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http://dx.doi.org/10.1121/1.4904528

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

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(Received 27 August 2013; revised 25 August 2014; accepted 14 November 2014)

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.11–14 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.15 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.16 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
survey of noise in Italian secondary schools found much lower background noise levels (measured with the students present but quiet) of 33–44 dBA $L_{Aeq}$,\textsuperscript{9} while university classrooms have been found to have background levels of 35 dBA.\textsuperscript{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.\textsuperscript{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.\textsuperscript{28} The limited amount of lesson activity noise reported in secondary schools has a wide range: In 1999, Hodgson et al.\textsuperscript{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 dBA $L_{Aeq}$ (Ref. 30) while a study of two high schools in Turkey\textsuperscript{31} found that levels varied between 60 and 63 dBA $L_{Aeq}$ in occupied classrooms. In a recent examination of the effects of acoustic treatments in a secondary school in Essex, England,\textsuperscript{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$^3$.\textsuperscript{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,\textsuperscript{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.\textsuperscript{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.\textsuperscript{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).\textsuperscript{1} 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,\textsuperscript{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.

<table>
<thead>
<tr>
<th>Enclosed classrooms</th>
<th>Design/technology workshops</th>
<th>Gymnasia</th>
<th>Music rooms</th>
<th>Sports halls</th>
<th>Science rooms</th>
<th>Art rooms</th>
<th>Open plan spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>IANL</td>
<td>≤35 dBA</td>
<td>≤40 dBA</td>
<td>≤40 dBA</td>
<td>≤35 dBA</td>
<td>≤40 dBA</td>
<td>≤40 dBA</td>
<td>≤40 dBA</td>
</tr>
<tr>
<td>$T_{mf}$</td>
<td>&lt;0.8 s</td>
<td>&lt;0.8 s</td>
<td>&lt;1.5 s</td>
<td>&lt;1.0 s</td>
<td>&lt;1.5 s</td>
<td>&lt;0.8 s</td>
<td>&lt;0.8 s</td>
</tr>
</tbody>
</table>
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. 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 including 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 II. Details of schools surveyed.**

<table>
<thead>
<tr>
<th>School</th>
<th>Gender</th>
<th>Age range (yr)</th>
<th>No. of pupils</th>
<th>Dates of buildings</th>
<th>Location</th>
<th>External noise level ($L_{eq}$,dB) Mean (sd)</th>
<th>Unoccupied measurements No. spaces</th>
<th>Occupied measurements No. rooms No. lessons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mixed</td>
<td>11–16</td>
<td>531</td>
<td>1970s–1990s</td>
<td>Suburban</td>
<td>–</td>
<td>7</td>
<td>3 15</td>
</tr>
<tr>
<td>2</td>
<td>Mixed</td>
<td>11–16</td>
<td>1178</td>
<td>1950s–2000s</td>
<td>Suburban</td>
<td>52.5 (0.1)</td>
<td>26</td>
<td>3 15</td>
</tr>
<tr>
<td>3</td>
<td>Mixed</td>
<td>11–18</td>
<td>1097</td>
<td>1960s–1990s</td>
<td>Suburban</td>
<td>51.6 (4.5)</td>
<td>5</td>
<td>3 13</td>
</tr>
<tr>
<td>4</td>
<td>Female (mixed 6th form)</td>
<td>11–18</td>
<td>1040</td>
<td>1940s–2009</td>
<td>Suburban</td>
<td>50.5 (2.7)</td>
<td>6</td>
<td>4 14</td>
</tr>
<tr>
<td>5</td>
<td>Mixed</td>
<td>11–18</td>
<td>723</td>
<td>1960s</td>
<td>Rural</td>
<td>–</td>
<td>9</td>
<td>7 23</td>
</tr>
<tr>
<td>6</td>
<td>Female (mixed 6th form)</td>
<td>11–18</td>
<td>1141</td>
<td>1950s–2000s</td>
<td>Suburban</td>
<td>52.8 (4.1)</td>
<td>14</td>
<td>11 43</td>
</tr>
<tr>
<td>7</td>
<td>Mixed</td>
<td>11–16</td>
<td>725</td>
<td>1960s</td>
<td>Suburban</td>
<td>58.8 (0.9)</td>
<td>12</td>
<td>3 13</td>
</tr>
<tr>
<td>8</td>
<td>Mixed</td>
<td>11–16</td>
<td>1633</td>
<td>1950s–1990s</td>
<td>Suburban</td>
<td>49.1 (4.0)</td>
<td>33</td>
<td>5 24</td>
</tr>
<tr>
<td>9</td>
<td>Mixed</td>
<td>11–16</td>
<td>1166</td>
<td>1960s–1990s</td>
<td>Suburban</td>
<td>51.1 (1.3)</td>
<td>26</td>
<td>9 41</td>
</tr>
<tr>
<td>10</td>
<td>Mixed</td>
<td>11–18</td>
<td>1411</td>
<td>2009</td>
<td>Rural</td>
<td>50.0 (1.6)</td>
<td>15</td>
<td>3 13</td>
</tr>
<tr>
<td>11</td>
<td>Mixed</td>
<td>11–18</td>
<td>1417</td>
<td>1960s</td>
<td>Suburban</td>
<td>53.5 (2.7)</td>
<td>13</td>
<td>10 33</td>
</tr>
<tr>
<td>12</td>
<td>Mixed</td>
<td>11–12a</td>
<td>700</td>
<td>2008</td>
<td>Suburban</td>
<td>49.2 (3.8)</td>
<td>4</td>
<td>4 12</td>
</tr>
<tr>
<td>13</td>
<td>Mixed</td>
<td>11–16</td>
<td>1320</td>
<td>2000s</td>
<td>Outer city</td>
<td>51.7 (1.6)</td>
<td>15</td>
<td>15 15</td>
</tr>
</tbody>
</table>

*aThe building surveyed was for 11–12 year old pupils only although the whole school catered for pupils from 11 to 16 years of age.

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

<table>
<thead>
<tr>
<th>Open plan spaces</th>
<th>Enclosed classroom</th>
<th>Design/tech workshop</th>
<th>Gym</th>
<th>Music room</th>
<th>Sports hall</th>
<th>Science room</th>
<th>Art</th>
<th>Semi</th>
<th>Full</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. measured</td>
<td>86</td>
<td>13</td>
<td>4</td>
<td>10</td>
<td>5</td>
<td>33</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Volume (m$^3$)</td>
<td>Mean 161</td>
<td>244</td>
<td>1454</td>
<td>208</td>
<td>8035</td>
<td>233</td>
<td>262</td>
<td>186</td>
<td>729</td>
<td>458</td>
</tr>
<tr>
<td></td>
<td>sd 39</td>
<td>61</td>
<td>146</td>
<td>62</td>
<td>1891</td>
<td>60</td>
<td>122</td>
<td>48</td>
<td>298</td>
<td>345</td>
</tr>
<tr>
<td>Height (m)</td>
<td>Mean 2.9</td>
<td>2.9</td>
<td>5.6</td>
<td>3.1</td>
<td>12.6</td>
<td>2.9</td>
<td>3.1</td>
<td>2.7</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>sd 0.4</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>2.7</td>
<td>0.5</td>
<td>0.8</td>
<td>0.01</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Floor area (m$^2$)</td>
<td>Mean 56</td>
<td>84</td>
<td>259</td>
<td>67</td>
<td>6510</td>
<td>7.9</td>
<td>81</td>
<td>69</td>
<td>285</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>sd 11</td>
<td>18</td>
<td>24</td>
<td>10</td>
<td>165</td>
<td>12</td>
<td>18</td>
<td>18</td>
<td>112</td>
<td>134</td>
</tr>
<tr>
<td>Percentage glazing</td>
<td>Mean 5.7</td>
<td>7.5</td>
<td>6.7</td>
<td>5</td>
<td>a</td>
<td>4.7</td>
<td>4.7</td>
<td>5</td>
<td>5.2</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>sd 2.9</td>
<td>6.0</td>
<td>3.0</td>
<td>2.6</td>
<td></td>
<td>2.1</td>
<td>1.3</td>
<td>3.2</td>
<td>2.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>

*aOnly 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 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 ($T_{20}$), 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 EDT33,39 and minimum value for C50 of 10 dB39 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.

![Diagram of a typical unoccupied classroom measurement configuration](image1)

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

![Photograph of microphone set up in an unoccupied mathematics classroom](image2)

**FIG. 2.** (Color online) Photograph of microphone set up in an unoccupied mathematics classroom.
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 LA_{eq} and LA_{90} levels measured during lessons. In the current study, the speech to noise ratio is approximated by the difference between occupied LA_{eq} and LA_{90} 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 IV. Occupied noise surveys: Numbers and types of core lessons and rooms measured.

<table>
<thead>
<tr>
<th>School</th>
<th>No. of lessons</th>
<th>No. of rooms</th>
<th>Maths</th>
<th>English</th>
<th>Science</th>
<th>MFL</th>
<th>Humanities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>5</td>
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<td>5</td>
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<td>15</td>
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<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13</td>
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<td>4</td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5 (2 rooms)</td>
<td>5</td>
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</tr>
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<td>5</td>
<td>23</td>
<td>7</td>
<td>0</td>
<td>5</td>
<td>8 (4 rooms)</td>
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</tr>
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<td>6</td>
<td>43</td>
<td>11</td>
<td>16 (4 rooms)</td>
<td>10 (3 rooms)</td>
<td>11 (3 rooms)</td>
<td>6</td>
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</tr>
<tr>
<td>7</td>
<td>13</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>24</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>9 (2 rooms)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>41</td>
<td>9</td>
<td>8 (2 rooms)</td>
<td>10 (2 rooms)</td>
<td>9 (2 rooms)</td>
<td>5</td>
<td>9 (2 rooms)</td>
</tr>
<tr>
<td>10</td>
<td>13</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>33</td>
<td>10</td>
<td>9 (3 rooms)</td>
<td>10 (3 rooms)</td>
<td>14 (4 rooms)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4 (2 rooms)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>15</td>
<td>15</td>
<td>5 (5 rooms)</td>
<td>5 (5 rooms)</td>
<td>5 (5 rooms)</td>
<td>19</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>274</td>
<td>80</td>
<td>71</td>
<td>72</td>
<td>88</td>
<td>19</td>
<td>24</td>
</tr>
</tbody>
</table>

TABLE V. Activities observed during lessons.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plenary</td>
<td>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.</td>
</tr>
<tr>
<td>2</td>
<td>Individual work</td>
<td>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.</td>
</tr>
<tr>
<td>3</td>
<td>Group work</td>
<td>Pupils working in groups around a table. Greater level of discussion; more movement; teacher(s) moving around helping pupils.</td>
</tr>
<tr>
<td>4</td>
<td>Watching/listening</td>
<td>Pupils watching video or listening to audio replay.</td>
</tr>
</tbody>
</table>
TABLE VI. Unoccupied average noise levels (UANL) $L_{Aeq}$ dB (values where specifications are exceeded are in bold italic).

<table>
<thead>
<tr>
<th>School</th>
<th>BB93 UANL</th>
<th>Enclosed classrooms</th>
<th>Design/tech workshops</th>
<th>Gymnasia</th>
<th>Music rooms</th>
<th>Sports halls</th>
<th>Science rooms</th>
<th>Art rooms</th>
<th>Open plan spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\leq 35$</td>
<td>$\leq 40$</td>
<td>$\leq 40$</td>
<td>$\leq 35$</td>
<td>$\leq 40$</td>
<td>$\leq 40$</td>
<td>$\leq 40$</td>
<td>$\leq 40$</td>
<td>$\leq 40$</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>32.7</td>
<td>5.7</td>
<td>37.5</td>
<td>34.6</td>
<td>36.4 0.4</td>
<td>36.8 2.8</td>
<td>38.2 4.7 6.6</td>
<td>32.8 6.2 38.5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>34.4</td>
<td>4.9</td>
<td>39.6</td>
<td>36.4</td>
<td>43.5</td>
<td>43.4 3.5</td>
<td>39.2 4.7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36.7 1.0</td>
<td>41.7</td>
<td></td>
<td></td>
<td></td>
<td>42.7</td>
<td></td>
<td>39.2 4.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>29.0 0.6</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
<td>27.1</td>
<td></td>
<td>34.4 3.5 6.8</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>34.4 0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32.7</td>
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<td>37.2 4.7 6.8</td>
<td>43.4 6.8</td>
</tr>
<tr>
<td>6</td>
<td>32.8 3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34.9 1.3</td>
<td></td>
<td>31.2 4.6 6.8</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>41.6 4.8</td>
<td>45.5</td>
<td>40.4</td>
<td></td>
<td>33.1</td>
<td></td>
<td></td>
<td>40.8 4.1 6.8</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>34.7 5.6</td>
<td>40.2</td>
<td>8.8</td>
<td></td>
<td>39.0 3.0</td>
<td></td>
<td></td>
<td>39.2 4.7 11.0</td>
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</tr>
<tr>
<td>9</td>
<td>35.6 4.4</td>
<td>32.3</td>
<td>8.1</td>
<td>35.6</td>
<td>42.4 4.3</td>
<td></td>
<td></td>
<td>36.7 4.2 39.6</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>30.5 5.4</td>
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<td></td>
<td></td>
<td>29.5 6.5</td>
<td></td>
<td>30.8 4.1 6.8</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>34.7 6.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28.2</td>
<td></td>
<td>42.8 4.1 6.8</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>34.1 3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>34.1</td>
<td></td>
<td>41.3 9.9 6.8</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>26.8 1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>31.7</td>
<td></td>
<td>36.7 0.7 6.8</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>33.6 5.8</td>
<td>38.4</td>
<td>7.7</td>
<td>38.5 3.6</td>
<td>36.8 4.9</td>
<td>36.1 6.2</td>
<td>36.2 6.8</td>
<td>36.0 7.5 35.4 7.1</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>School</th>
<th>BB93 $T_{mf}$</th>
<th>Enclosed classrooms</th>
<th>Design/tech Workshops</th>
<th>Gymnasia</th>
<th>Music rooms</th>
<th>Sports halls</th>
<th>Science rooms</th>
<th>Art rooms</th>
<th>Open plan spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$&lt;0.8$ s</td>
<td>$&lt;0.8$ s</td>
<td>$&lt;1.5$ s</td>
<td>$&lt;1.0$ s</td>
<td>$&lt;1.5$ s</td>
<td>$&lt;0.8$ s</td>
<td>$&lt;0.8$ s</td>
<td>$&lt;0.8$ s</td>
<td>$&lt;0.8$ s</td>
</tr>
<tr>
<td>1</td>
<td>0.50</td>
<td>0.15</td>
<td>0.50</td>
<td>1.41</td>
<td>0.56 0.01</td>
<td>0.44 0.75</td>
<td>0.48 0.16</td>
<td>0.49 0.05</td>
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<tr>
<td>2</td>
<td>0.51</td>
<td>0.14</td>
<td>0.83</td>
<td>0.21</td>
<td>2.43</td>
<td>0.36 0.65</td>
<td>0.44 0.05</td>
<td>0.50 0.15</td>
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<tr>
<td>3</td>
<td>0.70</td>
<td>0.02</td>
<td>0.30</td>
<td></td>
<td>4.44</td>
<td>0.54 0.75</td>
<td>0.48 0.05</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.40</td>
<td>0.03</td>
<td>0.48</td>
<td></td>
<td>3.11</td>
<td>1.03 0.75</td>
<td>0.48 0.05</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.44</td>
<td>0.04</td>
<td></td>
<td>0.43</td>
<td></td>
<td>0.41</td>
<td>0.50 0.15</td>
<td>0.50 0.15</td>
<td></td>
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<tr>
<td>6</td>
<td>0.86</td>
<td>0.05</td>
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<td></td>
<td></td>
<td>0.64 0.75</td>
<td>0.50 0.15</td>
<td>0.50 0.15</td>
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</tr>
<tr>
<td>7</td>
<td>0.80</td>
<td>0.11</td>
<td>0.96</td>
<td>1.84</td>
<td>0.42</td>
<td>0.76</td>
<td>0.50 0.15</td>
<td>0.50 0.15</td>
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<tr>
<td>8</td>
<td>0.65</td>
<td>0.25</td>
<td>0.79</td>
<td>0.17</td>
<td></td>
<td>0.67 0.75</td>
<td>0.57 0.19</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.73</td>
<td>0.10</td>
<td>0.72</td>
<td>0.19</td>
<td>1.52</td>
<td>0.39 0.75</td>
<td>0.50 0.15</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.68</td>
<td>0.05</td>
<td></td>
<td></td>
<td>3.43</td>
<td>2.09 0.75</td>
<td>0.57 0.19</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.80</td>
<td>0.30</td>
<td></td>
<td></td>
<td>2.51</td>
<td>2.09 0.75</td>
<td>0.57 0.19</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.50</td>
<td>0.03</td>
<td></td>
<td></td>
<td>2.51</td>
<td>2.09 0.75</td>
<td>0.57 0.19</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.50</td>
<td>0.08</td>
<td></td>
<td></td>
<td>0.59</td>
<td>0.57 0.19</td>
<td>0.57 0.19</td>
<td>0.50 0.15</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>0.64</td>
<td>0.20</td>
<td>0.72</td>
<td>0.23</td>
<td>1.8 0.4</td>
<td>0.51 0.12</td>
<td>4.01 1.41</td>
<td>0.75 0.29 0.63 0.29 0.53 0.09</td>
<td></td>
</tr>
</tbody>
</table>
However, problems of speech intelligibility in open plan classrooms have been extensively documented. Despite low reverberation times in such spaces, speech intelligibility during lessons is often compromised by intrusive noise from adjacent spaces.

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 dBA $L_{A90}$. The values of STI and C50 are consistent with the reverberation time and noise measurements and confirm that, in general, gymnasias 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.

**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. VA.1b.

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. The main acoustic problem that needs to be avoided in open plan areas is disturbance from intrusive noise from other parts of the school.

**b. Effects of absorption and carpet.** The effects on reverberation time of absorptive finishes and carpet have been investigated. Gymnasias 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 VIII. Means and standard deviations of unoccupied measurements of $L_{A90}$ and broadband T20, EDT, C50, and STI.

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

<table>
<thead>
<tr>
<th>TABLE IX. Effects on reverberation time of absorptive finishes (installed acoustic absorption and carpet).</th>
</tr>
</thead>
<tbody>
<tr>
<td>\begin{tabular}{</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>\hline</td>
</tr>
<tr>
<td>No carpet</td>
</tr>
<tr>
<td>Carpet</td>
</tr>
<tr>
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<tr>
<td>Absorption</td>
</tr>
<tr>
<td>No absorption, no carpet</td>
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<td>No absorption, carpet</td>
</tr>
<tr>
<td>Absorption, no carpet</td>
</tr>
<tr>
<td>Absorption, carpet</td>
</tr>
</tbody>
</table>

Table X shows the effects on reverberation time of different types of absorptive ceiling.

<table>
<thead>
<tr>
<th></th>
<th>Suspended ceiling</th>
<th>Acoustic panels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Carpet</td>
</tr>
<tr>
<td>All spaces (N)</td>
<td>97</td>
<td>65</td>
</tr>
<tr>
<td>(\text{Mean } \tau_{\text{mf}} \text{ (sd)})</td>
<td>0.52 (0.12)</td>
<td>0.51 (0.11)</td>
</tr>
<tr>
<td>Enclosed classrooms (N)</td>
<td>49</td>
<td>45</td>
</tr>
<tr>
<td>(\text{Mean } \tau_{\text{mf}} \text{ (sd)})</td>
<td>0.51 (0.12)</td>
<td>0.52 (0.12)</td>
</tr>
</tbody>
</table>

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. 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 \(\tau_{\text{mf}}\), 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 \(L_{\text{Aeq}}\) dB, science rooms from 39 to 31 \(L_{\text{Aeq}}\) dB, and open plan spaces from 41 to 31 \(L_{\text{Aeq}}\) 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
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, 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, 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.

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 Tmf and UANL and lesson noise levels were examined. Considering all 274 lessons there were significant positive correlations between Tmf 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 Tmf ($r = 0.405$, $p < 0.01$) and UANL ($r = 0.363$, $p < 0.01$) and also between $L_{A90}$ and Tmf ($r = 0.250$, $p < 0.05$) and UANL ($r = 0.332$, $p < 0.01$). In addition,
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 $Tmf$ 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, 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 $Tmf$ ($r = 0.132$, $p < 0.05$); 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. 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 ($r = 0.346$, $p < 0.01$), $Tmf$ ($r = 0.347$, $p < 0.01$) 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 $Tmf$, 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 ($r = 0.375$, $p < 0.01$), $Tmf$ ($r = 0.289$, $p < 0.05$) 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 $Tmf$ ($y = 5.16x + 61.18$) 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 $Tmf$ corresponds to lesson noise of 71 dB $L_{Aeq}$ while the standard for UANL of 35 dB corresponds to 64 dBA. A reduction of $Tmf$ 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, 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, 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 level 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 is 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. 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 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

The authors would like to thank the Engineering and Physical Sciences Research Council for funding this project and the schools, pupils, and teachers who have participated in the study.
