ACOUSTIC DESIGN OF SCHOOLS – WHERE ARE WE NOW?

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1 INTRODUCTION

For over one hundred years acousticians have been concerned about the effects of poor acoustics in educational establishments and have attempted to achieve an acoustic environment which enhances teaching, learning and listening conditions.

Over the past 80 years a considerable amount of guidance on typical noise and acoustics problems in an educational setting has been published in the UK, culminating in current discussions concerning revision of Building Bulletin 93, which since 2003 has set out the acoustic requirements of the Building Regulations with regard to the acoustic design of schools.

The early recommendations were based upon the need to provide good speaking and listening conditions through control of background noise and reverberation. However, since the early 1970s there has been increasing evidence of the detrimental effects of noise and poor acoustic design on children's cognition and academic performance, annoyance and distraction, and teachers' health[1]. Much of the research has concerned children and teachers in primary schools but a current study is investigating the acoustic environment of secondary schools and effects of noise and acoustic design on older students and their teachers[2,3].

This paper provides an overview of the historical background to guidelines on school acoustics, and summarises some of the UK recommendations which have been published in the past 80 years. Current changes and revisions to legislation on the acoustic design of schools are discussed and some relevant interim results from the current study on secondary schools are presented

2 HISTORICAL BACKGROUND

2.1 Early writings on school acoustics

The scientific study and theoretical modeling of room acoustics developed directly from problems concerning acoustics in an educational setting. In 1895 Wallace Sabine, a 27 year old assistant professor of Physics at Harvard University, was asked by the Corporation of Harvard University to investigate acoustical difficulties in the lecture room of the Fogg Art Museum at the university. Sabine wrote[4]

'In the lecture room of Harvard University the rate of absorption was so small that a word spoken in an ordinary tone of voice was audible for five and a half seconds afterwards. Successive enunciations blended into a loud sound through which it was necessary to hear and distinguish the orderly progression of speech. Across the room this could not be done; even near the speaker it could only be done with an effort wearisome in the extreme if long maintained.'

Sabine spent two years experimenting with absorption of various materials in the Fogg Lecture Theatre, developing the theory of reverberation and absorption, and ultimately correcting the problem by reducing the reverberation time from 5.61 to 0.75 seconds[4].

In the early years of the 20th Century Hope Bagenal, who had trained as an architect, became interested in acoustics through his interest in auditorium design and love of music. In 1914 he communicated with Sabine after reading one of his articles, shortly before meeting Alexander Wood, a physicist at Cambridge University who was also interested in acoustics. Bagenal went on to become the first British acoustic consultant, advising on the acoustics of many important buildings. In 1931 Bagenal and Wood published the first British text book on the acoustic design of buildings[5]. The book discusses the planning of school buildings to prevent disturbance by noise, and advises on how to minimise reverberation in classrooms so as to avoid *'much fatigue and irritation [to] teachers'*. The book also contains a section on the design of music schools.

In a later book, published in 1942[6], Bagenal gives further guidance on siting of school rooms, sound proofing between rooms and sound absorption to prevent *'bathroom conditions'*. He is particularly critical of recently built technical colleges where *'we who lecture to evening classes know the echoing corridors, the grim reverberant classrooms, the traffic noise without,…and as a result the extra effort on the part of lecturer and students to convey instruction and absorb it intelligently.'* He is also critical of modern school buildings *'which have been left empty, swept and garnished by the hygiene experts so that they are occupied by the Seven Echoes'*.

Evidence of the problems caused by noise in schools was provided to the Summer Symposium of the Acoustics Group of the Physical Society (a forerunner of the Institute of Acoustics) in 1948 by John Lancelot Burn who was Medical Officer of Health for Salford[7]. Burn became aware of the problem of 'unquiet' schools while attempting to carry out audiometric testing of children in quiet conditions in Salford schools. Many of his comments are relevant to today's schools:

'It is well established that the normal development of infants and young children is seriously affected by constant loud noises… In addition to the disadvantages which noise may bring to the health and comfort of teachers and children …teaching is still largely oral, and the teacher's voice must be clearly heard above the background noise… In some schools the problem has become worse – partly because of modern educational trends… Some recent schools are surprisingly noisy...modern architectural methods do not help in neutralizing sounds… Many modern materials have a reverberant effect… In such conditions teachers must often have a sense of hopelessness – and frequent attacks of laryngitis – endeavouring to make their voices heard.'

Thus, during the 1930s and 1940s problems in schools of disturbance by noise, poor speech intelligibility and teachers' voice strain due to excessive noise and reverberation were recognised and written about. The 1940s also saw the first publication of recommendations for noise levels, reverberation times and sound insulation in schools.

2.2 Early recommendations on acoustic design of schools

After the war there was increasing interest in the UK in the problems of noise. This was reflected in the increasing amount of research on building acoustics carried out, for example at the Building Research Station, in the immediate post war period. Committees were established and meetings held to disseminate research results and ideas among the international acoustics community.

In its 1944 report the Committee on Sound Insulation and Acoustics of Buildings[8] suggested that intruding noises for classrooms should be 25 or 30 phons; this is based upon a suggested standard of 15 to 20 phons for study, reading and writing and allowing for *'the enhanced background noise due to the numbers of children normally in a classroom'*. The report discusses the siting and planning of schools, and airborne and impact sound insulation requirements.

The following recommendations are given:

- The site should be selected to be as quiet as possible; a minimum distance of 100 feet between classrooms and the nearest road is recommended
- Within schools the classroom block should be separated from noisier rooms
- Minimum standard for airborne sound insulation between classrooms and corridors and between classrooms: 45 dB
- Minimum standard for impact sound insulation between any classroom and a classroom beneath: improvement of 15 phons on a bare concrete floor and of 20 phons on a bare timber floor
- Maximum reverberation time in an occupied classroom: 1 second at 500 Hz

In their textbook published in 1950, Knudsen and Harris[9] recommended 35 to 40 dBA as the acceptable level for unoccupied classrooms and lecture rooms. They explain the importance of choosing quiet sites for schools and devote a long chapter to the design of school buildings, stating that *'Acoustics in one of the most important physical properties that determine how well a school's building can serve its primary function. Thus the exclusion of noise and the reduction of reverberation are indispensable in adapting classrooms to the function of oral instruction'*. Knudsen and Harris also discuss the siting and layout of school buildings, plus the acoustical design of classrooms and other spaces (including lecture rooms, music rooms, gymnasia and libraries) with particular reference to the amount of acoustic absorption required in each room.

3 GOVERNMENT GUIDELINES ON SCHOOL ACOUSTICS: BUILDING BULLETINS

In October 1949 the Ministry of Education published the first of a series of Building Bulletins which were designed to meet the *'need for guidance on educational building matters which is less formal than regulations, circulars or administrative memoranda, and which will reach a wider audience than official letters'* [10]. Building Bulletin 1[10] was concerned with the building of new primary schools and Building Bulletin 2[11], published in February 1950, with new secondary schools. There is no detailed discussion of acoustic design in these two publications. Building Bulletin 1 refers to the need to provide quiet spaces where children may rest and to the conflicting acoustic requirements of school halls. Reduction of noise in dining halls and corridors through the installation of sound absorbent ceilings and floor finishes is recommended. Building Bulletin 2 contains a short section on noise which briefly discusses sound insulation and absorption and again recommends the use of quiet resilient floor coverings, and rubber stops on the feet of movable furniture.

3.1 Building Bulletin 51

A building bulletin designed to address specifically the area of acoustic design of educational buildings, Building Bulletin 51 (BB51), was published by the Department of Education and Science in 1975[12]. BB 51 contained sections on the fundamentals of sound, noise control, and listening conditions in different types of school spaces: 'small rooms', 'large rooms' and 'large teaching areas' (ie open plan classrooms), and its principles and calculations were illustrated by several examples. Recommendations were given for background noise levels and reverberation times. Background noise level, BNL, was defined by a series of curves which were modifications of NC curves, while a chart of preferred reverberation times for music or speech in different room volumes, being the optimum RT at 500 Hz, was given.

It is interesting to note that a significant part of the document concerns open plan areas, reflecting the school design trends of the 1970s[13], with considerable discussion of screens, enclosures and double partitions, and three of the eight case studies referring to open plan spaces.

Requirements and recommendations for noise control to optimise speech intelligibility and speech privacy and to prevent speech interference are given. These are combined to give maximum BNL for various school areas and teaching group sizes; some examples are shown in Table 1.

Table 1. Building Bulletin 51 : Maximum background noise levels

Type of space	BNL
Music and drama rooms	25
Teaching groups > 35 people Theatres, large lecture rooms	30
Teaching groups 15 to 35 people Theatres, large lecture rooms	35
Teaching groups < 15 people	40
Libraries, study area	45

3.2 Building Bulletin 87

BB51 was followed in 1981 by Design Note 17[14] which covered all aspects of the environmental design of school buildings. Design Note 17 was revised and published as Building Bulletin 87 in 1997[15]. BB87 covered acoustics, lighting, heating, ventilation, water supplies and energy ratings. The acoustics section provided guidance on planning and noise control in school buildings, and gave recommended constructional standards for background noise levels, reverberation times and sound insulation. Brief guidance was given on particular topics such as open plan areas, art and music rooms, and design for pupils with hearing and visual impairments. Optimum RTs were specified by a chart, similar to that in BB51, and also tabulated for various types of space in primary and secondary schools, as the mean of RTs at 500 Hz and 1000 Hz. Sound insulation was specified as D_w required for various combinations of activity noise and noise tolerance in adjacent spaces. Maximum background noise levels, specified as $L_{Aeq,1hr}$, arising from noise unassociated with teaching activities such as traffic and ventilation noise, and noise from adjacent areas in the school, were specified.

Tables 2 and 3 give some examples of BNL and RT for various school areas.

Table 2. Building Bulletin 87: Maximum background noise levels

Type of space	BNL
Music and drama rooms	30
Teaching rooms and classbases	40
Lecture rooms	35
Indoor sports rooms	50
Libraries	40

Table 3. Building Bulletin 87: Recommended RTs

Type of space		RT (s)
Primary schools	Classroom	0.5 – 0.8
	Library	0.5 – 0.8
	Hall	0.8 – 1.2
	Dining room	0.5 – 0.8
Secondary schools	Classroom	0.5 – 0.8
	Library	0.5 – 1.0
	Hall	1.0 – 1.4
	Dining room	0.5 – 0.8
	Gymnasia	1.0 – 1.5

3.3 Building Bulletin 93

Despite the many guidelines on acoustic design of schools, and the increasing body of research evidence on the detrimental effects of noise and poor acoustics on children and teachers, many schools continued to have inadequate acoustic conditions for teaching and learning. Therefore in 2001 the government decided to control the acoustic design of new school buildings through the Building Regulations, as is the case with the acoustic design of dwellings.

Since 2003 new schools in England and Wales have been required to comply with Requirement E4 of the Building Regulations through meeting the acoustic performance specifications contained in Building Bulletin 93: Acoustic Design of Schools[16].

Accordingly, in 2003 BB93 was published by the Department for Education and Skills (DfES) to replace the Acoustics section of BB87, and to specify the acoustic performance standards which must be met by new school buildings. BB93 specifies maximum indoor ambient noise levels (IANL) and mid-frequency reverberation times T_{mf} (average of RT at 500 Hz, 1000 Hz and 2000 Hz) for a range of spaces within schools. The IANL is the highest $L_{Aeq,30min}$ likely to occur during normal teaching hours in unoccupied and unfurnished spaces, due to external sources and building services. Airborne and structural sound insulation between spaces are also specified, together with a speech intelligibility requirement (STI > 0.6) for open plan classrooms. Some examples of IANL and T_{mf} requirements are given in Table 4.

Table 4. Some BB93 performance specifications (spaces unoccupied and unfurnished)

Type of room	IANL $L_{Aeq,30min}$ (dB)	T_{mf} (s)
Primary school classroom	35	< 0.6
Secondary school classroom	35	< 0.8
Open plan teaching area	40	< 0.8
Music classroom	35	< 1.0
Small lecture room	35	< 0.8
Large lecture room	30	< 1.0
Classrooms for hearing impaired students	30	< 0.4
Science lab	40	< 0.8
Assembly/multi purpose hall	35	0.8 – 1.2
Drama studio	30	< 1.0

3.4 Revision of BB93

When BB93 was introduced in 2003 it was agreed that it was likely to need reviewing after around 5 years; and the two government departments responsible, the Department for Children, Schools and Families (DCSF, formerly DfES) and the Department of Communities and Local Government (DCLG) agreed in November 2008 to a minor review[17]. The aim of the review was to bring BB93 up-to-date; to clarify points where there were uncertainties or ambiguities; to reference other more recently published relevant guidelines such as those referring to sustainability and disabled access and inclusion; and to review the original performance standards. Following wide consultation it was agreed that the values of the latter should only be altered where there was good research evidence for a change. However there were concerns that the needs of pupils with hearing and other communication difficulties were not being met under the current regulations; that more guidance regarding open plan classrooms was required; and that there were conflicts between noise level and ventilation requirements.

A draft revision was circulated in the spring of 2009 which addressed these points while maintaining most of the original performance specifications. However, nothing further was heard from DCSF or DCLG concerning the publication of the revised document.

In the meantime the National Deaf Children's Society (NDCS) had been lobbying the government to introduce mandatory acoustic testing of new schools to ensure that they complied with the Building Regulations. In October 2009 the then Minister of State for Schools and Learners, Vernon Coaker, made a statement in which he endorsed the need for good acoustics in school buildings; promised a review of BB93 in 2010; and agreed to issue a formal consultation in 2010 on mandatory testing of schools.

However, in May 2010, before this consultation was issued or a revision of BB93 published, there was a General Election which resulted in a change of government. This has had significant implications for the revision of the regulations and guidance on the acoustic design of school buildings.

In the early days of the new government two announcements concerning the building of schools were made. The Building Schools for the Future (BSF) project was discontinued; this had been introduced under the previous government and led to the building of many new schools during the first decade of the 21st century. The Government also announced the setting up of 'free schools', that is independent state-funded schools which may be established by any interested group and may be housed in any available and suitable building (not necessarily previously used as a school building). Both of these changes mean that refurbishment rather than new build is going to be of primary concern for school buildings for the foreseeable future and hence any new or revised guidelines on school acoustics need to address in detail the acoustics of refurbishments.

Under the new government the regulations on the acoustic design of school buildings, namely Requirement E4 and BB93, have come under threat on two fronts. In July 2010 the DCLG launched a review of the Building Regulations with a view to reducing *'the burden of technical and administrative aspects of regulation'*. In announcing the publication of the report in December 2010[18] Andrew Stunell, Under-Secretary of State for Communities and Local Government, stated that *'there are a number of key areas where we want to explore the potential for deregulation and streamlining of the existing provisions'***.** In the report the DCLG say that they are working with the Department for Education (formerly DCSF) to determine whether Requirement E4 plus guidance *'is the most appropriate and effective way of achieving appropriate [acoustic] standards for school buildings'.*

Simultaneously, the Department for Education carried out a comprehensive review of capital investment in education (the 'James' review). The report was published in April 2011[19] and is critical of the *'burden of regulation and guidance'* including the large number of Regulations, Building Bulletins and other bureaucracy involved in the building of a new school. The review recommended revision of school premises regulation and guidance to *'remove unnecessary burdens'*.

The acoustics community became very concerned that, following these reviews, Requirement E4 and Building Bulletin 93 would be withdrawn, and that there would no longer be any legal requirements governing the acoustic design of schools.

A symposium was arranged jointly by the Institute of Acoustics (IOA) and Association of Noise Consultants (ANC) in December 2010 to debate the issue of school acoustics and raise awareness of the importance of good acoustic design for both students and teachers, and of the threat to the regulations. At the same time the IOA launched its 'Sound Schools' campaign, calling on the government to retain standards for classroom acoustics. Letters were written to MPs and government ministers and meetings were held with, among others, the chair of the Commons Select Committee on Communities and Local Government; representatives of the Department for Education and Partnerships for Schools; members of the House of Lords; and the Under Secretary of State for Education. A briefing note was prepared highlighting the costs of poor acoustic design, for example the costs of remedial treatments, or of compensation paid to teachers with voice problems.

The IOA and ANC agreed that, even if Requirement E4 and BB93 were withdrawn, a revision of BB93 would be published to provide guidance on good acoustic design of schools. A revised version of BB 93, which contained several substantial changes to the 2009 draft revision, was drafted in consultation with PfS, in late 2010, but was not widely circulated owing to the uncertainties around the future of the regulations. The main changes between the 2009 and 2010 draft revisions were in the specifications for indoor ambient noise levels and sound insulation; RT requirements for design and technology spaces, art rooms and sports halls; changes in the parameters for specifying noise levels and sound insulation; and more complex requirements for open plan spaces. In the 2010 draft most of the IANLs were increased by 5 dBA over those in BB93, supposedly to reflect the 5 dBA tolerance allowed by Building Bulletin 101[20], published in 2006, for ventilation conditions of 8 litres per second per person.

At the time of writing (August 2011) there is cautious optimism that Requirement E4 will be retained, although no official statement has yet been made. One option that has been suggested is that noise levels, reverberation times and sound insulation may continue to be controlled through the Building Regulations, but that speech intelligibility in open plan spaces, which relates to the classroom 'in use' rather than being a purely design condition, may come within the remit of the School Premises Regulations.

Although it appears that all Building Bulletins will be withdrawn, it is recognised by the IOA, ANC and PfS that updated guidelines on the acoustic design of schools are required. Discussions are ongoing as to the form this guidance should take and, in particular, what changes are required to the BB93 performance specifications.

The remainder of this paper presents some evidence on issues related to BB93 from a current research project on the acoustic environment of secondary schools.

4 ACOUSTIC CONDITIONS IN SECONDARY SCHOOLS

Most of the recent research concerning the effects of noise on school children and acoustic conditions in schools has focused on primary schools[1]. A research project is therefore currently being undertaken to investigate the acoustic design of secondary schools and its impact on students and teachers.

The project, 'Identifying a Sound Environment for Secondary Schools', is being carried out by London South Bank University, the Institute of Education and the University of Salford. The project aims, through acoustic and noise surveys of schools, questionnaire surveys of students and teachers, and experimental cognitive testing of students in different noise levels, to examine a) typical acoustics and noise conditions in secondary schools; b) students' and teachers' attitudes to noise; c) levels of noise and reverberation which affect students ability to hear and understand their teachers and d) the levels of noise in which academic performance of students is affected at different ages. Below are presented some interim results from the acoustic and questionnaire data collected to date (August 2011).

4.1 Methodology

4.1.1 Acoustics and noise surveys

Acoustics and noise surveys have been carried out in a range of unoccupied and occupied spaces in schools across England. All measurements were made using a Norsonics N140 sound analyzer, with the microphone at seated head height (~1.2 m).

Indoor ambient noise levels, reverberation times and STI were measured in each room when it was unoccupied. To obtain the indoor ambient noise level the equivalent continuous noise level was measured for a period of between 1 and 5 minutes. Although the BB93 performance specifications are in terms of $L_{Aeq,30min}$, as the noise was constant it was judged that the shorter measurement periods were sufficient to give an accurate indication of the $L_{Aeq,30min}$. Unoccupied reverberation time and STI were measured in each room at two receiver positions with three source positions, using balloon bursts to generate the room impulse response. WINMLS software was used to post process the impulse responses to extract the room acoustics data.

Measurements have also been made during lessons in occupied classrooms. In most cases one room was selected for each subject area and lessons during the day were monitored in that room. Throughout the day, the researcher was present during each lesson to observe the lesson activities and noise sources, to note any occurrences of high noise levels and identify the sources, and to record the numbers of pupils and adults present.

4.1.2 Questionnaire surveys

Questionnaire surveys of students and teachers are being carried out to investigate their perceptions of noise and room acoustics, and the extent to which noise and acoustics interfere with or enhance their ability to hear and understand/speak in particular rooms[2]. The questionnaire is administered online so each school can complete the questionnaire over a period of weeks or months. Once the teacher and student questionnaire surveys for a school are complete an unoccupied acoustic survey of rooms which are cited as being particularly hard or easy to hear in is carried out.

4.2 Results of acoustics and noise surveys

4.2.1 Unoccupied spaces

Room acoustics and noise level measurements have been made in 123 unoccupied rooms in 12 schools. The mean and standard deviations of indoor ambient noise level, T_{mf} and STI in various categories of rooms are shown in Table 5, together with the BB93 specifications for these spaces.

It can be seen that all spaces except cellular classrooms and music rooms comply with the BB93 IANL specifications; and all except gymnasia/sports halls comply with the RT requirements.

In order to investigate whether BB93 has resulted in overall improvements in the acoustic characteristics of schools, the average values of IANL, T_{mf} and STI in schools built before and after the introduction of BB93 have been compared where possible. Nine of the 17 open plan spaces were built after the introduction of BB93, but only six of the 59 surveyed cellular classrooms. Of the remaining spaces only one science laboratory was built post 2003.

Table 5. Unoccupied measurements in 123 school spaces

		IANL, dBA		T_{mf}, s		STI	
	n	Mean (sd)	BB93	Mean (sd)	BB93	Mean (sd)	BB93
Cellular classrooms	59	35.9 (5.0)	35	0.66 (0.22)	<0.8	0.72 (0.06)	
Open plan rooms	17	35.7 (7.1)	40	0.56 ().08)	<0.8	0.74 (0.03)	>0.6
Science labs	22	38.7 (5.8)	40	0.76 (0.32)	<0.8	0.68 (0.08)	
Design Tech rooms	7	39.8 (8.4)	40	0.81 (0.17)	<0.8	0.66 (0.04)	
Gym/sports hall	4	36.2 (4.8)	40	2.86 (1.01)	<1.5	0.5 (0.06)	
Music rooms	7	39.5 (3.6)	35	0.59 (0.14)	<1.0	0.74 (0.04)	
Art & design	4	39.1 (8.2)	40	0.79 (0.30)	<0.8	0.7 (0.07)	
Drama studios	3	30.7 (5.0)	30	0.68 (0.09)	<1.0	0.7 (0.03)	

The average values of IANL, T_{mf} and STI for cellular classrooms and open plan spaces built before and after BB93 are shown in Table 6.

Table 6. Values of acoustic parameters for cellular and open plan classrooms pre and post BB93

			IANL, dBA		T_{mf}, s		STI	
Type of room	Pre/post BB93	n	Mean	sd	Mean	sd	Mean	sd
Cellular classrooms	Pre	53	36.1	5.1	0.68	0.22	0.71	0.06
	Post	6	34.0	4.5	0.51	0.09	0.77	0.04
Open plan rooms	Pre	8	39.5	8.1	0.6	0.07	0.72	0.02
	Post	9	32.4	3.7	0.52	0.06	0.76	0.03

It can be seen that IANLs and RTs have reduced since the introduction of BB93, while there has been a corresponding increase in average values of STI. The standard deviations of all parameters have also reduced for the newer schools suggesting that there may now be more consistency in the acoustic design of school spaces.

4.2.2 Occupied spaces – lesson and activity noise levels

Continuous measurements have been made of 257 lessons in 65 rooms, including 15 open plan rooms, in 12 schools.

A histogram showing the distribution of lesson L_{Aeq} levels (that is, L_{Aeq} levels integrated over the whole lesson for all 257 lessons) is shown in Figure 1.

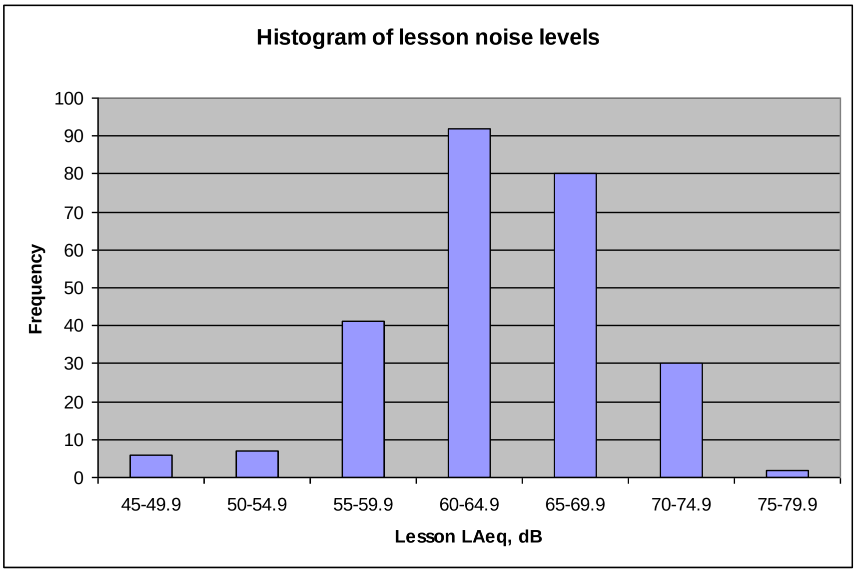


Figure 1. Histogram of lesson noise levels

It can be seen that lesson noise varies from below 50 dB L_{Aeq} to over 75 dB L_{Aeq}, with the majority of lessons having L_{Aeq} levels between 60 and 70 dBA.

Various classroom activities were noted during the lessons, the most common of which are described in Table 7.

Table 7. Most common classroom activities

	Activity	Description
1	Instruction/Discussion	Plenary – Teacher instruction, teacher led Q&A, reading out loud, class room discussion. Most often one person speaking at a time.
2	Individual Work	Pupils working individually either from information on the board or from books, in quiet study, exam. Often accompanied by low level discussion and movement and the teacher(s) moving around helping pupils.
3	Group Work	Pupils working in groups around a table. Higher level discussion and more movement, and the teacher(s) moving around helping pupils.
4	Using A/V equipment	Pupils watching video or listening to audio replay.
5	Science experiment	Practical work in a science lesson. High level of discussion and more movement.

Table 8 shows the averaged percentages of time observed being spent in each of these activities and L_{Aeq} levels for different subjects, considering all 257 lessons.

Table 8 Whole lesson and activity L_{Aeq} levels

Activity		Subject						
		Maths	English	Science	MFL	Humanities	Other	All subjects
1 Instruction/ discussion	% Time	42%	53%	42%	48%	50%	39%	45%
	L_{Aeq}, dB	63	63	64	63	63	62	63
2 Individual work	% Time	51%	29%	33%	35%	33%	60%	37%
	L_{Aeq}, dB	63	59	64	63	60	62	62
3 Group work	% Time	6%	12%	17%	6%	12%	2%	12%
	L_{Aeq}, dB	68	67	68	70	65	62	67
4 Using AV equipment	% Time		6%	5%	11%	5%		4%
	L_{Aeq}, dB		66	64	66	66		65
5 Science equipment	% Time			3%				1%
	L_{Aeq}, dB			70				70
All lessons	L_{Aeq}, dB	63	63	65	65	63	62	64

It can be seen that levels in occupied classrooms during lessons are very consistent across subjects, with the average level for a secondary school lesson being 64 dB L_{Aeq}. There is also relatively little variation in levels between activities. This is different to the situation in primary schools where a difference of 20 dBA has been found between the quietest and noisiest activities[21]. However, it is interesting to note that the average level across all activities and all subjects is 64 dBA which is close to the level of 64.7 dBA for primary school classrooms engaged in individual work at tables, the most common activity[21].

It can also be seen from Table 8 that, for all subjects, between 40% and 50% of the time during a lesson is spent in instruction/discussion, that is all the class being taught together with one person (teacher or student) speaking at any one time.

Relationships between lesson noise levels and various acoustics and class based factors have been investigated.

Considering all 257 lessons significant correlations were found between L_{Aeq} levels for whole lessons and numbers of students ($r = .218$, $p < 0.01$) and year/age group of students ($r = -.194$, $p < 0.01$). That is, noise levels increase with the number of students and decrease with age group, as would be expected. Controlling for these two factors significant positive correlations were found between T_{mf} and whole lesson L_{Aeq} ($r = .431$, $p < 0.01$); Activity 1 L_{Aeq} ($r = .386$, $p < 0.05$); and Activity 3 L_{Aeq} ($r = .485$, $p < 0.01$). There was also significant positive correlation between IANL and Activity 1 L_{Aeq} ($r = .410$, $p < 0.01$).

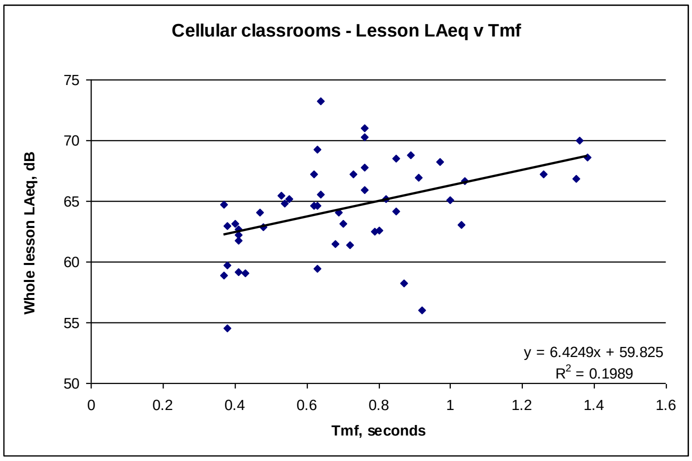
Table 9 shows significant (** at 1% level, * at 5% level) positive correlations between T_{mf} and IANL and lesson L_{Aeq}s for all rooms and for enclosed teaching spaces. No significant relationships were found for levels measured in open plan classrooms.

Table 9. Correlation coefficients between T_{mf} and IANL and lesson noise levels

			Occupied L_{Aeq}			
	n		Whole lesson	Activity 1	Activity 2	Activity 3
All rooms	65	T_{mf}	.444**	.450**	-	.527**
		IANL	.612**	.583**	.318*	.347*
All rooms controlling for room volume	65	T_{mf}	.608**	.475**	.380*	.517**
		IANL	.528**	.562**	-	.354*
Enclosed teaching spaces	50	T_{mf}	.446**	.442**	-	.525**
		IANL	.652**	.641**	.407**	.374*
Enclosed teaching spaces controlling for room volume	50	T_{mf}	.620**	.512**	.389*	.532**
		IANL	.563**	.634**	-	.369*

These results show that both reverberation time and indoor ambient noise level affect the noise levels which occur during teaching, particularly when the class is engaged in whole class teaching (instruction/discussion) or group work. It is therefore important to control both these aspects of the acoustic environment to control classroom noise in enclosed spaces. The lack of a relationship between T_{mf} or IANL and noise levels in open plan classrooms confirms that the ambient noise in an open plan space, which affects the noise level and speech intelligibility within the space, is due to activities in adjacent areas[22].

Figure 2 shows the relationship between whole lesson L_{Aeq} and T_{mf} and IANL respectively for enclosed classrooms.



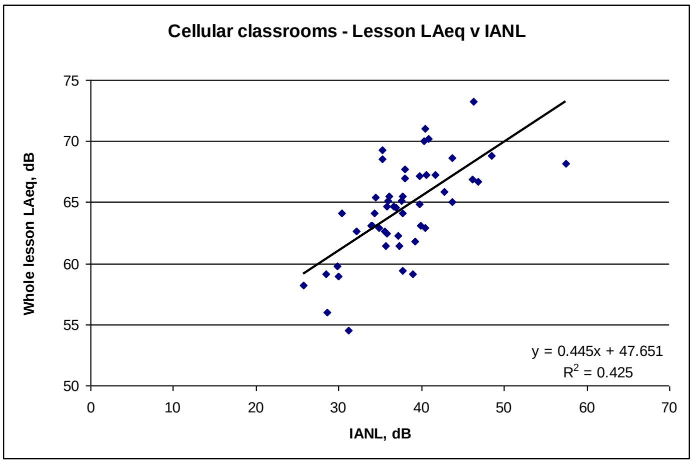


Figure 2. Lesson L_{Aeq} plotted against T_{mf} and IANL for cellular classrooms

It can be clearly seen that the higher the Tmf or the IANL, the higher will be the lesson noise, although the relationship between L_{Aeq} and IANL is stronger than that with T_{mf}. The increase of classroom noise associated with higher IANLs is similar to the relationship between speech and ambient levels found by Bradley and Gover in meeting rooms, and is due to the 'Lombard effect' whereby a speaker raises their voice in order to be heard above background noise[23].

4.3 Results of questionnaire surveys

4.3.1 Teachers

To date, responses have been received from 195 teachers in six schools. The respondents have a roughly equal distribution of teaching experience from under one year to 25 years, with 20% having taught for more than 25 years.

Teachers' health
The teachers' responses provide further evidence of the incidence of voice problems among teachers; 100 (51%) of respondents reported having experienced voice or throat problems in the previous two years, with 11 (6%) having been referred to a voice specialist. A number of respondents (17%) had taken time off work in the previous two years because of voice problems, most (13%) had been absent for less than one week but some (3.5%) had taken off between one and four weeks.

Interestingly, 16% of respondents also had hearing problems which is slightly higher than the '1 in 7' figure generally quoted for incidence of hearing loss; this may however be due to the age distribution of respondents as reflected in the relatively large number who had taught for over 25 years.

Acoustic conditions
Preliminary inspection of the teacher questionnaire responses shows that teachers are aware of the acoustics of their teaching environment and of the impact it has upon their ability to teach in a particular room.

Teachers were given a selection of reasons to choose if they reported a room as being particularly hard or easy to teach in. The most frequently cited reasons are shown in Tables 10 and 11.

Table 10. Percentages of teacher respondents giving reasons for room being hard to teach in

	Room too large	Room too 'echoey'	Students make too much noise	Too much noise outside room	Too much (ambient) noise inside room	Students not motivated
% teachers responding	29	34	26	18	13	15

Table 11. Percentages of teacher respondents giving reasons for room being easy to teach in

	Room is small	Not many students	Students quiet	No noise outside room	Students well motivated
% teachers responding	32	17	15	23	27

These responses show that teachers are aware of the contributions of reverberation, student noise both inside and outside the classroom, and ambient noise to the ease or difficulty of teaching in a particular room. The behaviour (motivation, noise) of the students is obviously also a critical factor affecting teaching conditions.

4.3.2 Students

Ease/difficulty of hearing in different spaces

Students were asked to rank several areas in the schools for ease/difficulty of hearing. In all four schools the dining room/canteen was rated as the most difficult space, while ICT rooms were cited as the easiest rooms in two schools and art rooms in the other two schools.

Each student was asked to name the classrooms in which they found it hardest or easiest to hear the teacher, and to select reasons for the ease or difficulty of hearing. Most students (2046 out of 2355) specified both 'hard' and 'easy' rooms. Table 13 shows the percentages (of those who answered the question) of students citing each reason for finding a room hard to hear in in each school, and overall..

Table 13. Percentages of students giving reasons for room being hard to hear in

Answer option	School 1 n = 712	School 2 n = 675	School 3 n = 406	School 4 n = 253	Overall n = 2046
Teacher too far away	18.3	21.2	23.9	18.6	20.4
Room echoey	22.6	18.5	21.4	23.7	21.2
Teacher not loud/clear enough	24.4	28.3	23.9	32.0	26.5
Students make too much noise talking	43.0	42.7	41.4	39.1	42.1
Too much noise from outside the classroom	13.3	11.7	15.0	42.3	16.7
Too much (equipment) noise inside the classroom	17.7	13.6	26.4	12.3	17.4
Teacher cannot get class to be quiet	24.4	29.6	25.4	20.9	25.9
Sound is too muffled	9.6	10.5	14.0	7.9	10.6

Table 13 shows that, in general, the most common reasons for difficulty in hearing the teacher are related to classroom noise, that is students talking and teacher unable to quieten the class. In general between 20% and 25% of students also cite the room being 'echoey' and the teacher not speaking loudly and clearly which suggests that reverberation is these spaces is reducing speech intelligibility. It can also be seen that, in School 4, the major cause of difficulty is 'Too much noise from outside the classroom'. This school has many open plan spaces which explains the high number of students giving this reason.

Table 14 shows the percentages (of those who answered the question) of students citing each reason for finding a room easy to hear in in each school and overall..

Table 14. Percentages of students giving reasons for room being easy to hear in

Answer option	School 1 n = 703	School 2 n = 572	School 3 n = 402	School 4 n = 250	Overall n = 1927
Teacher speaks loudly and clearly	54.8	62.4	68.9	61.2	60.9
Classroom is small	24.9	22.0	23.1	37.2	25.1
Not many students	13.8	18.0	10.4	12.8	14.4
Students very quiet	27.5	27.7	39.8	26.4	29.8
Teacher good at quietening class	37.1	38.7	47.0	43.6	40.4
No noise from outside the classroom	18.3	19.3	26.9	37.2	22.7

Table 14 shows that the most common reason given for finding it easy to hear the teacher is the teacher speaking loudly and clearly, followed by the teacher being good at quietening the class. It is interesting to note that over one third of students in School 4 cite ‘classroom being small’ and ‘no noise from outside the classroom’ as reasons, given that this school has many large open plan spaces. This suggests that the students find the smaller enclosed classrooms easier to hear in than the large open plan spaces.

4.4 Comparison of noise and questionnaire data

The questionnaire survey has been completed in three schools for which acoustic data for many of the rooms cited are also available. The numbers of rooms in the three schools for which both questionnaire and acoustic data are available are: School 1, 32; School 2, 26; School 3, 16.

The numbers of students citing each room as ‘easy’ or ‘hard’ to hear in have been compared with room acoustic data in each school. It is necessary to perform this analysis on a school by school basis as the students are asked to give the room in their school which is ‘easiest’ or ‘hardest’ to hear in, so it is not possible to compare across schools.

The only significant correlations between IANL or T_{mf} and hard and easy scores are between T_{mf} and ‘Hard’ scores for School 1 ($r = .374$, $p<0.05$) and School 2 ($r = .723$, $p<0.01$) indicating that as the reverberation time increases the room becomes more difficult to hear in, as would be expected. However, it should be noted that the results are heavily weighted by three sports halls of large volume (1427 m^3 to 8951 m^3) and excessively long reverberation times (2.3 s to 4.2 s).

Further analysis of noise and questionnaire data has been carried out by designating each room cited in each school as ‘harder’ or ‘easier’ depending on whether the hard or easy score is higher. Considering all schools together, the average volumes, reverberation times and IANLs of ‘harder’ and ‘easier’ spaces are shown in Table 15, for all rooms and for different categories of rooms.

Table 15. IANL and Tmf of spaces scored as harder and easier to hear in

	Easier				Harder				BB93	
	n	Vol	IANL	T_{mf}	n	Vol	IANL	T_{mf}	IANL	T_{mf}
All spaces	33	276.6	35.8	0.69	38	678.4	36.3	0.97		
Open plan spaces	0	-	-	-	2	276.6	35.8	0.69	40	<0.8
Gym/sports halls	0	-	-	-	4	4594.5	36.2	2.86	40	<1.5
Music rooms	0	-	-	-	6	214.7	39.6	0.57	35	<1.0
Science labs	4	227.5	34.3	0.89	6	221.6	35.5	0.87	40	<0.8
ICT/DT/Art	4	276.2	41.7	0.66	3	483.3	38.7	0.78	40	<0.8
Drama studio	2	385.1	28.2	0.61	1	218	35.8	0.81	30	<1.0

Although the numbers of individual room types are low, certain observations can be made. For all except science laboratories the ‘harder’ rooms have longer reverberation times than the ‘easier’ rooms although for most room types the reverberation times are within the limits set by BB93. Given the volumes and long reverberation times of the gymnasia/sports halls it is not surprising that they are rated as hard to hear in, although one of them has a reverberation time equal to the BB93 specification. It is interesting to note that music rooms in all three schools are cited as hard to hear in, even though they all have relatively short reverberation times (0.4 s to 0.7 s). Obviously classroom management and teacher factors are important and are not represented here.

Questionnaire data collection, plus further analyses of acoustic and questionnaire data is ongoing. When more data is available it may be possible to reach more definitive conclusions concerning the interrelationships of acoustic and other factors which affect listening conditions in teaching environments.

5 CONCLUSIONS

People have been concerned about acoustic conditions in classrooms and the effects of noise on students and teachers for over 100 years. Furthermore, recommendations on the acoustic design of schools, very similar to today's guidance, have been published for the past 80 years. A current research project aims to provide evidence on the acoustic quality of secondary schools and its impact on students and teachers. Interim results from questionnaire and acoustic surveys emphasise the importance of controlling both ambient noise and reverberation in teaching spaces to reduce noise levels and improve speech intelligibility, thereby optimising teaching and learning conditions. It is therefore to be hoped that the Coalition Government will maintain the current Building Regulations and guidance on the acoustic design of schools which have been shown to be effective in improving acoustic conditions in classrooms over the past decade.

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