EXTERNAL AND INTERNAL NOISE SURVEYS OF LONDON PRIMARY SCHOOLS

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ABSTRACT

Internal and external noise surveys have been carried out around schools in London, UK, to provide information on typical levels and sources to which children are exposed while at school. Noise levels were measured outside 142 schools, in areas away from flightpaths into major airports. 86% of the schools surveyed were exposed to noise from road traffic, the average external noise level outside a school being 57 dB L_{Aeq}. Detailed internal noise surveys have been carried out in 140 classrooms in 16 schools, together with classroom observations. It was found that noise levels inside classrooms depend upon the activities in which the children are engaged, with a difference of 20 dB L_{Aeq} between the 'quietest' and 'noisiest' activities. The average background noise level in classrooms exceeds the level recommended in current standards. The number of children in the classroom was found to affect noise levels. External noise influenced internal noise levels only when children were engaged in the quietest classroom activities. The effects of the age of the school buildings and types of window upon internal noise were examined but results were inconclusive.

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I. INTRODUCTION

There are several national and international guidelines relating to the acoustics of classrooms[1-4]. These mainly take the form of recommended values for reverberation time and background noise levels in teaching spaces, together with sound insulation requirements for schools. For example, the World Health Organisation (WHO) Guidelines for Community Noise[2] specify an appropriate background level for classrooms as 35 dB L_{Aeq} during teaching sessions. This is also the level recommended in the USA in a recently approved ANSI standard[3]. In the UK legislation governing noise and acoustic conditions in schools was introduced in July 2003. The required acoustic standards are contained in Building Bulletin 93[4], which specifies a maximum ambient level of 35 dB $L_{Aeq,30\ min}$ due to noise from sources such as ventilation, plant and intrusive external noise in unoccupied teaching spaces. Some standards also include guideline values for noise levels outside schools, for example the WHO recommends that noise levels in school playgrounds should not exceed 55 dB L_{Aeq} whereas in the UK Building Bulletin 93 specifies an upper limit of 60 dB $L_{Aeq,30min}$ at the site boundary and 55 dB L_{Aeq} in outdoor areas such as playgrounds and playing fields.

Despite the existence of guidelines for school and classroom noise, and a body of research on the effects of noise on children and teachers in the classroom, there is relatively little information on noise levels in classrooms and outside schools. The purpose of the study described here was to provide objective data on the external and internal noise environment of typical urban schools; and to investigate to what extent the external noise climate influences the noise levels inside schools and classrooms. Noise levels were measured outside 142 schools in London, England, and inside 16 schools, in approximately 200 locations including empty and occupied classrooms, assembly halls and corridors. In parallel with the noise surveys described, questionnaire surveys of children and teachers

were carried out in over 50 schools, and the questionnaire results compared with the measured noise levels[5].

II. BACKGROUND TO THE STUDY

Although there have been many previous studies concerning the effects of chronic noise exposure on children at school, there is relatively little published data quantifying the noise environment inside and outside schools. Previous work has shown that noise can have a detrimental effect upon the cognitive development of primary school children, and that older children in this group appear to be more affected than younger children[6,7]. Many of these studies have concluded that the chronic noise exposure of young children has a particularly detrimental effect upon their reading ability[8,9]. In general it has been shown that aircraft noise has more effects than noise from other sources noise[10-15], although effects on children's reading, attention and long term recall have also been found due to school exposure to train and road traffic noise[16-21]. Noise from road traffic has also been found to cause dissatisfaction with the classroom environment among teachers[18]. In a comparison of the effect of noise from different sources it was found that aircraft and road traffic noise played at 66 dB(A) in the classroom affected long term recall whereas train noise had no effect[22]. Studies which have considered the effects of internal classroom noise [8,23-25] have found a significant drop in children's performance, particularly in learning to read, when the background noise level interferes with speech. By corollary, the reduction of background noise through acoustic treatment has been shown to improve the performance of both pre-school[24] and primary school children[25]. Thus, overall, the evidence provided by previous studies shows that noise from a variety of sources inside or outside a primary school has a detrimental effect upon children's learning and performance

at school, particularly reading, and that the effect can be greater with older children in this age range[17,26].

Despite the proven significance of noise exposure at school, the number of schools affected by noise from different sources is unknown and there is relatively little data available on typical noise levels inside and outside schools. Examples of external noise levels outside schools in a densely populated urban environment are provided by surveys carried out in central Istanbul in the late 1990s[27-29], which found levels ranging from 54 to 79 dB $L_{Aeq,5min}$[27,28]; and, in the most densely populated areas from 72 to 97 dB L_{Amax}; from 55 to 73 dB L_{A10}; and from 49 to 61 dB L_{A90}, all schools being subject to road traffic noise[29].

With regard to noise levels inside schools, a further problem arises in interpreting previously published data owing to the lack of a standard method for measuring noise in schools, and the difficulty of deciding what measurement represents a 'typical' classroom noise level. These problems are acknowledged by Hodgson *et al.*[30] and by Picard and Bradley[31] in reviews, published in 1999 and 2001 respectively, of classroom noise surveys. There is a wide range of levels in the published data. For example, Hodgson *et al.*[30] in summarising previous classroom noise surveys, dating from 1977 to 1991, found that classroom speech (that is, teacher) levels ranged from 40 to 80 dB(A); student activity levels from 40 to 70 dB(A); and ventilation noise levels in classrooms from 23 to 55 dB(A). Similarly, Picard and Bradley[31] noted that reported occupied levels in a full range of classrooms from kindergarten to university varied from 42 to 94 dB(A).

In a survey of university classrooms in Canada, Hodgson[32] found that a typical background noise level of 35 dB(A) in an empty classroom increased to 56 dB(A) when students were present. These levels are very similar to those measured in two recent surveys of classroom noise levels in Istanbul[28,29]. In another survey of noise during

lectures in occupied university classrooms, Hodgson *et al.*[30], identify the contributions from particular sources to the overall noise levels, for example ventilation noise (mean 40.9 dB), student-activity noise (mean 41.9 dB), and background level (mean 44.4 dB).

In the UK there have been a few small surveys of classroom noise. A survey in 1989[33] found, in primary schools, a mean level of 47 dB(A) for empty classrooms, with a range of 35.0 to 64.2 dB(A), and, for occupied classrooms, a mean of 65 dB(A) and range of 47.5 to 81.3 dB(A). Another survey of seven UK primary school classrooms[34] measured background noise levels in empty classrooms from 35 to 45 dB L_{Aeq} and in occupied classrooms with the children talking and working from 58 to 72 dB L_{Aeq}. These studies agree with the studies elsewhere in finding that 35 dB(A) is the lowest level likely to occur in an empty classroom, but that in an occupied classroom the levels are significantly higher.

More recently Mackenzie and Airey[25,35] measured average background noise levels of 44.7 dB(A) in empty classrooms, and 55.5 dB(A) and 77.3 dB(A) when the children were silent and working, respectively. Other recent studies have found pre-school children exposed to levels of 75 dB(A) in the classroom[24] and older children working in levels of 58 to 69 dB(A) during mathematics classes[36].

In order to reduce the effects of noise on school children it is essential to determine the types of sound in a classroom in order to apply the most appropriate noise control methods. Thus it is necessary to understand what determines classroom noise levels, that is, the noise sources in the classroom and, in particular, the impact of external noise upon the internal environment. The previous surveys of classroom noise have shown a wide range in noise levels. However, the reported levels have in many cases been presented as single figure ratings in dB(A), with no explanation of whether these represent instantaneous or time averaged sound levels, or whether they are maximum (eg L_{Amax}),

ambient (eg L_{Aeq}) or background (eg L_{A90}) levels. Other measurements are presented in terms of L_{Aeq}, but without the time period being specified. Furthermore, there has been little reported examination of the factors that determine classroom levels, for example occupancy of the classroom, activity of the children, or presence of external noise. There has also been no discussion of the variation of noise in a classroom throughout the school day, or comparison of classroom levels with other levels around a school. Furthermore there has been little reported examination of what determines classroom levels, for example occupancy of the classroom, activity of the children, or presence of external noise. In particular there has been no large scale detailed study of levels in schools in an urban environment.

In the current study noise levels were measured outside 142 schools around London, and the types of noise sources present were examined, to give a general indication of the noise environment around schools in central London. Detailed measurements were also made, at different times to the external measurements, inside 16 of the schools to provide data on typical classroom noise levels of primary school children aged between 4 and 11, and to enable comparison of internal levels with external levels. The variation of a number of noise parameters throughout the day in 140 classrooms was examined, and classroom noise levels were related to children's activities and age. Noise was also measured in other school locations and the effects of the age of the school buildings and of double glazing were also examined. External noise levels were compared with internal levels to determine the influence of external noise on the internal noise environment of the schools.

III. CHOICE OF SURVEY AREAS AND SCHOOLS

The overall aim of the study of which this survey was a part was to examine the influence of general environmental noise upon children in schools. It was therefore

necessary to survey schools subject to a wide range of noise levels. Some schools in London are subject to high levels of noise being located close to main roads or industrial areas, whereas other London schools are sheltered from road traffic noise by surrounding buildings. It was therefore decided to focus on areas of London to provide a range of external noise levels and sources. As there already exists a considerable body of research studying the effects of aircraft noise on children[10-15,37], it was decided that areas of London in which aircraft are the dominant environmental noise source (that is areas to the west of London) should be excluded from the current survey. The choice of areas in which to carry out the survey was further determined by an examination of demographic data in boroughs across London, so as to choose areas that were typical of the demography of London as a whole. Data on educational attainments of primary schools across London was also examined to ensure that the schools in the areas of London selected for the surveys reflected the academic performance of primary schools across London.

Three London boroughs (Haringey, Islington and Lambeth) were chosen according to the criteria described above, and so as to include schools within inner London, that is, within approximately 1 mile of central London, and outer London, that is approximately 5 miles from central London. Noise levels were measured outside every primary school in Haringey (n = 53) and Islington (n = 50), and outside a majority of schools in Lambeth (n = 39). Detailed noise surveys were carried out in 16 of the schools in one outer and one inner borough (Haringey and Islington).

Primary schools in London generally fall into one of two types. Many are in large Victorian buildings, built in the latter half of the 19th century. These are brick buildings, often two or three storeys high, with large windows and high ceilings, many of which are surrounded by large grounds and playgrounds, separating them from the nearest road. Other schools are in more modern buildings, typically built during the 1960s or 1970s.

These tend to be low rise buildings with many windows. The locations of the schools in relation to noise sources vary; some are adjacent to busy roads; others are set back from the road, separated from the kerb side by playgrounds; and many are set away from main roads in side streets.

Some of the schools have windows consisting of a single pane of glass throughout ('single glazing') while others have double paned windows ('double glazing'), or secondary panes fitted internally to the original windows to increase sound insulation ('secondary glazing').

IV. EXTERNAL NOISE SURVEY

A. Measurement method

Five minute samples of noise were measured outside each school using a Bruel and Kjaer hand held sound level meter, Type 2236. For security reasons measurements were made off the school premises, where possible outside the noisiest façade, at the curbside of the nearest road. In most cases this was at approximately 1 m from the nearside lane of traffic. For many schools the measurement position was at approximately 4 metres from the school façade. For consistency, where measurements were at other distances from the traffic or from a school, the appropriate distance correction was applied to give the corresponding level 4 metres from the façade.

The 5 minute measurement period was chosen to be typical of the school day when the children would be working in the classroom. Thus rush hour periods, times when children were arriving at or being collected from school, lunch hours and times when children were outside in the school playground were avoided. Furthermore, it was felt that the noise climate during the measurement was typical of the noise environment of the area.

The environmental noise parameters $L_{Aeq,5min}$, $L_{A10,5min}$, $L_{A90,5min}$, $L_{A99,5min}$, $L_{Amax,5min}$ and $L_{Amin,5min}$ were recorded at each site. These parameters give an indication of the ambient ($L_{Aeq,5min}$), background ($L_{A90,5min}$) and underlying ($L_{A99,5min}$) noise characteristics of the local environment. $L_{A10,5min}$ was included in the measurements as it gives an indication of the higher noise levels, and is used in the UK for the assessment of road traffic noise. $L_{Amax,5min}$ and $L_{Amin,5min}$ were also measured to show typical maximum and minimum levels to which schools may be exposed during the school day. All these parameters were subsequently compared with the internal levels measured, in an attempt to determine the characteristics of external environmental noise that affect internal levels. They were also compared with the results of a questionnaire survey of children's and teachers' attitudes to noise[5], to assess those aspects of noise that affect annoyance.

In addition to noise levels, during the 5 minute measurement period the noise sources heard by the researchers were noted.

B. Results of external noise survey

1. Measured noise levels

The means and standard deviations of the measured parameters for each borough are shown in Table I.

It can be seen that the values of all parameters are similar across the three boroughs, although the means of all parameters in Islington are between 1 and 5 dB(A) below those in the other two boroughs. Many schools in Islington are located in side streets, which are particularly quiet being sheltered from main roads. Also many of these inner city schools are in large Victorian buildings which typically are surrounded by large grounds and playgrounds, separating them from the nearest road. The subjective impression formed when carrying out the external noise survey was that noise levels outside several schools in

this area were unrepresentative of (normally lower than) the general environmental noise climate in the area. It can also be seen that the standard deviations of all parameters for Islington are greater than for the other two boroughs; this again reflects the fact that many Islington schools are in very quiet surroundings in side streets, whereas other school in the borough are on main roads and therefore exposed to high levels of road traffic noise. Thus the distribution of noise levels outside schools in this borough may not be typical of London as a whole.

Considering all schools together, the means, standard deviations and ranges of the measured parameters are shown in Table II. There is a relatively small (11 dB(A)) difference between L_{A10} and L_{A90} levels; this is to be expected of levels measured during the day in an urban environment. It can be seen that for most parameters the standard deviation is approximately 9 dB(A). The greatest variation in levels occurs for the L_{Amax} levels, with a high standard deviation of approximately 13 dB(A). The L_{Amax} measured during a 5 minute period will reflect the occurrence of individual events with noise levels higher than the ambient noise. This parameter would therefore be expected to demonstrate the widest variation of all parameters.

The wide range of levels occurring is illustrated in Figures 1 to 3 which show the distributions of the parameters $L_{Aeq,5min}$, $L_{A90,5min}$ and $L_{Amax,5min}$ measured outside all schools. The figures show that the most commonly occurring ambient levels are in the range of 56 to 60 dB L_{Aeq}, and background levels from 46 to 50 dB L_{A90}.

2. Sources of noise

During the external noise survey observations were made of the noise sources heard outside each school during the 5 minute sampling period. Figure 4 shows the incidences of the most commonly occurring sources. It can be seen that, as would be expected in an

urban environment, the most common source of noise was road traffic, principally cars, which was heard outside 86% of schools. Sirens were heard at surprisingly few schools, although they are commonly regarded as a regular feature of the London noise environment, and reported as being frequently heard by teachers and children[5].

It can also be seen that, although west London boroughs subject to predominantly aircraft noise were excluded from the study, aircraft were still heard at over 50% of the schools.

IV. INTERNAL NOISE SURVEY

Detailed internal noise surveys were carried out in 16 of the schools measured in the external survey, eight in the outer London borough (Haringey) and eight in the inner borough of Islington. The schools were chosen to give examples from across the range of external noise levels measured, the external L_{Aeq} levels outside the 16 schools ranging from 49 to 75 dB(A). As with the external surveys it was found that levels were consistent across the two boroughs; for this reason the boroughs have not been considered separately, all 16 schools are considered together.

Measurements were made in approximately 200 school locations including 110 occupied classrooms, 30 empty classrooms and 50 other school locations. Approximately half of the school buildings were Victorian and half dated from the latter half of the twentieth century. Around 50 per cent of the schools were single glazed, the remainder having some form of double or secondary glazing. At the time of the surveys, all windows were shut. Ventilation/heating systems were in operation in some schools at the time of measurement.

In addition to noise surveys in each school, detailed classroom observation was carried out to record the activities the children were undertaking in the classrooms at the

times of the measurements and to note any noise sources that were particularly obvious. It was therefore possible to relate the measured noise levels to classroom activities, as well as to the number of children in the class and the age of the children. The effects of the age of the school buildings and of double glazing were also considered.

A. Method

When measuring noise in schools various important practical issues need to be taken into account. To obtain representative data in occupied classrooms care must be taken not to disrupt the work of the teachers, and not to disturb or distract the children. Safety considerations are also important when measuring noise in the presence of young children. Therefore, prior to the main survey, pilot studies using various measurement techniques, and classroom observation, were carried out to determine the most appropriate form of noise measurement in classrooms[38].

As a result of the pilot study it was decided that the most appropriate technique for the measurement of noise in primary school was the use of a hand held sound level meter. Short (2 minute) samples of noise measured in this way in classrooms and other school locations give a good indication of the fluctuation in noise during the day in a classroom and of the variation in level throughout a school. Furthermore, using this method in an occupied classroom does not appear to interfere with the teaching or affect the children's concentration.

During the pilot study, continual noise monitoring during a morning or afternoon classroom session showed that the fluctuations of all noise parameters with time were very similar, and that the relative values of all parameters were approximately constant. For this reason the following discussion is confined to L_{Aeq} and L_{A90} levels only.

In each school, 2 minute measurements of L_{Aeq} and L_{A90} were made during lessons in classrooms and other occupied and unoccupied spaces around the school, such as assembly halls, foyers, stairs and corridors, and empty classrooms. For each measurement the time, the current activity and occupancy (number of teachers and children) of the space, and the occurrence of any noticeable noise events, internal or external, were noted.

B. Results of classroom observation

1. Occupied classrooms

During the noise surveys in occupied classrooms the ages of the children, details of the classroom activity and occupancy (numbers of teachers, other adults and children) were noted, together with the types of noise that were present. The subjective impression formed was that during lessons it was normally not possible to hear external noise or internal background noise from building services or classroom equipment. The classroom noise appeared to be dominated by the noise of the children themselves, and dependent upon the particular classroom activity that was being carried out. The lack of intrusion of external noise during the majority of activities was confirmed by subsequent correlation analysis of internal and external levels (see Section V).

Subjectively it was found that, in general, classroom sessions could be broken down into six distinct activities, each with a characteristic noise level resulting from all the sources related to the activity, including the teacher's voice.

The six activities identified were as follows:

Activity 1 Children sitting at tables doing silent reading or tests

Activity 2 Children sitting at tables or on the floor, with one person (teacher or child) speaking at any one time

Activity 3 Children sitting at tables working individually, with some talking

Activity 4 Children working individually, moving around the classroom, with some talking

Activity 5 Children working in groups, sitting at tables, with some talking

Activity 6 Children working in groups, moving around the classroom, with some talking

2. Unoccupied classrooms

In all except one of the empty classrooms surveyed the doors were closed during the measurement period. The audible noise included external noise from road traffic, planes and people (adults and children), and internal noise from heating or ventilation and lighting systems. Noise was also heard from other parts of the school including the corridors outside the classrooms, adjacent or nearby teaching spaces and classrooms above the rooms being measured. The occurrences of the different sources heard in the empty classrooms are shown in Figure 5.

C. Results of internal noise survey

In total in the 16 schools over 220 measurements were made in 110 occupied classrooms, 30 empty classrooms, and 50 other locations including occupied and empty assembly halls and corridors. The L_{Aeq} and L_{A90} levels measured have been analysed as follows. For each school the data were averaged according to year group, classroom activity and type of space. The data for individual schools were then combined to give overall average figures. The relationships between each of the following factors and noise levels have been examined: numbers of children in the classroom; ages of children; type of glazing (single or double); and age of the school buildings.

1. Variation of noise with number of children

The number of children in classes measured during the surveys varied from 7 to 32, although there were only one or two samples for numbers lower than 18. Figure 5 shows the relationships between average L_{Aeq} and L_{A90} levels corresponding to class sizes of greater than 18. These levels are the averages of all samples for the relevant number of children. There is significant correlation between class size and ambient L_{Aeq} level ($r = 0.669$, $p < 0.01$) and background level L_{A90} ($r = 0.566$, $p < 0.05$).

2. Variation of noise with age

The L_{Aeq} and L_{A90} levels corresponding to different year groups, averaged over all activities, are shown in Table III. It was found that, in several of the schools, there was a general trend for the noise levels to decrease as the age of the children increases. There is anecdotal evidence among teachers that this is the case and that nursery and reception classes can be particularly noisy. Picard and Bradley[38], in reviewing published data on noise levels in schools, found a general reduction in classroom noise levels with increasing age. However, the occurrence of high noise levels in some Year 5 and Year 6 classes meant that the decreasing pattern was not repeated in all schools in the current survey, and is not reflected in the average levels for the 16 schools. Furthermore, there is no evidence of noise reduction with age if the levels for each activity are broken down into the different age groups.

3. Variation of noise with activity

The average L_{Aeq} and L_{A90} levels for each of the six classroom activities listed above are shown in Table IV.

It can be seen that the noise levels increase with activity number, as would be expected, given the nature of the work and communications involved in the activities defined above. There is a difference of 20 dB(A) on average between the quietest and noisiest classroom activities. When the children are engaged in the quietest activity, such as working in silence, doing a test or silent reading, the average ambient noise level is 56 dB L_{Aeq}. It is interesting to note that this level agrees with that measured by Hodgson in a university classroom with students present, but silent[32]. The noisiest activity, Activity 6, has an average level of 77 dB L_{Aeq}. The measured levels also agree closely with those of MacKenzie[25] who recorded an average background level of 55.5 dB(A) in acoustically untreated classrooms when pupils were silent, and an average level of 77.3 dB(A) when pupils were working.

4. Variation of noise within a school

Table V shows the averaged L_{Aeq} and L_{A90} levels measured within each school in the following types of space: occupied classrooms, unoccupied classrooms, corridors and foyer areas, occupied assembly halls and empty assembly halls.

The average L_{Aeq} of occupied classrooms is 72 dB(A). It can therefore be assumed that this represents a child's noise exposure during a school day. The average L_{A90} of occupied classrooms is 54 dB(A). The areas with the lowest noise levels, in terms of both L_{Aeq} and L_{A90} levels, are empty classrooms with average L_{Aeq} of 47 dB(A) and L_{A90} of 37 dB(A). There is thus a difference of 25 dB L_{Aeq} on average between the 'noisiest' and 'quietest' areas in a school, that is, between occupied and unoccupied classrooms. It can also be seen that the difference in noise level between an empty classroom and a classroom with children being 'silent' is 9 dB L_{Aeq}. This is similar to the difference found by MacKenzie[25] in acoustically untreated primary school classrooms where the average

unoccupied level was 44.7 dB(A) and average level with pupils silent was 55.5 dB(A). Hodgson[32] refers to the noise when pupils are silent as 'student-generated background noise' which includes noise such as movement of chairs and rustling of paper but not voices.

If the L_{Aeq} of empty classrooms is regarded as the 'background' level as defined in the World Health Organisation and other guidelines[2-4], then the averaged level measured here is 12 dB(A) higher than the guideline value.

5. Noise levels in empty classrooms

It was not possible from the results of the noise survey to identify the contribution of particular sources to the overall noise level, as reported by Hodgson *et al*[30]. Four of the seven rooms where heating/ventilation noise was heard were in the same school and examination of all the sound levels measured shows that the average levels for unoccupied classrooms in this school are the highest average levels measured out of the 16 schools (51.8 dB L_{Aeq} and 49.0 dB L_{A90}, compared with average levels for empty classrooms of 47.0 dB L_{Aeq} and 36.9 dB L_{A90}). However, the occupied classroom levels for this school are not higher than those for other schools (70.1 dB L_{Aeq} and 54.0 dB L_{A90}, compared with average levels of 72.1.0 dB L_{Aeq} and 54.1 dB L_{A90}), suggesting that ventilation system noise may not increase the noise levels in occupied classrooms.

6. Effects of age of school buildings

Of the 16 schools surveyed, six were in Victorian buildings and seven in 20th century buildings dating from the 1960s or later. The remaining three schools were housed in a mixture of Victorian and modern buildings. The space average noise levels of the Victorian schools and of the modern schools have been compared (the three schools in 'mixed'

buildings have been omitted from this analysis) to see if there are any differences between noise levels in ‘old’ and ‘new’ schools. The average levels of the two types of school are shown in Table VI. In unoccupied classrooms and assembly halls the background and underlying noise levels are the same for the two types of school. However, the levels in occupied spaces and in circulation spaces are slightly higher in the Victorian schools than in the more modern schools. This could be because room volumes in Victorian schools tend to be greater than those in modern buildings, with a corresponding increase in the amount of reflective surface area, so that the reverberant sound level may be higher in general in the Victorian schools. However, the sample size is too small for definite conclusions regarding the effect of the age of school buildings to be made.

7. Effects of glazing

Six of the 16 schools in the internal survey had windows of single pane glass while the other ten had some form of secondary or double glazing. Insufficient data were available for any quantification of the sound insulation of the schools' facades, or of the glazing. Measurement of the sound insulation was beyond the scope of this survey, and as the schools in the survey were all between 30 and 130 years old, no specifications of the building materials used were available. However, an attempt was made to examine the effectiveness of secondary/double glazing in schools by comparing the average space noise levels of the group of single glazed schools with those of the group of ten schools with secondary/double glazing. The average levels of the two groups are shown in Table VII. There is no repeated pattern to the differences between the groups: the ambient, background and underlying levels are very similar for occupied and unoccupied classrooms for both groups. However, it can be seen from Table VII that the background and underlying levels are slightly less, by between 1 and 5 dB(A), for the group of schools

with secondary glazing than for the single glazed schools. Again the sample size is too small for definite conclusions to be drawn.

V. RELATIONSHIP BETWEEN INTERNAL AND EXTERNAL NOISE

As stated earlier, the subjective impression formed during the survey of internal classroom noise was that the noise was dominated by the sound of the children's activities and was therefore not dependent upon the external noise environment.

To examine this further, for the 16 schools in the internal noise survey the internal L_{Aeq} and L_{A90} levels, classified by activity, age and space, were correlated with all the measured external noise parameters. It is recognised that this provides a relatively crude examination of the effects of external noise on the indoor noise environment, given that it was only possible to compare averaged internal and external noise levels, indoor and outdoor levels not having been measured simultaneously. However, statistically significant correlations were found between the L_{Aeq} for Activity 1 ('quiet', test conditions) and the external L_{Amin}, L_{A99} and L_{A90} levels. The correlation coefficients were high: 0.962, 0.975, and 0.960 respectively, all statistically significant at the 1% level. Thus it would appear that when children are engaged in quiet activities in the classroom the ambient classroom level is closely related to the background and underlying levels outside. This is consistent with the results of the questionnaire survey of over 2000 children and their teachers which was carried out in the borough of Haringey in parallel with the noise surveys. Children, particularly in the older age group (11 years) reported being able to hear a variety of external noise sources while in the classroom, and over 90% of the teachers questioned felt that noise affected the pupils' concentration[5].

An attempt was made to further examine the effectiveness of secondary/double glazing by correlating internal and external levels for each of the groups of single glazed

schools and those with secondary/double glazing. There were not sufficient data to obtain meaningful results for the set of single glazed schools. For the secondary/double glazed group, although there were only 4 schools for which there was relevant data, there were still significant positive correlations between Activity 1 L_{Aeq} levels and external L_{Amin}, L_{A99} and L_{A90} levels (L_{Amin}: $r = 0.914$, $p < 0.05$; L_{A99}: $r = 0.949$, $p < 0.05$; L_{A90}: $r = 0.995$, $p < 0.01$). This suggests that the secondary/double glazing is ineffective in these cases. This may be due to the specification or fitting of the glazing, or simply to the fact that no particularly 'noisy' events occurred outside these schools at the times of the measurements. Alternatively it could be because the predominant external noise is road traffic noise which tends to be mainly low frequency in character, and therefore more difficult to attenuate by glazing. However, there is insufficient data to draw any firm conclusions on the effectiveness of double or secondary glazing in schools.

VI. CONCLUSIONS

A survey of noise levels outside 142 primary schools in three London boroughs has shown that the average L_{Aeq}, measured over a typical 5 minute period during the school day, is approximately 57 dB(A). However, there was a wide range of levels for all the parameters measured, with some schools in supposedly 'noisy' areas being exposed to relatively low levels of noise. This suggests that in work concerning environmental noise exposure at school it is necessary to measure the noise rather than rely on noise contours or noise maps to give an indication of a school's noise exposure level.

The predominant noise source outside the London schools surveyed was road traffic, in particular cars, which could be heard outside 86% of the schools. Although schools where aircraft noise dominates the noise environment were deliberately excluded from this study, aircraft could be heard at over 50% of the schools surveyed.

The noise inside classrooms is, in general, dominated by the noise of children and depends upon the particular classroom activity in which they are engaged, there being a range of approximately 20 dB(A) between the quietest and noisiest activity. The age of the children was not closely related to noise levels, but there were significant relationships between number of children in a classroom and the ambient and background classroom noise levels. The average L_{Aeq} of occupied teaching spaces, which could be assumed to be the average exposure for a child at school, was found to be 72 dB L_{Aeq}.

Subjectively external noise appeared to have little effect on the internal noise environment. Correlation analysis confirmed that this is the case for the majority of classroom activities. However, when children are engaged in a quiet activity such as silent reading or doing a test then the noise level in the classroom is closely related to the background and underlying levels outside. Thus children may be distracted by the noise and their concentration affected at times when they are working in silent conditions.

The survey has shown that the presence of pupils, even when silent, increases the noise level in a classroom. The appropriate measurement to compare with guideline values is therefore the average L_{Aeq} in *unoccupied* classrooms. In this survey this level was 47 dB(A), which is 12 dB(A) above the level of 35 dB(A) recommended by published guidelines [2-4].

The levels measured relate to schools in an urban area. It is reasonable to assume that schools in rural areas, especially those away from main roads and airports would have lower noise exposures. However, as the internal classroom noise depends on classroom

activity, it could be assumed that internal levels in other schools would be similar to those in schools in urban areas. Further investigation is needed to examine noise levels in schools in suburban and rural areas for comparison with urban schools.

VII. ACKNOWLEDGEMENTS

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TABLE I

Means and standard deviations of external levels in each borough

	$L_{Aeq,5min}$		$L_{A10,5min}$		$L_{A90,5min}$		$L_{A99,5min}$		$L_{Amax,5min}$		$L_{Amin,5min}$	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Haringey	57.4	8.8	59.4	9.0	49.2	7.7	47.0	7.4	70.5	10.5	46.0	7.5
Islington	56.2	9.4	58.4	9.9	46.5	9.3	44.3	9.2	68.3	17.0	41.3	12.4
Lambeth	58.9	7.4	61.2	7.7	50.2	8.2	47.8	8.2	72.0	9.0	47.0	8.3

TABLE II

Means, standard deviations and ranges of external levels (dB(A))

	$L_{Aeq,5min}$	$L_{A10,5min}$	$L_{A90,5min}$	$L_{A99,5min}$	$L_{Amax,5min}$	$L_{Amin,5min}$
Mean	57.4	59.6	48.5	46.3	70.1	44.6
sd	8.7	9.0	8.6	8.6	12.9	10.0
Range	31 - 78	32 - 81	25 - 71	21 - 68	42 - 93	20 - 67

TABLE III

Average L_{Aeq} and L_{A90} levels for different age groups

	CLASS/AGE							
	Nursery (3-4)	Reception (4-5)	Year 1 (5-6)	Year 2 (6-7)	Year 3 (7-8)	Year 4 (8-9)	Year 5 (9-10)	Year 6 (10-11)
L_{Aeq}	71.9	73.9	74.3	66.3	68.9	69.6	73.2	71.2
L_{A90}	57.3	62.3	61.0	51.3	52.5	49.8	53.8	52.9

TABLE IV

Average L_{Aeq} and L_{A90} levels for different classroom activities

	ACTIVITY					
	Activity 1 *Silent reading/test*	Activity 2 *1 person speaking*	Activity 3 *Individual work*	Activity 4 *Individual work and movement*	Activity 5 *Group work*	Activity 6 *Group work and movement*
L_{Aeq}	56.3	61.2	64.7	72.2	72.9	76.8
L_{A90}	42.4	45.8	52.1	59.6	58.6	63.9

TABLE V

Average L_{Aeq} and L_{A90} levels in various school locations

	SPACE				
	Occupied teaching space	Unoccupied classrooms	Corridor/ foyer/ stairs	Occupied hall	Unoccupied hall
L_{Aeq}	72.1	47.0	58.1	73.4	53.2
L_{A90}	54.1	36.9	44.6	55.1	44.3

TABLE VI

Average noise levels in Victorian and modern schools

	Occupied teaching space		Unoccupied classrooms		Corridors/ foyers/stairs		Occupied assembly hall		Unoccupied assembly hall	
	Vict[n]	Mod	Vict[n]	Mod	Vict[n]	Mod	Vict[n]	Mod	Vict[n]	Mod
L_{Aeq}	72.0	71.5	46.0	49.2	61.3	55.0	75.7	70.2	54.4	51.3
L_{A90}	56.2	52.5	38.2	38.5	46.2	43.3	58.7	50.2	44.8	45.0

TABLE VII

Average noise levels in schools with single and secondary/double glazing

	Occupied teaching space		Unoccupied classrooms		Corridors/foyers/stairs		Occupied assembly hall		Unoccupied assembly hall	
	Single glazing	2nd ry glazing	Single glazing	2nd ry glazing	Single glazing	2nd ry glazing	Single glazing	2nd ry glazing	Single glazing	2nd ry glazing
L_{Aeq}	71.4	71.8	47.3	47.4	60.6	55.6	70.9	74.4	54.7	49.7
L_{A90}	54.6	53.8	38.1	36.0	46.4	43.7	58.2	53.3	46.3	41.7

FIGURES

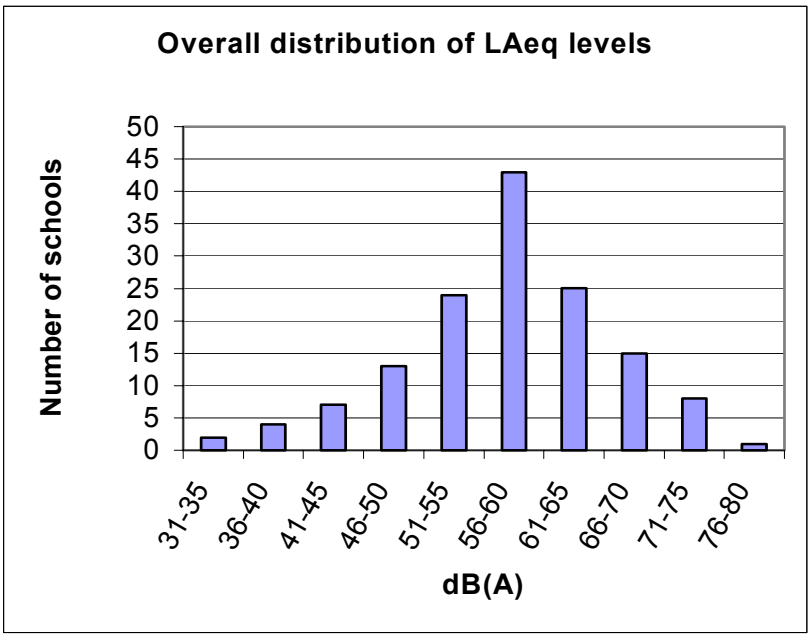

Figure 1. Distribution of external $L_{Aeq,5min}$ levels

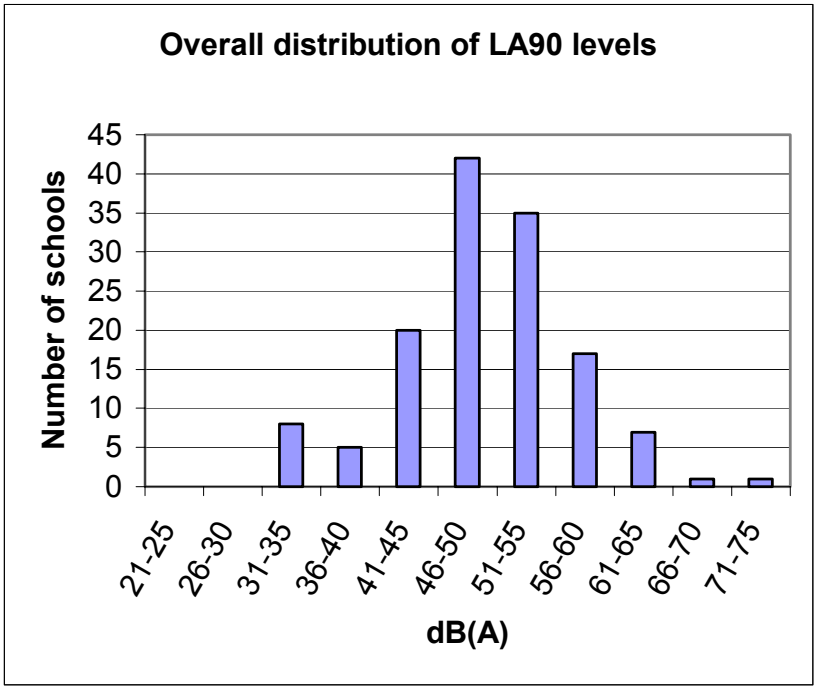

Figure 2. Distribution of external $L_{A90,5min}$ levels

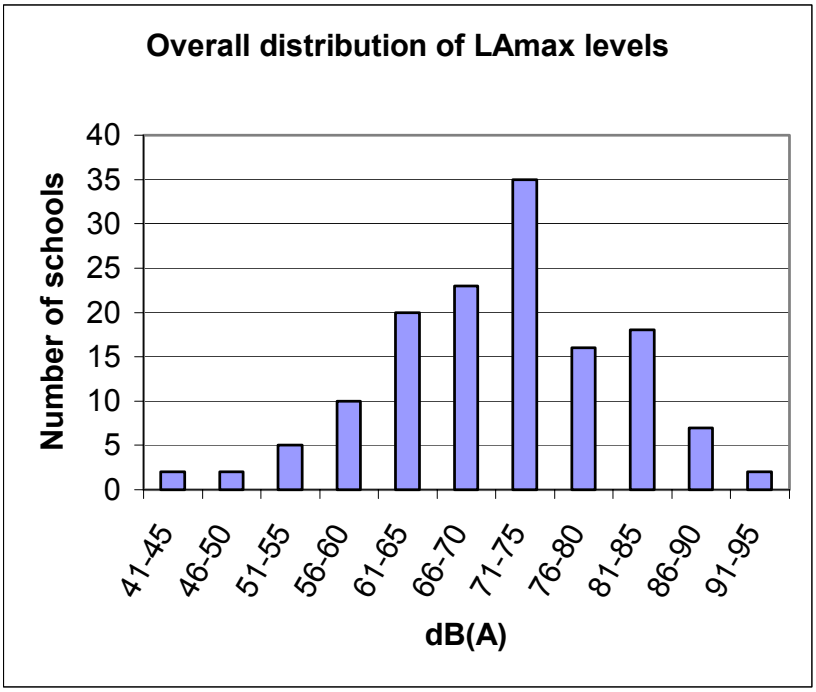

Figure 3. Distribution of external $L_{Amax,5min}$ levels

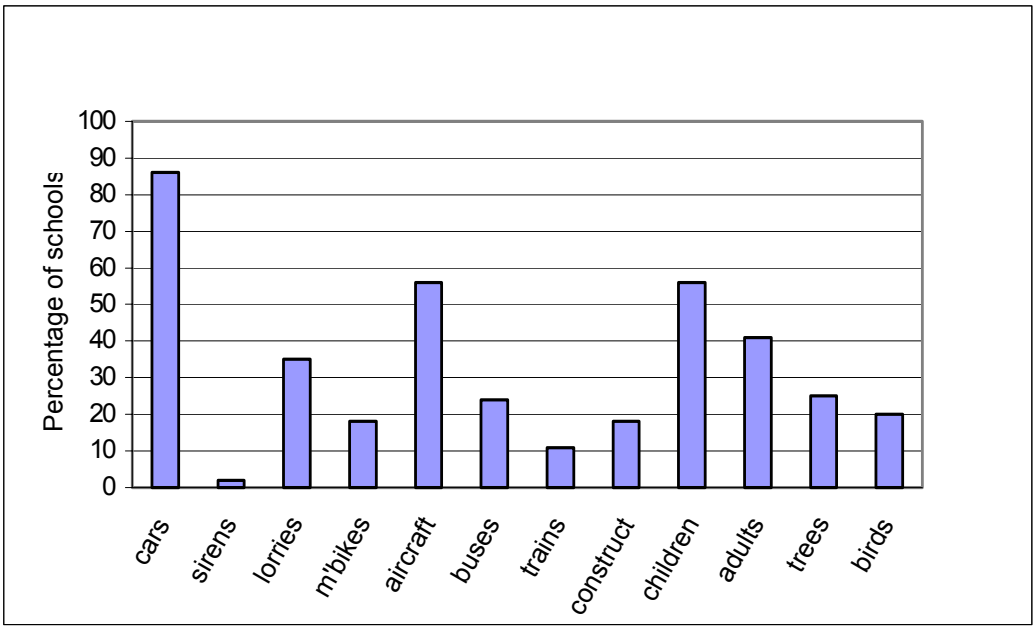

Figure 4. Incidence of commonly occurring noise sources outside schools

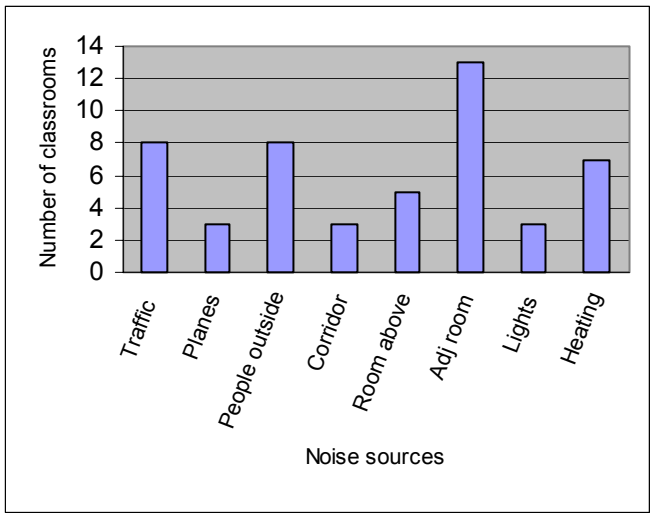

Figure 5. Incidence of commonly occurring noise sources in empty classrooms

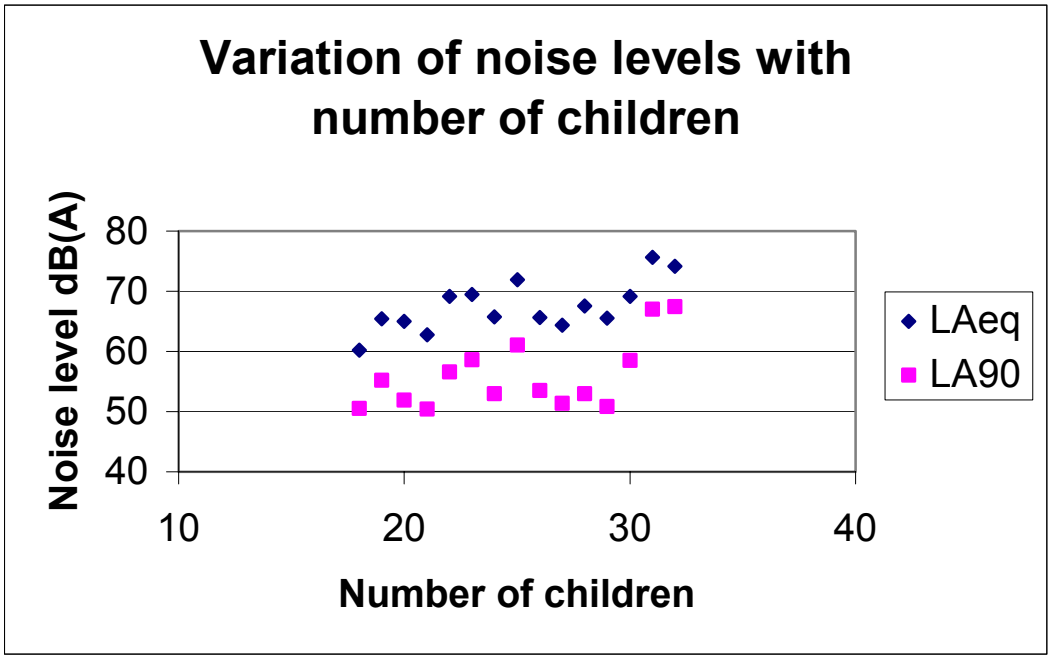

Figure 6. Relationship between classroom L_{Aeq} and L_{A90} levels and number of children