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A survey of acoustic conditions and noise levels in secondary school classrooms in England

Bridget Shield[a)] and Robert Conetta
Acoustics Group, Department of Urban Engineering, London South Bank University, London SE1 0AA, United Kingdom

Julie Dockrell and Daniel Connolly
Department of Psychology and Human Development, Institute of Education, London WC1H 0AA, United Kingdom

Trevor Cox and Charles Mydlarz
Acoustics Research Centre, University of Salford, Salford M5 4WT, United Kingdom

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An acoustic survey of secondary schools in England has been undertaken. Room acoustic parameters and background noise levels were measured in 185 unoccupied spaces in 13 schools to provide information on the typical acoustic environment of secondary schools. The unoccupied acoustic and noise data were correlated with various physical characteristics of the spaces. Room height and the amount of glazing were related to the unoccupied reverberation time and therefore need to be controlled to reduce reverberation to suitable levels for teaching and learning. Further analysis of the unoccupied data showed that the introduction of legislation relating to school acoustics in England and Wales in 2003 approximately doubled the number of school spaces complying with current standards. Noise levels were also measured during 274 lessons to examine typical levels generated during teaching activities in secondary schools and to investigate the influence of acoustic design on working noise levels in the classroom. Comparison of unoccupied and occupied data showed that unoccupied acoustic conditions affect the noise levels occurring during lessons. They were also related to the time spent in disruption to the lessons (e.g., students talking or shouting) and so may also have an impact upon student behavior in the classroom.
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I. INTRODUCTION

Difficulties caused by noise and poor acoustics in educational environments have been recognized and understood for over 100 yr.[1] In the past 15 yr, several countries have introduced acoustic design guidelines for schools to prevent potential problems.[2–7] However, many schools continue to provide an acoustic environment that is not ideal for teaching and learning with background noise levels and/or reverberation times exceeding recommended values.[8–10] This paper describes a study of the acoustic characteristics of secondary schools in the UK to provide information on the acoustic environment typical of today's schools and to examine factors which affect acoustic conditions in schools. The study includes noise and acoustic surveys of unoccupied and occupied spaces in secondary school buildings.

II. BACKGROUND

In the past 40 yr, there has been a significant body of research investigating the specific effects of noise and poor acoustics on pupils and teachers. The research has shown that a poor acoustic environment has a negative influence upon teaching, learning, and teachers' health.[11–15] However, most of this research has focused on primary/elementary schools. Far less is known about the acoustic quality of secondary/high schools and the impact of noise and poor acoustics upon children of secondary school age. The evidence from primary schools is that the effect of noise on pupils' behavior and attainment is complex, depending not only on classroom conditions and individual factors concerning the child but also on the task being undertaken and the corresponding cognitive demands.[16] It has also been found that noise has more of an impact upon the academic performance of older children in the primary school age range, although the reasons for this are not fully understood.[17] Demands on pupils' cognitive abilities and behaviors increase significantly in secondary schools. Pupils are taught by subject specialists, move classrooms, have less opportunity for individual support, and are exposed to different pedagogic approaches. It is therefore likely, considering the evidence from primary schools and a smaller body of research on older children,[18–22] that secondary school children will also be disadvantaged by poor acoustic environments.

Previous surveys of acoustic conditions in schools have also been undertaken mainly in primary schools.[8,10,15,23] Noise surveys of primary school classrooms have found that background noise levels in unoccupied classrooms typically average around 40–48 dBA (Ref. 13); a recent study of 67 elementary school classrooms in the U.S. (Ref. 10) found that unoccupied levels ranged from 33 to 54 dB L_{Aeq}. A

[a)]Author to whom correspondence should be addressed. Electronic mail: shieldbm@lsbu.ac.uk

survey of noise in Italian secondary schools found much lower background noise levels (measured with the students present but quiet) of 33–44 dBA L_{Aeq},[9] while university classrooms have been found to have background levels of 35 dBA.[24] There are less published data on occupied levels during lesson activities, particularly in secondary schools. Levels in occupied primary school classrooms in the UK typically average 56 dBA when the pupils are engaged in quiet activities, rising to 77 dBA for the noisiest activities with the most common teaching activity giving rise to a level of 65 dBA.[8,25–27] Bradley's 1986 study of speech intelligibility in classrooms for 12–13 yr old pupils measured background noise levels in occupied rooms of 38–45 dBA.[28] The limited amount of lesson activity noise reported in secondary schools has a wide range: In 1999, Hodgson *et al.*[29] found levels of student noise from 40 to 70 dBA quoted in the literature; a study of mathematics classes of 13–15 yr old pupils in two schools in Sweden measured noise levels of 58–69 dB L_{Aeq} (Ref. 30) while a study of two high schools in Turkey[31] found that levels varied between 60 and 63 dB L_{Aeq} in occupied classrooms. In a recent examination of the effects of acoustic treatments in a secondary school in Essex, England,[19] classroom L_{Aeq} levels during mathematics lessons were found to increase from around 60 dBA in a room with a reverberation time of 0.3 s to over 70 dBA with a reverberation time of 1.3 s, while L_{A90} levels increased more dramatically, from approximately 41 to 64 dBA.

In the past 10 yr, the UK has seen an extensive school building program with many new secondary schools being designed and built around the country. Many of these new buildings feature complex learning areas with large fully open plan spaces often designed to accommodate simultaneous teaching of several pupil groups. These open spaces are of large volume, typically from 500 to 1300 m^3. Some older schools, dating from the 1990s, have semi-open plan classrooms, that is, single rooms without doors leading off a common space, with volumes of around 200 m^3.[32,33]

This paper presents results of a study that has recently been undertaken to provide information on acoustic conditions and pupils' and teachers' attitudes toward their acoustic environment in secondary schools of different ages in England. The study has comprised questionnaire surveys of students and teachers,[34] cognitive testing of students in different levels of noise, noise and acoustic surveys of many spaces typical of secondary schools, plus monitoring of environmental conditions in classrooms.[35] This paper presents the results of noise and acoustic surveys of unoccupied and occupied spaces in 13 secondary schools.

These data have enabled a comprehensive picture of the typical acoustic environment in English secondary schools to be established. Factors affecting both unoccupied and occupied noise levels have been examined. In addition it has been possible to assess the impact of the introduction in 2003 of legislation on the acoustic design of schools. The influences of room acoustic design and ambient noise on occupied noise levels have also been investigated.

III. CURRENT ACOUSTICS STANDARDS FOR SCHOOLS

Concerns about acoustic conditions in schools have led to many countries introducing standards or guidance on the acoustic design of schools.[2–7] The most comprehensive of these are those introduced in the U.S. in 2002 (revised in 2010) (Ref. 2) and in England and Wales in 2003 (currently under revision).[3] Both documents give performance standards for unoccupied noise levels, reverberation times, and sound insulation for a range of spaces in schools.

New schools in England and Wales are required to comply with the Building Regulations in terms of their acoustic design. The required performance standards are contained in Building Bulletin 93 (BB93), published in 2003,[3] which lists unoccupied noise levels and mid-frequency reverberation times, plus sound insulation specifications for a wide range of spaces in schools. Unoccupied noise levels are specified in terms of the "indoor ambient noise level" (IANL), which is the highest $L_{Aeq,30min}$ likely to occur during teaching hours. The IANL may include noise from ventilation systems and external sources, if present, but excludes noise from teaching activities elsewhere in the school premises and equipment used in the space, such as computers or projectors. Reverberation times are specified in terms of the "mid-frequency reverberation time" (T_{mf}), which is the average of reverberation times at 500, 1000, and 2000 Hz. Examples of specifications of IANL and T_{mf}, which are relevant to the data presented here are shown in Table I. In addition, everywhere in an open plan teaching space must achieve a speech transmission index (STI) of at least 0.6 when in use. The Building Regulations and BB93 are currently under revision, although it is likely that most of the specifications for ambient noise and reverberation times will be unchanged.

IV. METHODOLOGY

Noise and acoustic surveys were conducted in 13 schools in England. Unoccupied noise levels and room acoustic parameters (e.g., reverberation times and speech transmission index) were measured in 185 spaces of various types. Continuous noise monitoring was conducted during 274 lessons in core subjects in 80 rooms. In addition, external noise levels were recorded at 11 of the schools.

TABLE I. Relevant Building Bulletin 93 (Ref. 3) performance specifications.

	Enclosed classrooms	Design/technology workshops	Gymnasia	Music rooms	Sports halls	Science rooms	Art rooms	Open plan spaces
IANL	≤35 dBA	≤40 dBA	≤40 dBA	≤35 dBA	≤40 dBA	≤40 dBA	≤40 dBA	≤40 dBA
T_{mf}	<0.8 s	<0.8 s	<1.5 s	<1.0 s	<1.5 s	<0.8 s	<0.8 s	<0.8 s

TABLE II. Details of schools surveyed.

School	Gender	Age range (yr)	No. of pupils	Dates of buildings	Location	External noise level (L_{Aeq},dB) Mean (sd)	Unoccupied measurements No. spaces	Occupied measurements No. rooms	Occupied measurements No. lessons
1	Mixed	11–16	531	1970s–1990s	Suburban	–	7	3	15
2	Mixed	11–16	1178	1950s–2000s	Suburban	52.5 (0.1)	26	3	15
3	Mixed	11–18	1097	1960s–1990s	Suburban	51.6 (4.5)	5	3	13
4	Female (mixed 6th form)	11–18	1040	1940s–2009	Suburban	50.5 (2.7)	6	4	14
5	Mixed	11–18	723	1960s	Rural	–	9	7	23
6	Female (mixed 6th form)	11–18	1141	1950s–2000s	Suburban	52.8 (4.1)	14	11	43
7	Mixed	11–16	725	1960s	Inner city	58.8 (0.9)	12	3	13
8	Mixed	11–16	1633	1950s–1990s	Suburban	49.1 (4.0)	33	5	24
9	Mixed	11–16	1166	1960s–1990s	Suburban	51.1 (1.3)	26	9	41
10	Mixed	11–18	1411	2009	Rural	52.0 (1.6)	15	3	13
11	Mixed	11–18	1417	1960s	Suburban	53.5 (2.7)	13	10	33
12	Mixed	11–12[a]	700	2008	Suburban	49.2 (3.8)	4	4	12
13	Mixed	11–16	1320	2000s	Outer city	51.7 (1.6)	15	15	15

[a]The building surveyed was for 11–12 year old pupils only although the whole school catered for pupils from 11 to 16 years of age.

A. Selection of schools

The schools were selected to be representative of current state-funded secondary schools in England. The aim was to select schools with buildings of different ages with different types of teaching space (including both enclosed and open plan spaces) and in a range of locations (rural, suburban and urban) and external noise environments. In total 28 schools located in different areas of the country were approached, evenly distributed in terms of building age and location, and invited to participate fully or partially in the project. Of these, 13 schools agreed to detailed noise and acoustic surveys of their buildings and to noise levels being measured during lessons. Although the characteristics of these 13 schools were not evenly distributed, it was decided to include them all in the surveys to ensure a sufficiently large sample of occupied and unoccupied measurements. Of the 13 schools, 1 was in an inner London borough, 1 was in outer London, 2 were in rural locations and the others were situated on large sites in suburban locations.

Table II shows the details of the schools surveyed including the numbers of teaching spaces and lessons measured. All except two schools were co-educational. The dates shown are those of the buildings measured. Where a range of dates is given this indicates that the school buildings of interest have been refurbished or built subsequent to the original buildings. Table III shows the total numbers of rooms of different types that were measured, grouped in categories corresponding to those in BB93.[3] The rooms represent the full range of sizes found in today's schools, from relatively small classrooms to very large sports halls: Volumes ranged from 116 to more than 11 000 m^3; floor areas from 44 to almost 1000 m^2; room heights from around 2 to over 17 m; and the percentages of room surfaces that were glazed from zero in several sports halls to 24% in a textile workshop. The means and standard deviations of the physical characteristics of the different types of space (volume, height, floor area, percentage of glazing) are also shown in Table III. Open plan spaces are divided into fully and semi-open plan, although the current legislation refers only to open plan teaching and resource spaces. In addition to the 174 spaces listed, 11 other rooms were measured in the 13 schools included dance and drama studios, drama, assembly and dining halls, and a lecture theater. Almost half the spaces measured were enclosed classrooms with between 2 and 17 being measured in each school. For the other types of space,

TABLE III. Numbers of unoccupied spaces of different types measured with average physical data of each type.

		Enclosed classroom	Design/tech workshop	Gym	Music room	Sports hall	Science room	Art	Open plan spaces Semi	Open plan spaces Full	Open plan spaces All
No. measured		**86**	**13**	**4**	**10**	**5**	**33**	**7**	**8**	**8**	**16**
Volume (m^3)	Mean	161	244	1454	208	8035	233	262	186	729	458
	sd	39	61	146	62	1891	60	122	48	298	345
Height (m)	Mean	2.9	2.9	5.6	3.1	12.6	2.9	3.1	2.7	2.6	2.6
	sd	0.4	0.4	0.6	0.8	2.7	0.5	0.8	0.01	0.4	0.3
Floor area (m^2)	Mean	56	84	259	67	6510	7.9	81	69	285	177
	sd	11	18	24	10	163	12	18	18	112	134
Percentage glazing	Mean	5.7	7.5	6.7	5	[a]	4.7	4.7	5	5.2	5.1
	sd	2.9	6.0	3.0	2.6		2.1	1.3	3.2	2.3	2.8

[a]Only one sports hall had glazing.

between one and six of each type were measured in each location.

The majority of suburban schools measured were on large sites surrounded by open spaces or playing fields at a distance from the nearest road. Although a detailed survey of external noise levels around schools was not carried out, to give an indication of the typical external noise environment of the schools, short sample measurements were made at between three and seven locations at varying distances from the site perimeter and school buildings. The L_{Aeq} of the external noise was recorded, using a Norsonics 140 sound analyzer, for a short period, typically 3–5 min (depending on the stability of the sound) during the school day. Periods when the noise level was enhanced due to events, such as recreation periods, sports lessons on playing fields, or pupils arriving at and leaving the school, were avoided. Table III includes the arithmetically averaged external levels measured at each site. It can be seen that for the majority of schools the averaged external levels ranged from 49 to 53 dBA; however, the inner city school has a higher external level of 59 dBA.

B. Measurement of unoccupied noise levels and room acoustics

Noise levels and room acoustic parameters were measured in unoccupied spaces in the schools. The rooms were furnished, and the measurements were made during the school day when other areas of the school were occupied. The rooms were measured as far as possible in the environmental state in which they would be used in typical mid-season weather conditions, that is, without ventilation and with windows closed. The survey data are therefore not directly comparable with BB93 specifications,[3] which apply to unoccupied and unfurnished rooms, but can be used as an approximation to give an indication as to whether or not the standards are complied with.

The unoccupied ambient noise level was measured in each room using a Norsonics N140 sound analyzer with the microphone at a standing head height (1.55 m). The measurement period used was in general between 3 and 5 min, depending on the stability of the noise level; as the noise was constant, it was judged that this relatively short measurement period was sufficient to give an approximation of the 30 min level. The indoor ambient noise level (IANL) specified in BB93 is defined as the highest $L_{Aeq,30min}$ likely to occur during normal teaching hours, in finished but unoccupied and unfurnished spaces. The L_{Aeq} levels measured here are referred to as the unoccupied ambient noise levels (UANL) and have been used as an approximation to the IANL.

Room acoustic parameters and STI were calculated from impulse responses generated by balloon bursts, which were captured using a Norsonics N140 sound analyzer. The impulse responses were subsequently analyzed using WinMLS 2004 acoustic measurement software, which calculates room acoustics and speech parameters according to the relevant international standards.[36,37] As the spaces were unoccupied, the STI was calculated without the contribution

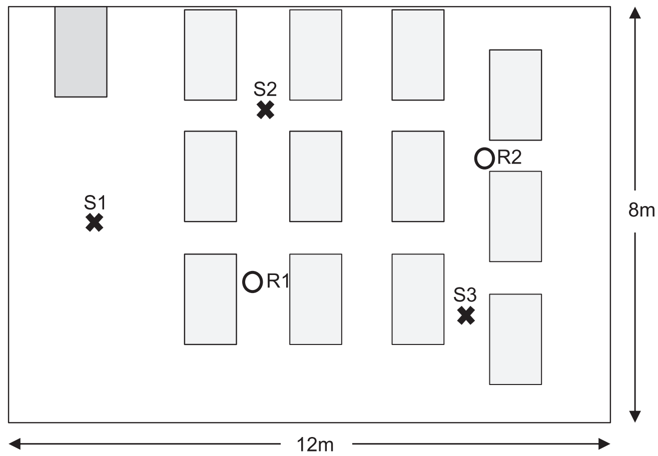

FIG. 1. Diagram of a typical unoccupied classroom measurement configuration (×, source position; o, receiver/microphone position).

of the signal-to-noise ratio; STI is hence likely to be lower in occupied conditions when classroom noise would be present. The following room acoustics parameters were calculated using the ISO preferred frequency range of 63 Hz to 16 kHz: Reverberation time (T20), early decay time (EDT) and clarity index (C50). Only broadband values are presented in the results section. The mid-frequency reverberation time, T_{mf}, was also calculated. Although there are no standards or recommendations for preferred values of EDT and C50 in classrooms, the importance of strong early reflections in teaching spaces is recognized,[3,23,38] and a study of open plan primary school classrooms in the UK recommended a maximum value of 0.35 s for mid-frequency EDT[33,39] and minimum value for C50 of 10 dB[39] to ensure compliance of open plan spaces with the speech intelligibility requirements of BB93.[3]

Measurements were made at either three or six source/receiver combinations with all source and receiver positions at a standing head height of 1.55 m. The calculated values were averaged arithmetically to provide a single figure for each parameter in each room.

Figures 1 and 2 illustrate the measurement set up in typical enclosed classrooms.

FIG. 2. (Color online) Photograph of microphone set up in an unoccupied mathematics classroom.

TABLE IV. Occupied noise surveys: Numbers and types of core lessons and rooms measured.

			Numbers of lessons (and rooms) for each subject				
School	No. of lessons	No. of rooms	Maths	English	Science	MFL	Humanities
1	15	3	5	5	5		
2	15	3	5	5	5		
3	13	3	4	3	5		1
4	14	4	4	5	5 (2 rooms)		
5	23	7	0	5	8 (4 rooms)	5	5
6	43	11	16 (4 rooms)	10 (3 rooms)	11 (3 rooms)		6
7	13	3	4	4	5		
8	24	5	5	5	9 (2 rooms)	5	
9	41	9	8 (2 rooms)	10 (2 rooms)	9 (2 rooms)	5	9 (2 rooms)
10	13	3	4	5	3		1
11	33	10	9 (3 rooms)	10 (3 rooms)	14 (4 rooms)		
12	12	4	2		4	4 (2 rooms)	2
13	15	15	5 (5 rooms)	5(5 rooms)	5 (5 rooms)		
Total	**274**	**80**	**71**	**72**	**88**	**19**	**24**

C. Measurement of occupied noise levels

In measuring noise levels during lessons, it was decided to focus on the core subjects of mathematics, English, modern foreign languages (MFL), humanities (that is, history and geography), and science. Measurements were undertaken during 283 lessons in total of which 274 were in these core subjects. The lessons were in a selection of rooms in each school, all of which had been surveyed in their unoccupied condition. The numbers of core lessons and corresponding rooms measured in each school are shown in Table IV. Between one and six lessons were measured in each room using a Norsonics N140 sound analyzer. For each lesson, the noise was monitored for the whole duration of the lesson. 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. The measurements were made at a position in the room chosen so as to minimize disruption to teaching (usually at the back or to one side of the room), while ensuring that the location was not within the direct sound field of the teacher and was over 1 m from the nearest reflecting room surface. In calculating the overall lesson noise levels, periods of activity unrelated to the lesson itself, such as pupils entering or leaving the classroom, or other disturbances (see Sec. V B 5), have been eliminated from the analysis so that the resulting noise levels are those generated solely by the teaching activities within each lesson. Secondary school lessons are typically 45 min to 1 h in length for all the core subjects. The average time of lesson measurement, once non-teaching related activities were excluded, was 43 min (with standard deviation 9 min). The measured lesson noise levels, overall and for each activity, were averaged arithmetically to provide a single figure for each subject and room.

Classroom observations during the monitoring of lesson noise levels showed that the teaching activities fell broadly into four categories as shown in Table V.

It has been suggested that an approximation to the speech to noise ratio is given by the difference between L_{Aeq} and L_{A90} levels measured during lessons.[19] In the current study, the speech to noise ratio is approximated by the difference between occupied L_{Aeq} and L_{A90} levels measured during activity 1, when only one person is speaking.

V. RESULTS

As many of the data sets are non-normal, non-parametric statistics have been used in the analysis, and the correlation coefficients reported in this section are Spearman rank correlation coefficients. The regression equations quoted are those of the best fit least squares regression lines.

A. Unoccupied conditions

Tables VI and VII show the arithmetic means and standard deviations of the unoccupied ambient noise (L_{Aeq}) levels

TABLE V. Activities observed during lessons.

Activity	Name	Description
1	Plenary	Teacher instruction to whole class; teacher led question and answer session; reading out loud; classroom discussion. Usually one person (pupil or teacher) speaking at a time.
2	Individual work	Pupils working individually either from information on the board or from books; pupils engaged in quiet study; doing a test. 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. Greater level of discussion; more movement; teacher(s) moving around helping pupils.
4	Watching/listening	Pupils watching video or listening to audio replay.

TABLE VI. Unoccupied average ambient noise levels (UANL) L_{Aeq}, dB (values where specifications are exceeded are in bold italic).

	Enclosed classrooms		Design/tech workshops		Gymnasia		Music rooms		Sports halls		Science rooms		Art rooms		Open plan spaces	
BB93 IANL	≤35		≤40		≤40		≤35		≤40		≤40		≤40		≤40	
School	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
1	32.7	5.7	37.5	–	34.6	–	–	–	–	–	39.2	–	–	–	–	–
2	34.4	4.9	39.6	6.2	***43.5***	–	***36.4***	0.4	36.8	–	38.2	4.7	36.2	6.2	38.5	–
3	***36.7***	1.0	***41.7***	–	–	–	–	–	***42.7***	–	39.7	–	–	–	–	–
4	29.0	0.6	30.3	–	–	–	–	–	27.1	–	***43.4***	3.5	–	–	–	–
5	34.4	0.4	–	–	–	–	32.7	–	–	–	37.2	–	–	–	***43.4***	6.8
6	32.8	3.0	–	–	–	–	–	–	–	–	34.9	1.3	–	–	31.2	4.6
7	***41.6***	4.8	***45.5***	–	40.4	–	33.1	–	–	–	***40.8***	–	–	–	–	–
8	34.7	5.6	40.2	8.8	–	–	***39.0***	3.0	31.1	–	39.4	1.0	36.7	11.0	–	–
9	***35.6***	4.4	32.3	8.1	35.6	–	***42.4***	4	–	–	36.7	4.2	39.6	–	–	–
10	30.5	5.4	–	–	–	–	–	–	–	–	29.5	6.5	30.8	–	–	–
11	34.7	6.2	–	–	–	–	28.2	–	***42.8***	–	***41.3***	9.9	–	–	–	–
12	34.1	3.7	–	–	–	–	–	–	–	–	–	–	–	–	36.7	0.7
13	26.8	1.6	–	–	–	–	–	–	–	–	31.7	1.7	–	–	–	–
Overall	33.6	5.8	38.4	7.7	38.5	3.6	36.8	4.9	36.1	6.2	36.2	6.8	36.0	7.5	35.4	7.1

and mid-frequency reverberation times for each room category in each school. The BB93 specifications are also included, and values that exceed the specifications are shown in bold italic font in the tables. Table VIII shows the means and standard deviations over all schools of other noise and room acoustic parameters measured.

It can be seen from Table VI that there is a wide range of average unoccupied noise levels. The mean UANL over all spaces measured is 35 dB L_{Aeq} with a standard deviation of 6.4 dBA. Considering all rooms measured, the school with the highest unoccupied ambient noise levels is school 7, which is the inner city school with the highest external noise level, as can be seen in Table II. It can also be seen that there is a large variation in ambient noise level within schools. This is likely to be due to noise from other areas in the school or to external noise from construction or environmental sources affecting particular facades of some schools. In the majority of schools, average levels are within the legal requirements. Compliance of noise levels with standards is discussed further in Sec. V A 2.

Table VII shows that, on average, in most schools, the current criteria for reverberation times in enclosed classrooms, workshops, music rooms, art rooms, and science rooms are met. However, in all except one school, T_{mf} in gymnasia and sports halls exceed the performance specifications with excessively long reverberation times of up to 6.5 s in sports halls. Compliance of reverberation times with the required performance specifications are discussed further in Sec. V A 2.

Tables VI and VII show that unoccupied noise levels and reverberation times in open plan spaces generally conform to current required standards. In particular it can be seen that average unoccupied reverberation times are well below the standard requirement of 0.8 s, resulting in a relatively high average STI of 0.74 (only just below a rating of "excellent" speech intelligibility), as seen in Table VIII.

TABLE VII. Unoccupied average mid-frequency reverberation time (T_{mf}), seconds (values where specifications are exceeded are in bold italic).

	Enclosed classrooms		Design/tech Workshops		Gymnasia		Music rooms		Sports halls		Science rooms		Art rooms		Open plan spaces	
BB93 T_{mf}	<0.8 s		<0.8 s		<1.5 s		<1.0 s		<1.5 s		<0.8 s		<0.8 s		<0.8 s	
School	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
1	0.50	0.15	0.50	–	1.41	–	–	–	–	–	0.41	–	–	–	–	–
2	0.51	0.14	***0.83***	0.21	***2.43***	–	0.56	0.01	***4.44***	–	0.75	0.44	0.48	0.16	0.66	–
3	0.70	0.02	0.30	–	–	–	–	–	***6.54***	–	0.54	–	–	–	–	–
4	0.40	0.03	0.48	–	–	–	–	–	***3.11***	–	***1.03***	0.00	–	–	–	–
5	0.44	0.04	–	–	–	–	0.43	–	–	–	0.41	–	–	–	0.58	0.12
6	***0.86***	0.05	–	–	–	–	–	–	–	–	0.64	0.01	–	–	0.49	0.05
7	***0.80***	0.11	***0.96***	–	1.84	–	0.42	–	–	–	0.76	–	–	–	–	–
8	0.65	0.25	0.79	0.17	–	–	0.67	0.01	***3.43***	–	***1.09***	0.25	0.57	0.19	–	–
9	0.73	0.10	0.72	0.19	1.52	–	0.39	0.02	–	–	***1.00***	0.27	***1.23***	–	–	–
10	0.68	0.05	–	–	–	–	–	–	–	–	0.72	0.15	0.60	–	–	–
11	***0.80***	0.30	–	–	–	–	0.36	–	***2.51***	–	0.57	0.24	–	–	–	–
12	0.50	0.03	–	–	–	–	–	–	–	–	–	–	–	–	0.51	0.02
13	0.50	0.08	–	–	–	–	–	–	–	–	0.59	0.03	–	–	–	–
Overall	**0.64**	**0.20**	**0.72**	**0.23**	**1.8**	**0.4**	**0.51**	**0.12**	**4.01**	**1.41**	**0.75**	**0.29**	**0.63**	**0.29**	**0.53**	**0.09**

TABLE VIII. Means and standard deviations of unoccupied measurements of L_{A90} and broadband T20, EDT, C50, and STI.

Parameter	Enclosed classrooms		Design/tech workshops		Gymnasia		Music rooms		Sports halls		Science rooms		Art rooms		Open plan spaces	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
L_{A90}, dB	30.5	6.1	36.1	7.9	36.3	3.7	35.9	5.1	33.0	7.1	33.1	7.5	30.6	6.7	33.9	6.9
T20, s	0.65	0.17	0.69	0.17	1.54	0.31	0.56	0.13	3.10	0.96	0.70	0.21	0.62	0.22	0.55	0.07
EDT, s	0.61	0.17	0.67	0.17	1.42	0.30	0.52	0.12	2.74	0.91	0.67	0.23	0.58	0.21	0.49	0.06
STI	0.71	0.05	0.69	0.05	0.57	0.03	0.75	0.04	0.51	0.05	0.69	0.07	0.72	0.06	0.74	0.03
C50	4.77	2.04	3.91	2.29	−0.01	1.69	5.95	1.80	−2.5	1.75	3.94	2.63	4.84	2.66	6.22	1.70

However, problems of speech intelligibility in open plan classrooms have been extensively documented.[32] Despite low reverberation times in such spaces, speech intelligibility during lessons is often compromised by intrusive noise from adjacent spaces.[33]

Table VIII shows that background noise levels, as indicated by L_{A90}, are between 30 and 35 dBA with enclosed classrooms having the lowest average level of 30.5 dB L_{A90}. The values of STI and C50 are consistent with the reverberation time and noise measurements and confirm that, in general, gymnasia and sports halls do not have good conditions for speaking and listening.

1. Factors affecting unoccupied acoustic conditions

Several factors relating to the geometry and design of the rooms and room finishes have been investigated to determine whether they affect the acoustic properties of the spaces measured. The data have also been used to study the impact of the legislation introduced in England and Wales in 2003 concerning the acoustic design of schools.[3]

a. Room geometry and design. The influence of the following factors has been investigated: Room volume, floor area, room height, and percentage of the wall area that is glazed.

Considering all 185 rooms together, as would be expected, mid frequency reverberation time, T_{mf}, was significantly related to room volume ($r = 0.215$, $p < 0.01$) and room height ($r = 0.441$, $p < 0.01$). Room height was also the factor most closely related to EDT ($r = 0.397$, $p < 0.01$), STI ($r = -0.440$, $p < 0.01$), and C50 ($r = -0.382$, $p < 0.01$). Thus as expected, reverberation time increases with increased room volume and height, leading to a decrease in speech intelligibility and clarity. For enclosed classrooms, height was related to T_{mf} ($r = 0.355$, $p < 0.01$) and STI ($r = -0.421, < 0.01$), but there was no significant relationship between volume and T_{mf}. It is therefore important that the height of a space is controlled to improve conditions for teaching and learning.

The linear regression equation relating T_{mf} and room height for all rooms is $y = 0.278x + 0.142$, which suggests that for reverberation to not exceed 0.8 s, the room height should not exceed 2.4 m. However, if sufficient absorption is installed, it may be possible to achieve an acceptable reverberation time with greater ceiling heights. Considering spaces with acoustic absorption ($n = 56$) and those without any additional absorption ($n = 129$) separately, T_{mf} was significantly correlated with height for both groups. However, the regression equations for both cases show that, whereas for those rooms without absorption a ceiling height of 2.3 m or lower is required to maintain T_{mf} to less than 0.8 s, for the spaces fitted with absorptive materials, a height of 4.3 m corresponds to a T_{mf} of 0.8 s. Further discussion of the effects of acoustic absorption occurs in Sec. V A 1 b.

There was also a statistically significant relationship between UANL and T_{mf} ($r = 0.366$, $p < 0.01$) considering all rooms, probably reflecting the fact that increased attention to acoustic design is likely to result in both lower indoor ambient noise levels and shorter reverberation times.

For open plan classrooms, there was a strong positive relationship between the percentage of glazing and T_{mf} ($r = 0.624$, $p < 0.01$), the amount of glazing in the measured open plan spaces ranging from 2% to 10% of the total surface area.

The amount of glazing was also significantly related to T_{mf} ($r = 0.375$, $p < 0.01$), EDT ($r = 0.451$, $p < 0.01$), T20 ($r = 0.357$, $p < 0.01$), STI ($r = -0.445$, $p < 0.01$), and C50 ($r = -0.430$, $p < 0.01$) in enclosed classrooms. Thus the amount of glazing provided needs to be considered in relation to optimizing the acoustic environment for speech intelligibility.

The regression relationship between the percentage of glazing and T_{mf} in open plan spaces showed that as long as the percentage is below 16%, T_{mf} will be below the required value of 0.8 s. However, as noted previously, all the open plan spaces measured complied with the current standard for reverberation time.[3] The main acoustic problem that needs to be avoided in open plan areas is disturbance from intrusive noise from other parts of the school.[32]

b. Effects of absorption and carpet. The effects on reverberation time of absorptive finishes and carpet have been investigated. Gymnasia and sports halls have been excluded from this analysis as they are exceptionally large spaces with, in general, very long reverberation times; thus the total number of spaces considered in this analysis is 176. Acoustic absorption generally took the form of a full suspended ceiling ($N = 97$) or acoustic panels partially covering the ceiling ($N = 23$). Two assembly halls had acoustic panels on the walls while four dance/drama hall/studios had acoustic panels on ceiling and walls. Absorption data were not available for the different materials and ceiling types encountered, so it is not possible in this section to draw more than general conclusions regarding the effects of absorptive surfaces.

TABLE IX. Effects on reverberation time of absorptive finishes (installed acoustic absorption and carpet).

	All spaces		Enclosed classrooms		D/T workshops		Science rooms	
	$N = 176$		$N = 86$		$N = 13$		$N = 33$	
	n	Mean T_{mf} (sd)	*n*	Mean T_{mf} (sd)	*n*	Mean T_{mf} (sd)	*n*	Mean T_{mf} (sd)
No carpet	65	0.73 (0.32)	7	0.75 (0.41)	8	0.74 (0.26)	29	0.72 (0.29)
Carpet	111	0.62 (0.18)	79	0.63 (0.17)	5	0.68 (0.17)	4	0.90 (0.21)
No absorption	50	0.91 (0.20)	28	0.86 (0.15)	7	0.87 (0.16)	13	1.03 (0.24)
Absorption	126	0.56 (0.19)	58	0.53 (0.12)	6	0.54 (0.18)	20	0.56 (0.11)
No absorption, no carpet	18	1.07 (0.22)	3	1.2 (0.15)	4	0.93 (0.11)	9	1.09 (0.24)
No absorption, carpet	32	0.83 (0.12)	25	0.8 (0.08)	3	0.77 (0.17)	4	0.9 (0.21)
Absorption, no carpet	46	0.60 (0.26)	4	0.41 (0.04)	4	0.55 (0.22)	20	0.56 (0.11)
Absorption, carpet	79	0.53 (0.12)	54	0.5 (0.12)	2	0.54 (-)	-	-

Table IX shows the averaged reverberation times for all spaces ($N = 176$), enclosed classrooms ($N = 86$), workshops ($N = 13$), and science rooms ($N = 33$) depending on whether or not they had any acoustic absorption installed on the ceiling and/or walls and whether or not they were carpeted. (Other room categories have been excluded as they did not have sufficient number of examples for comparison.) The table also shows the effects of combinations of absorptive finishes on ceiling and/or walls and carpet. It can be seen that an absorptive ceiling has more of an impact on reverberation time than carpet, reducing the reverberation time by between 0.3 and 0.4 s on average. The table also shows that the average reverberation time for all types of rooms with absorptive finishes is around 0.5 s. In general, to achieve the lowest possible reverberation time absorptive treatment and carpet should both be provided.

Table X shows the differences in average reverberation times between absorptive ceiling types for all spaces and enclosed classrooms (ignoring spaces with additional absorption on walls) and shows that a full suspended ceiling is more effective, by 0.14 s in both cases, than absorptive panels, regardless of whether or not the room is carpeted.

2. Compliance with standards and effects of introduction of legislation

As explained in Sec. III, new regulations were introduced in England and Wales in 2003 that required all new school buildings to meet certain specifications for noise levels, reverberation time, and sound insulation.[3] The date of construction of every space measured in the survey was noted, which enables a comparison to be made between those spaces constructed before ($N = 139$) and after ($N = 46$) the introduction of the regulations.

Considering all 185 spaces measured, 119 (64%) complied with the current requirement for indoor ambient noise level (as approximated by UANL), 137 (74%) with the specification for mid-frequency reverberation time, and 97 (52%) with both. For those spaces built before 2003, 61 (44%) met the requirements for both IANL and T_{mf}, while of those built after the regulations 40 (87%) complied. Thus the percentage of spaces meeting the current acoustic criteria for schools almost doubled following the introduction of legislation in 2003.

Considering the different types of space for which there were sufficient numbers built both before and after 2003 for meaningful comparison, the percentages of enclosed classrooms meeting the criteria increased from 36% to 86%, science rooms from 50% to 91%, and open plan spaces from 71% to 100%.

Average unoccupied ambient noise levels decreased by between 6 and 10 dBA (enclosed classrooms from 35 to 29 L_{Aeq}, dB, science rooms from 39 to 31 L_{Aeq}, dB, and open plan spaces from 41 to 31 L_{Aeq}, dB). Mean mid-frequency reverberation times also reduced by around 0.1 s for enclosed classrooms, science rooms, and open plan spaces. Furthermore standard deviations also decreased suggesting consistent improvement in the acoustic design.

These results show that the introduction in 2003 of regulations governing the acoustic design of schools has led to an overall improvement in acoustic standards.

B. Occupied noise levels

Table XI shows the lesson and activity noise levels averaged over all schools, for each of the subjects mathematics, English, science, MFL, and humanities, and over all

TABLE X. Effects on reverberation time of different types of absorptive ceiling.

		Suspended ceiling			Acoustic panels		
		All	Carpet	No carpet	All	Carpet	No carpet
All spaces	*N*	97	65	32	23	10	13
	Mean T_{mf} (sd)	0.52 (0.12)	0.51 (0.11)	0.54 (0.15)	0.66 (0.18)	0.65 (0.09)	0.68 (0.25)
Enclosed classrooms	*N*	49	45	4	9	10	0
	Mean T_{mf} (sd)	0.51 (0.12)	0.52 (0.12)	0.41 (0.04)	0.65 (0.09)	0.65 (0.09)	-

TABLE XI. Lesson and activity noise levels for different subjects and overall: Mean (standard deviation) (see Table V for definition of activities).

	Mathematics		English		Science		MFL		Humanities		All	
	N = 71		$N = 72$		$N = 88$		$N = 19$		$N = 24$		$N = 274$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
Lesson noise level	63.6 (5.9)	51.2 (7.1)	63.3 (5.2)	48.9 (6.3)	65.6 (5.3)	53.5 (5.8)	64.5 (4.4)	49.8 (5.9)	63.1 (4.6)	50.2 (5.0)	64.2 (5.4)	51.1 (6.5)
Activity 1	63.2 (4.8)	48.8 (5.1)	62.7 (4.6)	47.2 (4.7)	64.0 (4.3)	49.7 (3.8)	63.3 (4.3)	48.0 (4.5)	62.5 (4.4)	47.1 (3.9)	63.3 (4.5)	48.5 (4.6)
Activity 2	63.1 (6.5)	51.4 (7.6)	59.5 (7.6)	45.7 (8.4)	64.0 (6.8)	52.1 (7.1)	62.9 (5.8)	48.6 (7.3)	59.4 (6.5)	47.1 (6.9)	62.3 (7.1)	49.8 (8.0)
Activity 3	67.8 (5.4)	57.0 (6.8)	67.2 (6.2)	55.0 (7.2)	68.4 (4.2)	57.9 (5.0)	69.6 (2.3)	59.3 (3.0)	65.3 (7.7)	54.3 (7.4)	67.7 (5.5)	56.7 (6.3)
Activity 4	–	–	66.0 (5.8)	51.2 (5.1)	63.8 (4.3)	51.7 (4.0)	65.5 (4.7)	47.7 (7.8)	65.6 (2.8)	53.0 (5.9)	65.0 (4.7)	51.3 (5.5)

subjects, while Table XII shows the percentages of time spent in the four identified activities for the different subjects.

1. Overall lesson noise levels

It can be seen from Table XI that the overall average lesson noise level is 64.2 dB L_{Aeq} with an average background level of 51 dB L_{A90}. These levels agree closely with levels of classroom noise measured in previous surveys,[8,25–27,30,31] although as described in Sec. II, the majority of these have been carried out in elementary/primary schools.

In 7 of the 13 schools, the subject with the highest level was science, probably due to the activities involved in science lessons (see the discussion of activity levels in the following section) while in another seven English lessons had the lowest noise level.

The highest levels occurred in school 7, which is the inner city school with the highest external and unoccupied ambient noise levels. However, there are many additional factors, including demographic, that may have affected the noise levels in this school.

2. Activity noise levels

Table XII shows the percentage of teaching time spent in each of the four activities described in Table V. It can be seen that between 40% and 50% of teaching time, with 46% on average, is spent in plenary sessions with one person (usually the teacher) speaking to the whole class. This means that is essential that the acoustic design of the classroom enhances speech intelligibility throughout the classroom so that speech can be understood by all pupils.

The average L_{Aeq} and L_{A90} levels associated with each activity in each subject, and overall, are shown in Table XI. As would be expected activity 3 (students working in groups with discussion) has the highest noise levels, but there is little difference between the noise generated by activities 1 and 2 for most subjects. Table XI shows that science lessons have the highest occurrence of activity 3, which explains why science lessons have the highest average noise levels.

Considering the difference between L_{Aeq} and L_{A90}, which has been used elsewhere as an estimation of the speech to noise ratio,[19] the highest value (14.8 dBA averaged over all subjects) occurs for activity 1, which refers to the situation when one person is speaking in the classroom. The lowest difference between L_{Aeq} and L_{A90} (11 dBA) occurs for activity 3, which is to be expected as this is the activity involving group work and movement.

TABLE XII. Percentage of lesson time spent in different activities for different subjects and overall (see Table V for definition of activities).

Activity	Mathematics $N = 71$	English $N = 72$	Science $N = 88$	MFL $N = 19$	Humanities $N = 24$	All subjects $N = 274$
1	39.8	51.8	43.1	49.1	50.4	45.6
2	51.4	29.7	32.8	35.2	31.7	36.9
3	8.8	12.8	19.9	5.2	13.1	13.5
4	0	5.7	4.2	10.5	4.8	4.0

3. Student factors affecting noise levels in lessons

a. Number of pupils. The numbers of students in the measured lessons varied from 2 to 82 with mean 22.7 and standard deviation 11.0 (the average in UK state secondary school classrooms is currently around 20.5).

Considering all 274 core lessons, there were significant correlations between the number of students and lesson L_{Aeq} ($r = 0.272$, $p < 0.01$) and L_{A90} ($r = 0.436$, $p < 0.01$), indicating that noise levels during lessons are higher with greater numbers of students, as might be expected.

b. Age of students. There was a significant negative correlation between year group and lesson L_{Aeq} ($r = -0.179$, $p < 0.05$) and L_{A90} ($r = -0.204$, $p < 0.05$), indicating that the noise levels decrease with the age of students.

4. Effects of acoustic design on lesson noise

Relationships between unoccupied T_{mf} and UANL and lesson noise levels were examined. Considering all 274 lessons there were significant positive correlations between T_{mf} and lesson L_{Aeq} ($r = 0.352$, $p < 0.01$) and L_{A90} ($r = 0.236$, $p < 0.01$); and between UANL and lesson L_{Aeq} ($r = 0.382$, $p < 0.01$) and L_{A90} ($r = 0.303$, $p < 0.01$). Unoccupied STI was also significantly negatively correlated with L_{Aeq} ($r = -0.319$, $p < 0.01$) and L_{A90} ($r = -0.178$, $p < 0.01$).

Examining the data on a room by room basis and calculating the average level of all lessons in each room ($N = 80$), there were significant correlations between the lesson L_{Aeq} and T_{mf} ($r = 0.405$, $p < 0.01$) and UANL ($r = 0.363$, $p < 0.01$) and also between L_{A90} and T_{mf} ($r = 0.250$, $p < 0.05$) and UANL ($r = 0.332$, $p < 0.01$). In addition,

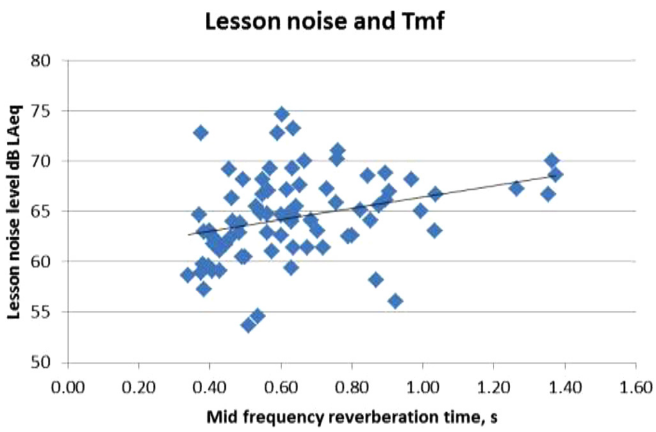

FIG. 3. (Color online) Scatter diagram showing the relationship between lesson noise and T_{mf}.

lesson L_{Aeq} was significantly negatively correlated with unoccupied STI ($r = -0.382$, $p < 0.01$). Figures 3 and 4 illustrate the relationships between average lesson L_{Aeq} and T_{mf} and UANL in the 80 rooms.

These results indicate that overall lesson noise is affected by both unoccupied ambient noise level and reverberation time; the higher the ambient noise level, the higher are both the equivalent continuous and background noise levels during lessons, and similarly the longer the reverberation time the higher are the lesson noise levels.

The significant negative correlations with STI show that the greater the unoccupied speech transmission index, the lower is the lesson noise level. This could be due to greater clarity of speech resulting in the teacher speaking at a lower level and/or the students making less noise when they are able to hear the teacher more clearly. However, it should be remembered that the STI is measured in the unoccupied condition and takes account of reverberation only, so may not be indicative of occupied conditions.

5. Effect of acoustic design on classroom behavior

The time spent in "disruptive activities," that is activities that were not related to the lesson (e.g., students talking among themselves, items being dropped, other teachers or pupils entering the room, pupils shouting, interruption by activities outside the classroom) was noted for each lesson,

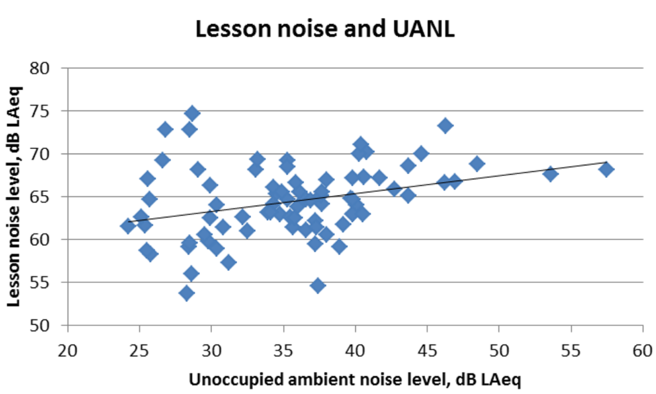

FIG. 4. (Color online) Scatter diagram showing the relationship between lesson noise and unoccupied ambient noise level.

plus the time spent entering and settling and packing up and leaving each lesson. The total time spent in disruption plus entering and settling for the lesson ("total disruption time") has been compared with unoccupied acoustic data to give an indication as to whether the acoustic environment has a direct effect upon behavior in the classroom.

There were small but statistically significant correlations between the total disruption time and UANL ($r = 0.144$, $p < 0.05$) and T_{mf} ($r = 0.132$, $p < 0.05$); thus the shorter the reverberation time and the lower the UANL, the less time is lost to disruptive activities. This suggests that the acoustic environment might have some impact upon the behavior of students in the classroom.

6. Comparison of noise levels in open plan and enclosed classrooms

Occupied noise conditions in open plan and enclosed classrooms have been compared. Of the 274 lessons measured, 40 were in 12 open plan classrooms and 234 were in 68 enclosed classrooms. As well as examining possible differences in noise levels, effects of the acoustic design in the two different types of space have been examined separately.

a. Lesson noise levels. Occupied noise levels measured in open plan and enclosed classrooms were similar, as has been found in previous studies:[32] The average lesson noise levels measured in open plan rooms were 63.2 dB L_{Aeq} and 52.4 dB L_{A90} compared with 64.4 dB L_{Aeq} and 50.9 dB L_{A90} in enclosed rooms.

However, the averaged approximated speech to noise ratio (the difference between L_{Aeq} and L_{A90} levels for activity 1, see Sec. IV C) was 4 dBA less in open plan rooms (9.9 dBA) than in enclosed classrooms (13.9 dBA). This is likely to be due to the increase in background noise consisting of intrusive noise from adjacent areas in open plan rooms.

b. Effects of acoustic design on lesson noise levels. Relationships between lesson noise levels and unoccupied ambient noise and reverberation time were examined for open plan and enclosed classrooms separately.

In enclosed rooms, lesson L_{Aeq} levels were significantly correlated with UANL ($r = 0.346$, $p < 0.01$), T_{mf} ($r = 0.347$, $p < 0.01$) and STI ($r = -0.342$, $p < 0.01$). The correlations were stronger for open plan rooms ($r = 0.543$ for UANL; $r = 0.564$ for T_{mf}, and $r = -0.425$ for STI), but the relationships were not significant, probably because of the smaller sample number (12).

L_{A90} levels were also significantly correlated with UANL ($r = 0.375$, $p < 0.01$), T_{mf} ($r = 0.289$, $p < 0.05$) and STI $r = -0.283$, $p < 0.05$) for enclosed rooms; however, the relationships were weak for open plan rooms.

From the linear regression equations relating lesson L_{Aeq} and T_{mf} ($y = 5.16x + 61.18$) and UANL ($y = 0.21x + 57.08$), it can be shown that the current standard for reverberation time in secondary school classrooms of 0.8 s T_{mf} corresponds to lesson noise of 71 dB L_{Aeq}, while the standard for UANL of 35 dB corresponds to 64 dBA. A reduction of T_{mf} to 0.6 s (the current requirement for primary school classrooms) would reduce the corresponding classroom noise level to 64 dBA.

c. Speech to noise ratios. Speech to noise ratios (as approximated by the difference between L_{Aeq} and L_{A90} levels for activity 1, see Sec. IV C) were significantly correlated with UANL in open plan rooms ($r = 0.350$, $p < 0.05$) but not in enclosed classrooms. It is well known that intrusive noise can cause problems for both teachers and pupils in open plan rooms,[32,33] and this result probably reflects this fact as the measured UANL would have included contributions from other areas in the school as the schools were occupied at the times of measurement. However, unlike a previous study of secondary school classrooms,[19] no significant relationships were found between reverberation times and speech to noise ratios.

VI. DISCUSSION

The unoccupied noise survey of 185 spaces in 13 English secondary schools shows that there is a wide variation in unoccupied ambient noise levels both between and within schools. The school with the overall highest unoccupied ambient levels is also the school with the highest average external noise level.

Considering rooms individually, two thirds (65%) complied with the current requirements for indoor ambient noise level and three quarters (74%) with reverberation time requirements, although only half of the spaces measured complied with both IANL and RT requirements. Sports halls in particular have excessively long reverberation times. The number of spaces complying with the current criteria doubled (from 44% to 87%) following the introduction in 2003 of building regulations on school acoustics. The data have therefore demonstrated that the legislation has been effective in improving the acoustic design of schools and has led to an overall improvement in the acoustic environment of schools.

Consideration of the physical design of the measured spaces showed that to achieve good speech intelligibility, it is necessary to control the height of the space and the amount of glazing; the latter particularly in open plan classrooms. The relatively short reverberation times in open plan spaces show that it is also essential to control intrusive noise to ensure good speech intelligibility. Examination of different ceiling types confirmed that absorptive ceilings are more effective than carpet at reducing reverberation time; however, both should be provided to reduce the RT as far as possible. In the current study, a full suspended ceiling was more effective than acoustic panels on the ceiling; however, as detailed absorption data for the different ceiling types were not available, this aspect of the acoustic design of teaching spaces could be more thoroughly investigated in future.

Measurement of noise levels during 274 lessons in the 13 schools found that, as might be expected, lesson noise increased with the number and decreased with the age of the students. However, both background (L_{A90}) and ambient (L_{Aeq}) levels during lessons were related to the (unoccupied) indoor ambient noise levels and mid-frequency reverberation times. The difference between average occupied lesson noise (64 dB L_{Aeq}) and unoccupied ambient levels (35 dB L_{Aeq}) is around 30 dBA, so it important that both ambient noise and reverberation are controlled to keep noise during lessons to a minimum. The necessity for good speech intelligibility is highlighted by the observations that nearly half of all lesson time (46%) is spent in plenary sessions, with one person addressing the whole class. Furthermore, the negative correlation found between STI and lesson noise suggests that the better the speaking and listening conditions in the classroom, the lower will be the lesson noise levels.

It is perhaps surprising, in view of reported problems caused by intrusive noise that little difference was found in overall noise levels between open plan and enclosed classrooms, although this is consistent with findings of previous research.[32,33] The particular difficulties caused by distraction from intrusive noise in open plan classrooms are likely to be due to the "irrelevant speech effect" reported in open plan offices[40] rather than to high levels of classroom noise. This was confirmed by the examination of the difference between L_{Aeq} and L_{A90} levels in the two types of space for plenary sessions when one person is speaking (activity 1); this ratio was 4 dBA lower in open plan classrooms. In addition, it was found that for open plan rooms, this approximated speech to noise ratio was related to the unoccupied indoor ambient noise level.

The small but significant correlation found between the amount of lesson time lost to disruptive activities and unoccupied acoustic data suggests that the acoustic environment may have some effect on pupil behavior; this aspect of the impact of acoustic design is worthy of further investigation.

VII. CONCLUSIONS

The extensive survey of acoustic conditions in secondary schools described here has highlighted the importance of good acoustic design to achieve good speaking and learning conditions in secondary school classrooms. In particular, relationships between lesson noise levels and unoccupied acoustic conditions emphasize the necessity of considering the acoustic conditions in all teaching spaces in a school at the design stage of a building or its refurbishment. The acoustic design should aim to reducing the unoccupied noise levels and reverberation times to minimize noise levels during lessons and to optimize acoustic conditions for teaching and learning.

ACKNOWLEDGMENTS

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