils can understand what the teacher is saying, but so that they can do so easily, without special effort, and so that they can concentrate on what they hear. This is a function of the absolute noise level and of the character of the noise. Much of the time, of course, the absolute noise level in a classroom is high due to teaching and other activities. The time at which noise from outside becomes a problem is during the quiet periods. These typically occur in primary schools when the teacher is reading or talking and pupils are listening quietly, or when children are just sitting doing written work or tests. In these cases we have to design so that the noise from outside or from other classrooms is not distracting during these quietest periods.

From the above it follows that there should in fact be two different noise criteria for most spaces – one for constant, broadband, "Non-distracting" noise such as that from well-designed ventilation systems, motorway traffic at a distance etc, and one for intermittent, tonal and generally intrusive noise such as individual vehicles, sirens, unwanted speech and music. In fact many acousticians will specify these separately for acoustically critical environments such as studios and performance spaces, but it would not be practicable to expect this in a regulatory document such as BB93.

In addition to signal/noise ratio and distraction, we should also consider "Acoustic comfort" or "Lack of stress", which is related to the absolute noise level. This is difficult to quantify other than through experience of the acceptability or otherwise of a large number of spaces over many years. In this regard it is worth noting that the World Health Organisation recommends background noise levels in classrooms not to exceed 35 dBA.

4.2 Noise measurement

There are many current and recent studies of the effect of noise in schools, of which one of the most thorough is the "West London Schools Study" [5] A matter which immediately arises from such studies is how to measure noise from a particular source in a school, and indeed what noise sources should be measured.

As discussed above, the absolute sound level in a classroom is often high due to teaching and other activities. This is not, however, really a "noise level" in that it also often includes the "signal". It is, by definition, very difficult to measure the "noise level" from pupils and from sources outside the classroom during lessons, because the sound pressure level of the signal (in this case the teacher's voice) exceeds that of the noise. There is, therefore, a limit to the usefulness of sound measurements during lessons. For this reason it is often necessary to measure the signal and the various noise levels separately. For example, we can measure LAeq in a classroom when pupils are working individually or in groups, and when there is no significant noise from outside the classroom. This has been measured by several researchers, with remarkably consistent results around 56 dB LAeq [6]. This may be useful as an indication of what we might call an "Activity background noise". It is not necessarily indicative of the lower levels of noise from pupils who are listening to a teacher, but it becomes significant when measuring or calculating Speech Transmission Index in classrooms and, in particular, in open-plan areas, when this level of 56 dB LAeq becomes the noise level over which the signal must be heard.

4.3 Level changes due to Soundfield systems

BB93 gives guidance on the use of “Soundfield” and other systems to assist both hearing impaired and other pupils. One concern was the effect of such systems on the noise levels in classrooms, both directly (through noise generated by the system) and indirectly (through teachers adapting their vocal effort and children reacting to the different acoustic conditions).

As part of the research before the implementation of BB93, we took some simple measurements at a school where a Soundfield system had been installed. Measurements of SPL, Leq, L_{90} and L_{min} and analysis of tape recordings failed to show a statistically significant change either in the sound level from the teacher’s voice, or in the underlying noise level, when the teacher is using the SoundField system. This is perhaps not surprising as the amplification provided by a Soundfield system needs only to be 3 dB or so at any location to be effective, and the random variation between results often exceeded this. It is also worth noting that these are not simply amplification systems, but are designed to distribute the sound from the teacher’s voice more evenly about the classroom. A detailed study would therefore need simultaneous measurements in several locations, under controlled conditions, with and without the Soundfield system.

It seems likely that teachers recognise through auditory feedback that they need to speak less loudly when the system is in use. This could be assessed in a more detailed study by using a measurement microphone very close to the teacher or by monitoring the signal going into the amplifier. Certainly, the teachers using systems that we have inspected have generally been pleased with the results, listing reduced vocal fatigue among the benefits of the systems. Subjectively, the systems seem to give an increase in speech clarity at mid-and high-frequencies, but again we would need much more controlled conditions to measure this. It is worth noting that this increase in clarity does not necessarily imply a pleasant quality of sound and there is no doubt that some systems sound subjectively much more “harsh” than others, probably as a result of the quality of the loudspeakers used. Clarity and intelligibility should not be confused with quality of sound, but are much easier to specify.

5. OPEN PLAN AREAS

Section 1 of BB93 states that a computer prediction model should be used to calculate the Speech Transmission Index (STI) in any open-plan space used for teaching several groups of children simultaneously, and that the STI should not be less than 0.6 for speech from teacher to student, from student to teacher or from student to student. The model must take account of an agreed open-plan layout and detailed activity plan, the full details of which are described in some detail in BB93 Section 1.1.7.

The STI is affected by a large number of factors including the acoustic characteristics of the space, the locations of sources and receivers, source levels (which are defined in ANSI 3.5:1997) and, of course, the background noise. For this purpose, the background noise will be the noise (measured in terms of Leq in each octave band) from all sources other than the speech source which comprises our signal.

Figure 1 shows a very simple model of a teaching area designed to accommodate three groups of students. It is a rectangular enclosed room 21 m long, 10 m wide and 4.5 m high. The floor is carpeted, the ceiling is of acoustically absorbent ceiling tiles and the walls are plasterboard up to 2 m from the floor, with a band of proprietary acoustically absorbent material above this height. The Activity plan denotes that there will be up to three groups of students seated in traditional classroom style, as shown by the seating “blocks”. There are two part-height, acoustically absorbent partitions between the groups. The teacher locations are shown as A1, A2 and A3 in plan and section in Figure 1, as are two receiver positions in “Block” 2.

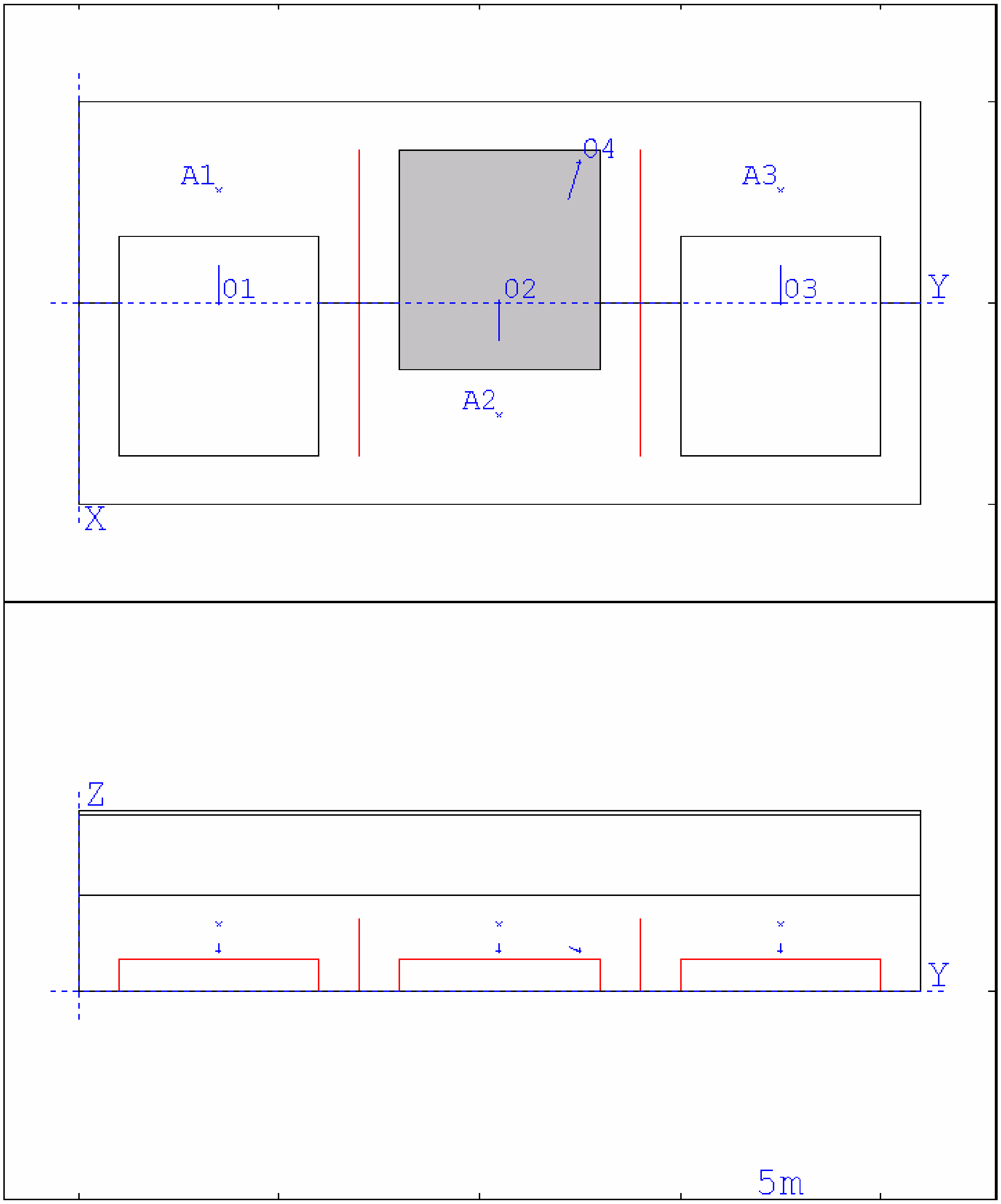

Figure 1– Plan and sections of a modelled open-plan space

In this example we wish to calculate the STI from teacher A2 to a student at the rear of the central block (shows as 04 in Figure 1), in the presence of noise from teachers A1 and A3, speaking with raised voices. We therefore run the model to calculate the sound pressure level at receiver 04 from sources A1 and A3. The model used in this example is CATT-Acoustic, with surface and edge diffuse reflection modelled, all surfaces having scattering coefficients individually input at all frequencies. In general no scattering coefficient is <0.3 and for the “blocks” representing seating areas for pupils, the diffusion coefficients are >0.7. The teachers are modelled as a speech sources using the “Raised vocal effort” levels from ANSI 3.9.

The results are as follows :

Octave Band	125	250	500	1k	2k	4K	8k	
SPL from A1	44.0	46.2	47.4	42.8	36.0	28.6	19.2	dB
SPL from A3	44.4	45.5	46.2	42.8	36.8	29.0	19.5	dB

We can sum the background noise from these sources and input these to the CATT model as a background noise, then run the model again with teacher A2 as the source. The resulting STI calculated at receiver 04 is 0.68, which would comply with the requirements in BB93.

There is, however, a serious problem with this approach.. As described above, researchers have established that there is also an “Activity background noise” from pupils working individually or in groups, and that this noise level is consistently around 56 dB LAeq. In an open-plan area, we have to assume that at times this noise will be generated by students in blocks 1 and 3, even if not in Block 2 while the teacher is speaking. This “Activity background noise” is approximately 10 dB higher at most frequencies than the noise from teachers A1 and A3, and if we include this in our computer model, the resulting STI at receiver 04 decreases to 0.32.

Matters become even worse when modelling the intelligibility of speech between students working in small groups. While the distance from source to listener is less, the source level is also less because it is assumed that students will talk to each other using “normal” rather than “raised” voice level. In the presence of the background noise from other students, the STI over a distance of 2 m is less than 0.3.

At the IoA meeting on 15th October 2002, a majority of those present voted in favour of using STI as a means of assessing the acceptability of open-plan areas. The conclusion from the above, however, seems to be that in this type of open-plan space with several teaching groups working simultaneously, it is not possible to achieve good values of STI. This is perhaps not surprising, given the problems that have arisen in the past with open-plan schools. Whether a criterion in terms of STI is technically sustainable is, however, open to discussion. STI is effectively a signal to noise ratio, and so is very sensitive to the background noise level, especially where background noise is close to the signal level. In the example above, an increase of 3 dBA in the noise level corresponds to a decrease of approximately 0.1 (10%) in STI. This may come as a surprise to many acousticians who look on STI as a way of assessing the effect of room acoustics on speech intelligibility, with background noise being only an incidental variable.

6. RAIN NOISE

The specified internal ambient noise levels in Table 1.1 of the Bulletin exclude rain noise, because there is currently no standard for measuring or specifying this. However, Section 1.1.1 of the Bulletin states that it is essential that rain noise is considered in the design of lightweight roofs and roof lights, and that design guidance is provided in Section 3.1. Section 3.1 suggests that the problem is limited to the use of profiled metal roofs (which is certainly our experience to date) and that **both** damping of the metal **and** an independent suspended plasterboard ceiling are required to control this.

We have not yet found a project in which it was considered practicable to add damping to the metal cladding or a proprietary roofing system. Our experience on a recent noise-sensitive office development using a standard proprietary metal roof with thermal insulation suggests that for classrooms at least, adequate sound insulation can be achieved by the use of a standard suspended sound insulating ceiling consisting of two layers of dense 12.5 mm plasterboard on a proprietary suspension system. This is, however, based on occupants' comments as commissioning measurements during heavy rain have not been possible, and the noise generated is obviously specific to the proprietary roof used in this case.

Any metal roof system used in a school is likely to be a proprietary multi-layer roof system made up of an outer metal cladding, thermal insulation, vapour barrier and an internal lining. Section 3.1 of the Bulletin states that for such multi-layer roofs, laboratory measured data is needed, and that advice should be sought from an acoustics consultant who will be able to calculate the sound pressure level in the space due to typical rainfall on the specific roof (including roof lights). We have yet to find a roof system manufacturer who can supply rain noise data, which is understandable as the proposed standard for measuring and rating rain noise [7] has not yet been published outside the relevant ISO committee (TC43/SC2). Although a few papers have been published on the subject, they are limited in scope and there is no generally accepted methodology for predicting rain noise from a multi-layer roof. It is therefore unlikely that many acoustics consultants would take on the responsibility of calculating this.

Many consultants will simply advise clients not to use metal roofs in noise-sensitive areas of schools. In some recent projects, however, we have found that the architect or contractor is already committed to using such a roof. A pragmatic approach would be to measure rain noise in a room of known volume and reverberation time with a roof identical to that under consideration. From this is would be possible to at least estimate the amount of airborne sound insulation needed. There are obvious practical problems in arranging the weather to coincide with the time of the measurements and in quantifying the "heaviness" of the rain. Our own efforts to achieve this during an unusually dry summer have so far been unsuccessful.

7. DEMONSTRATION OF COMPLIANCE

One of the main concerns raised about BB93 has been the additional workload imposed on Building Control Bodies (BCBs), and the question of their technical ability to deal with this. In the author's experience, this concern has been raised more often by acousticians and architects than by the BCBs themselves, and in the course of a series of presentations to BCBs throughout the country, the reaction has generally been constructive.

Section 1.2 of BB93 discusses how to demonstrate compliance with BB93 through the submission of plans, calculations and other information. In practice we have found that the very detailed list of requirements in Section 1.2 is not always necessary or desirable, and depends on the complexity of the scheme as well as on the individual Building Control Officer. An experienced BCO will not need every application for a classroom extension to include detailed calculations and laboratory test certificates to demonstrate that a 140 mm dense blockwork wall provides the required sound insulation between two classrooms. The most valuable asset in a submission to a BCB is a marked-up set of drawings showing the required and the predicted criteria for sound insulation, ambient noise and reverberation times. The BB93 website now includes a set of AutoCAD symbols developed for this purpose, along with detailed instructions for the use of these.

8. TEACHING AND NON-TEACHING AREAS

A note has been added to Section 1 of the Bulletin to clarify where the requirements are statutory and where they are for guidance. The extension to Part E of the Building Regulations 2000 to schools applies to teaching and learning spaces, including nursery rooms, open-plan teaching areas, music rooms, libraries and study rooms, technical design rooms, sports halls and multi-purpose halls where teaching or studying is expected to take place. The Regulations are not intended to cover administration and ancillary spaces such as offices, staff rooms, dining rooms, toilets and circulation spaces. For these areas the acoustic criteria listed in the Bulletin are for guidance only. None the less, given the very detailed guidance in BB93, we would expect the designers to have to justify not meeting these criteria in the event of a dispute over the acoustic suitability of a "non-teaching space".

9. SCHOOL DESIGN BEYOND BB93

A great deal of effort is now going into the acoustic design of schools to comply with BB93. It is easy to forget that, as part of the Building Regulations, BB93 sets only a minimum standard and that in some cases it may be desirable to design some areas of specific schools to higher standards than this. Typical questions that have been posed are :

- Music accommodation - How should one deal with music accommodation which might house a steel band generating 105 dBA. ?
- Third Party Lettings – what about parts of schools (such as recording studios) that may be hired out to third parties ? Examples are theatres, concert halls and recording studios in which hirers may expect near professional standards of sound insulation.
- Playground noise - The indoor ambient noise levels set in section 1 of BB93 excludes noise from playgrounds. How can we prevent noise from playgrounds interfering with classes ?

The simple answer is that, provided that the minimum standards are met, there is nothing preventing designers from going beyond the requirements of BB93, in exactly the same way as many housing developments are designed to sound insulation standards that exceed those in Approved Document E. BB93 can not offer a definitive acoustic design for each individual project, nor can it remove the need for intelligent design. In that respect, perhaps the greatest risk posed by BB93 is that some Design and Build and PFI contracts may be specified with the acoustic specification reading simply "Comply with Building Bulletin 93". While BB93 should do away with some of the worst acoustic problems in recent school design, it should not be seen as a substitute for intelligent thought and expertise from those specifying, commissioning and designing schools.

Note – Although the author has been closely involved in work for the DfES in developing parts of BB93, this paper is based on work implementing the Bulletin on a large number of schools projects for different clients. The views expressed in this paper are the author's own and there is no inference that they represent the views of the DfES or any other person or organisation.

10. REFERENCES

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