COMPLIANCE OF OPEN PLAN LEARNING SPACES WITH BUILDING BULLETIN 93

Emma Tate-Harte — Faculty of Engineering, Science and the Built Environment, London South Bank University, UK
Bridget M. Shield — Faculty of Engineering, Science and the Built Environment, London South Bank University, UK

1 INTRODUCTION

A current research project involves investigating room acoustics and speech intelligibility in open plan primary school classrooms using both objective measurements (room acoustic data) and subjective techniques (pupil and teacher questionnaire surveys). This paper reports some preliminary analysis of the objective data obtained to date, plus observations arising from the acoustic survey.

The project aims to investigate compliance of open plan learning spaces with current acoustic standards, legislation and guidance by addressing classroom organisation and management in addition to the acoustic design of the classroom. The outcomes of the project will be used to aid design of future school buildings.

2 OPEN PLAN CLASSROOMS

2.1 A brief history of open plan classrooms

Open plan classrooms, particularly in primary schools, became popular following the publication of the Plowden Report in 1967. This report promoted child centred teaching methods, self directed learning, and the development of children's social as well as academic development. The open plan classroom accommodated the wide variety of activity spaces, layouts and resources required to support individual learning techniques, and was particularly suitable for team (specialist) teaching methods. Removal of walls and doors also met cost and space limits by absorbing redundant ancillary areas into the main teaching space.

By 1976, 10% of UK primary schools were based upon open plan design[1]. This prolific increase in open plan school building prompted research by educationalists, acousticians and other disciplines. Various aspects of open plan schools were investigated, including pupil and teacher attitudes[1], performance standards[2], teaching methods and organisation[1,3], and acoustic assessments[3-8]. Generally, higher noise levels were measured in open plan environments[1-8]. However opinions were divided on whether this would cause distraction and affect performance. Often the *type* of noise rather than noise level was considered to be more important in determining levels of distraction[4,7,8]. Teaching activities had to be carefully planned and organised in order for the open plan design to work successfully.

Open plan classroom designs were open to criticism following some research reports, and the reactionary social and political climate of the late 1970s and early 1980s. The introduction of the National Curriculum brought about further changes in education methods in 1988, and the Alexander Report, published in 1992, purported that too much time was spent on individual teaching, and promoted whole class teaching to improve pupil-teacher contact time. More recently, the National Literacy Strategy, implemented in 1998, has set out a precisely defined daily literacy hour to include a whole class work session. Higher intrusive noise levels made it difficult for the teacher to communicate to a whole class seated at desks, especially in those open plan classrooms where little partitioning or absorbent treatment was used. As a result, many schools with open plan classrooms sought remedial treatment in the form of full or partial height walls and partitions, to accommodate the new brand of teaching methods. Other educationalists reacted by implementing a hybrid approach to teaching, combining both individual and whole class learning. In the 1990s, several post-Plowden 'semi-open' plan classroom designs were constructed, which accommodated these hybrid techniques. Semi-open plan designs are generally open but teaching spaces are defined by walls which have openings within them.

2.2 Open plan classrooms today

As a result of the changing trends in education, today's open plan classroom tends to be semi-open with restricted openings to limit noise transfer (most of the fully open plan classrooms built in the 1970s have undergone remedial treatment to achieve this). Classrooms are arranged linearly or in a cluster, with a central shared resource area.

The more successful classrooms tend to limit the number of pupils sharing an open space. Enclosed rooms are provided for quiet activities (e.g. special needs learning), and teachers generally co-ordinate teaching activities so that conflicts do not occur between adjacent classrooms. Teachers often make use of a 'carpet' area, situated away from the classroom opening, so that the whole class can gather closely together around the teacher for critical listening times such as the daily literacy hour. Rather than addressing a whole class at their desks, teachers tend to walk around the room, giving individual instruction. This design is particularly suitable for teaching the primary school years.

Today, Britain is investing in the largest building programme for new schools since the Plowden schools of the mid 1970s. The Government's 'Building Schools for the Future' programme aims to rebuild or renew every secondary school in England over a 10-15 year period. Further investment has been injected to rebuild or refurbish at least half of all primary schools. In addressing the issue of the future of school building design, the DfES have produced several publications highlighting future trends in learning and school design[9-11]. Open planning is a strong element in many of the published designs, as a move towards project based learning and student centred methods is predicted. Some of the new high profile City Academy schools have major open plan design elements. One such Academy has recently faced strong criticism, and plans have now been announced to enclose the three-walled classrooms – a repeat of circumstances in the 1970s.

Educational buildings and teaching methods are among the first to reflect current social and political trends, and as such, classrooms designed to accommodate a specific learning method often face strong reaction. Designers often try to predict future changes and trends in order to accommodate flexibility in design and to 'future proof' educational buildings. However since changes in classroom design trends often outrun the frequency of new school building, it is clear that new schools must incorporate facilities to support a variety of learning methods, including both whole class and individual teaching.

2.3 Classroom acoustics and guidelines

Design advice on school acoustics has long been available in the form of DfES Building Bulletins (BBs) and Guidance notes[12,13]. Since 2003 schools have been included within the scope of the Building Regulations. The normal way of satisfying requirement E4 of the Building Regulations is to meet the performance standards given in Section 1 of BB93[14]. These performance standards include criteria for ambient noise level, reverberation time and sound insulation, appropriate to enclosed classrooms. The performance criteria are largely based on existing research and extensive surveys[15-17] in existing classrooms, and aim to facilitate good speech intelligibility and prevent interference from noise in other areas of the school.

Speech intelligibility in open plan classrooms cannot be assured from the usual criteria, due to the complex layout of the room and the extent of multiple activities. Instead, BB93[14] requires a computer model of the classroom to be implemented to predict the speech transmission index (STI) in the classroom, based on a specific open plan layout and activity plan. BB93[14] requires a performance standard of at least STI = 0.6, which corresponds to 'good' or excellent' conditions. Some further performance standards required by BB93 for open plan and other classrooms are given in Table 1.

BB93 performance standard	Primary school classroom	Open plan teaching area
Speech Transmission Index, STI	-	> 0.60
Reverberation time (T_{mf})	< 0. 6 seconds	< 0.8 seconds
Ambient noise level ($L_{Aeq,30min}$)	= 35 dB	= 40 dB

Table 1: Summary of performance standards required by BB93 in open plan classrooms

In addition to the current legislation, recommended background noise levels for open plan classrooms were proposed in the research literature of the 1970s. Some suggested a satisfactory level of 50-70 dB(A) for when class groups were engaged in a similar activity and working closely together[8]. It was generally accepted that noise levels in excess of 70 dB(A) would impair language development and limit communication to two metres with a raised voice level, and also produce other factors such as emotional irritation, lack of motivation, disturbance of mental work, speech interference, reduced concentration and fatigue[4].

Walsh[4] proposed a maximum average (L_{A50}) background (i.e. intrusive) noise level of 65 dB(A), based on studies into annoyance. This is consistent with recent research findings, where classroom babble played at 65 dB(A) during performance testing in classrooms had a significant detrimental effect on children's performance in the classroom, particularly on verbal tasks such as reading and spelling[16]. Walsh[4] demonstrated that a fluctuating noise level was perceived to be much more annoying than a more consistent noise at the same average level (maintained by masking from adjacent classrooms) and proposed limits of acceptability for the statistical distribution of noise levels (maximum L_{A10}, L_{A50} and L_{A90} values).

BB93 includes computer modelling guidance and case study examples of measurements. However a detailed survey of speech intelligibility conditions in existing open plan schools (based on noise measurements of the classroom activity, classroom layouts and activity plans etc) has not previously been undertaken. The current project aims to address this lack of research through survey and analysis work in a range of open plan classroom designs.

3 THE CURRENT PROJECT

3.1 Classrooms included in survey

Preliminary measurements have been carried out in a total of 41 open plan classrooms (Years 1-6) in 12 primary schools. Rooms measured include a mixture of Plowden (1970s) and post-Plowden (1990s) designs. In addition, subjective data have been obtained from 870 children and 80 teachers. The preliminary results presented in this paper are taken from acoustic surveys of 29 classrooms in seven schools. Of these, two are original Plowden designs and five are post-Plowden designs. School and classroom details are presented in Table 2.

School	No. classrooms	Built	Year	Layout	No. classes sharing area
1	1	1976	2	Linear (courtyard)	5
2	3	1997	2	Linear	3
3	3	1992	2-3	Cluster	3
4	3	1992	2-3	Cluster	3
5	3	1972	2-3	Cluster	5
6	8	1992	3-6	Cluster	5
7	8	1990	3-6	Linear	14

Table 2: Summary of classroom details (preliminary data set)

3.2 Measurement procedure

Classrooms were assessed for teacher-student speech communication, assuming that the main class was engaged in a critical listening activity (i.e. quiet and listening to the teacher speak). Obtaining realistic occupied measurements of this situation is very difficult, since in reality the activity noise in the main classroom would include the teacher's voice (this has to be simulated during STI measurements). Therefore noise measurements were carried out with the main classroom unoccupied and surrounding classrooms occupied, i.e. the intrusive noise alone was measured. STI measurements were carried out with all classrooms unoccupied, and effects of intrusive noise were obtained through post processing of the data.

3.2.1 Noise

Sample measurements of the intrusive noise level from adjacent spaces ($L_{Aeq,2min}$) were carried out in the unoccupied main classroom, using a Larson and Davis 824 sound level meter. Statistical parameters (L_{A10}, L_{A20}, L_{A30}, L_{A40}, L_{A50}, L_{A90}) were also recorded. Noise measurements were carried out in three main positions: at the back of the classroom near the opening (worst case); in the middle of the room; and at the front on the carpet near to the teacher's usual position. The dominant activity occurring in adjacent classrooms was recorded using the following categories as identified in previous research[17]:

- One person speaking at any one time
- Individual work with some talking
- Individual work with talking and movement
- Group work with some talking
- Group work with talking and movement

The ambient classroom noise level ($L_{Aeq,\ 5min}$) with all spaces unoccupied was also measured.

3.2.2 Speech Transmission Index

Measurements of STI were carried out in unoccupied rooms at six receiver positions with one source position. Source and receiver positions were arranged to represent the typical use of the classroom by teachers and children. Source and receiver heights were set at 1.6 m and 1.2 m respectively as recommended in BB93. The Speech Transmission Index was measured in accordance with BS 60268-16:2003[18] using WinMLS, a PC based analyser with a professional soundcard. A Maximum Length Sequence signal, shaped to the average long term spectrum for raised voice, was sent to the sound source. The output signal was adjusted to 66.5 dB(A) at 1 m (i.e. vocal effort for 'raised' voice).

The sound source was an ASC MK III head–sized loudspeaker with a cone diameter of 10 mm. An omni directional microphone was used as the receiver. Pilot tests were carried out to compare the performance of a GRAS 44A M mouth simulator and the head sized loudspeaker source. The tests found that use of the head sized loudspeaker resulted in a small over-estimation in STI, although this was equal to the typical standard deviation of STI for measurements at a fixed position under steady state conditions[19].

Occupancy noise was corrected for during post processing of results. It has been shown[20] that the value of STI in the presence of ambient noise may be determined from two independent measurements: the noiseless system impulse response (SNR>15 dB), and the measured system signal-to-noise ratio. This is convenient for when expected background noise levels cannot be experienced in a measurement situation. The broadcast simulated speech signal was sampled at each receiver position using a Larson and Davis 824 sound level meter. Thus the STI measured in noiseless conditions was corrected using the speech and intrusive noise level samples to obtain the STI in a variety of speech/noise situations. When compared to direct measurement method (using a calibrated microphone to measure speech and noise levels), this correction method was verified to be accurate to within 0.01 STI.

3.2.3 Reverberation time

The reverberation time was measured at three receiver positions with two source positions. An omni-directional loudspeaker was used as the test source, located at a height of 1.6 m. The microphone was set at a height of 1.2 m. The reverberation time was measured using a log-sine sweep excitation signal on the WinMLS analyser. This has been shown to be a more robust method compared to MLS, impulsive or other methods[20].

4 RESULTS AND DISCUSSION

4.1 Noise levels

Of the thirty measurements carried out in the classrooms, the mean ambient noise level was $L_{Aeq,5min}$ 35 dB, with levels ranging between 33 and 40 dB. Results were generally consistent between schools and classrooms (standard deviation = 1.6 dB). It should be noted that the 5 minute samples only give an approximation of the $L_{Aeq,30min}$ performance standard as required by BB93. However most schools were situated on quiet sites exposed to very little traffic noise, therefore the 5 minute sample may be considered a reasonable indicator of the 30 minute L_{Aeq}.

All classrooms achieved the BB93 maximum criterion for ambient noise levels in open plan teaching spaces of 40 dB(A). In addition, 63% of the classrooms met the BB93 standard of 35 dB for primary school class bases. Those which exceeded this criterion had higher levels of building services noise, rather than external noise.

A summary of the average measured intrusive noise levels is outlined in Table 3. Note that the main classroom was unoccupied during measurements. Overall the most commonly occurring classroom activity during noise measurements was individual work at tables, followed by whole class critical listening activities (i.e. one person talking at any one time), and then individual work with movement. Group work (either at tables or with movement) occurred much less frequently. This finding is consistent with a recent observational study of primary school lessons[21], in which the most common form of class organisation was whole class and individual teaching, with group work observed in less than 10% of lessons.

Since the sample sizes are very low for group work activities (at tables and with movement), results for this preliminary data set should be regarded as approximate, pending analysis of further data. However Table 3 indicates a general trend for intrusive noise levels to increase with increasing activity in the adjacent classrooms.

Adjacent activity	Mean L_{Aeq} (dB)	N	Std. Deviation (dB)
One person talking	48	102	4.4
Individual work at tables	55	229	4.8
Individual work with movement	57	44	3.5
Group work at tables	53	7	5.6
Group work with movement	62	13	6.4

Table 3: Summary of intrusive noise levels

Figure 1 shows the average intrusive noise levels measured for each different activity and measurement position (the number of samples n is indicated on each bar). Noise levels for each activity also increase as the position moves towards the back of the class (i.e. near the opening). This has a detrimental effect on the speech-to-noise ratio at the back of the class, where speech levels are lowest and intrusive noise levels are highest.

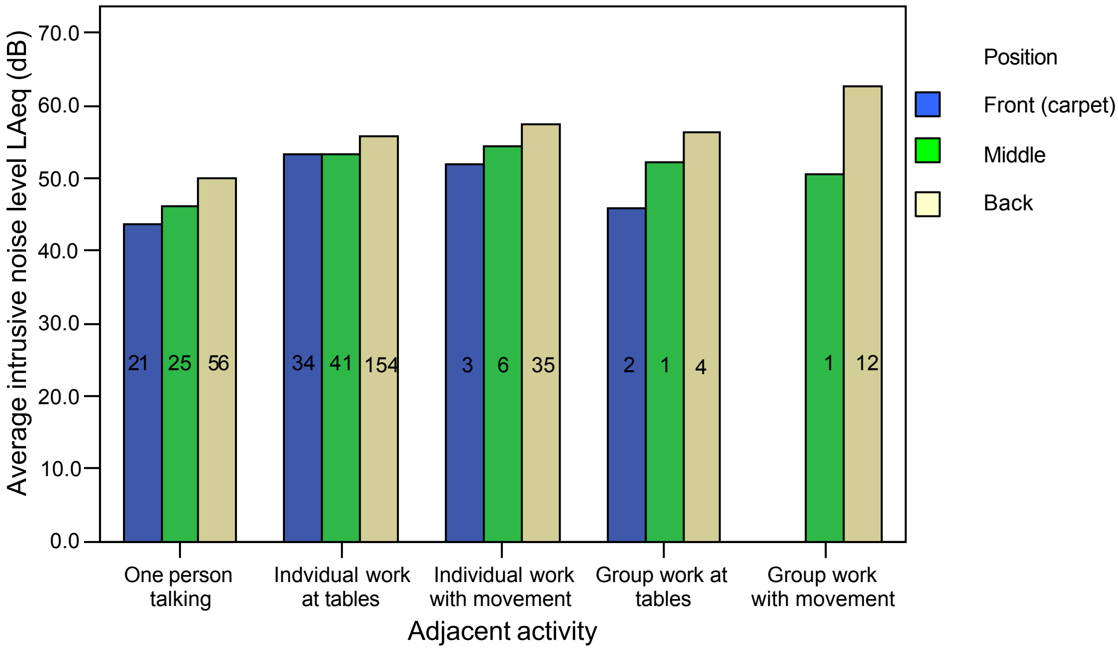

Figure 1: Summary of measured intrusive noise levels

The level of classroom noise is not only important to achieve good speech intelligibility. The measured intrusive noise levels can be related to recommended noise limits to avoid distraction and annoyance. The measured statistical noise parameters (L_{A10}, L_{A20}, L_{A30}, L_{A40}, L_{A50}, L_{A90}) are plotted in Figures 2 and 3 as a function of noise level and compared to the recommended noise distribution limits proposed by Walsh[4]. The graphs are split into acceptable, unacceptable and marginal recommended regions.

Figure 2 includes those classrooms situated in an open layout of three class bases (referred to as 'limited layouts'). Figure 3 includes rooms situated in a layout of more than three class bases (referred to as 'large' layouts). The figures show that noise levels were acceptable for the three class base layout, however noise levels for layouts with more than three class bases were higher, with some measurements falling into the unacceptable region, where distraction and annoyance are likely.

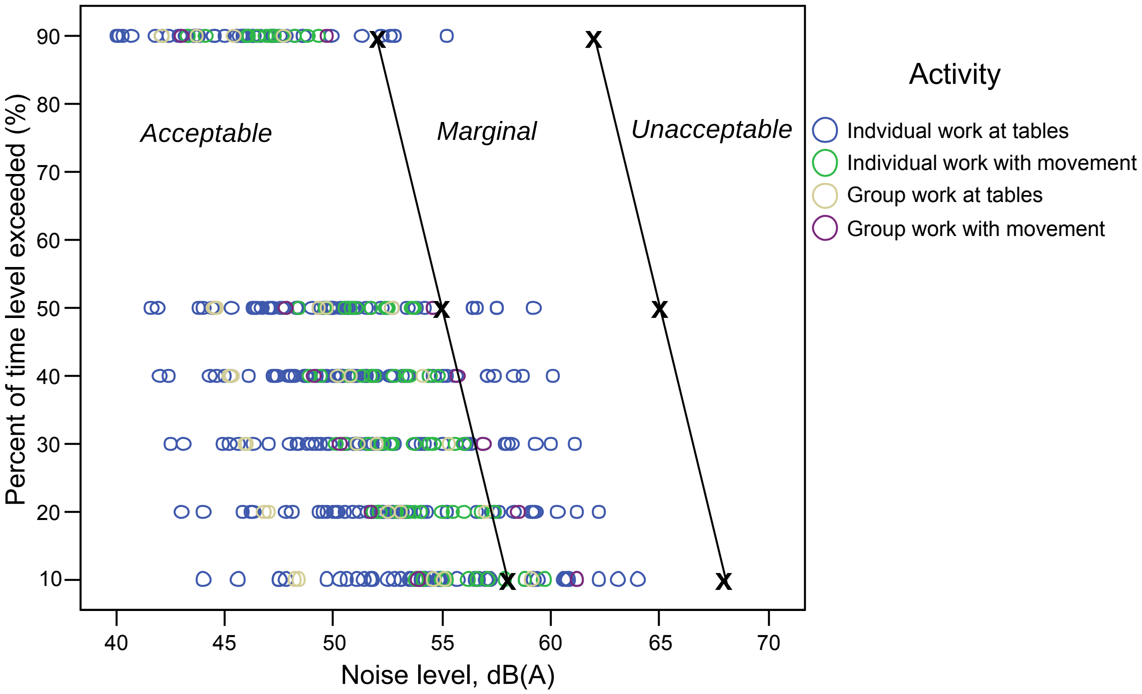

Figure 2: Statistical distribution of intrusive noise levels (limited layout)

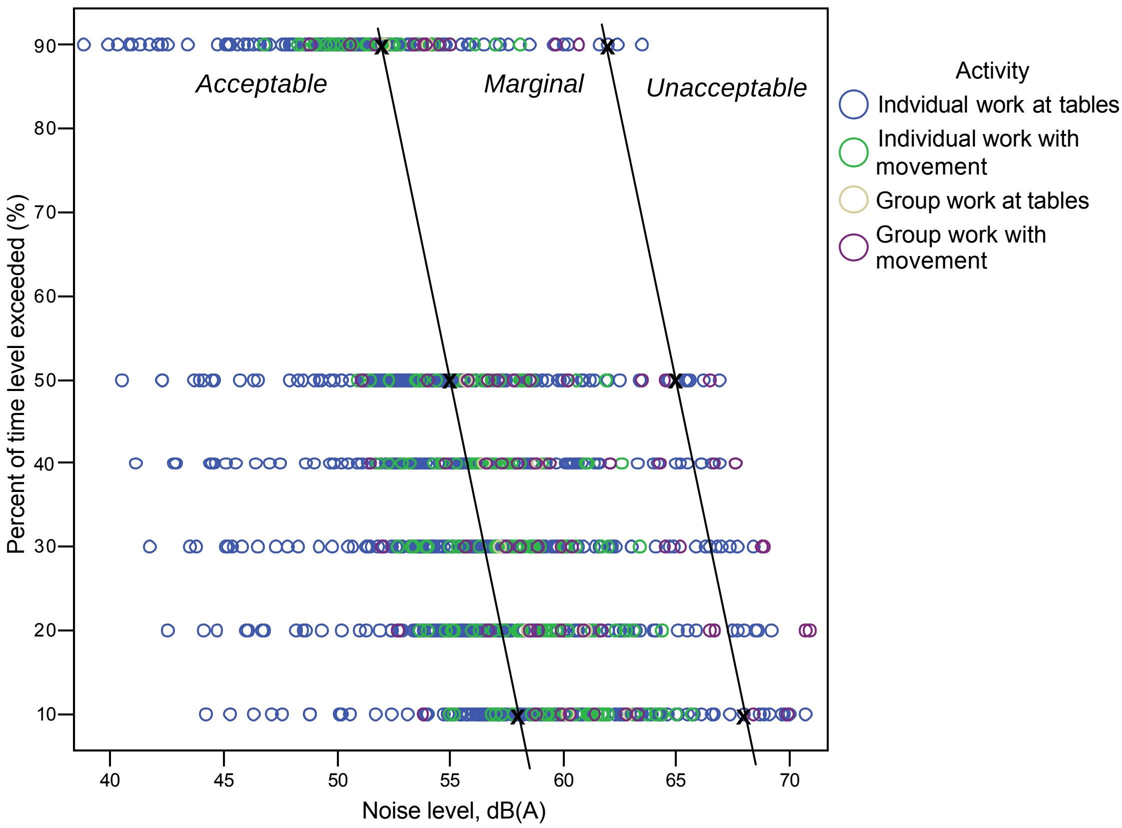

Figure 3: Statistical distribution of intrusive noise levels (large layout)

4.2 Speech Transmission Index

Figures 4 and 5 present the mean STI achieved for each type of activity at each position, for limited and large layouts respectively. Again the number of samples n is indicated on each bar, and as with the measured noise samples, the data set for group work and work with movement in particular should be regarded as preliminary. As expected, for the measurements with a significant number of samples there is a general trend for the STI to decrease with increasing level of activity, and for the STI to decrease as the position moves towards the 'back' of the class (i.e. the measurement moves further away from the teacher and nearer to the noise source).

For the limited layout (Figure 4), the BB93 criterion of STI > 0.6 was achieved at the front and middle positions for reasonable levels of adjacent classroom activity (i.e. individual work at tables). However for this activity, at the back (opening) of the class, the criterion was not achieved. Therefore, if activities are not co-ordinated, children should gather closer to the teacher, away from the opening for listening tasks.

When activities were co-ordinated for this layout (e.g. all classes engaged in listening with one person speaking), the criterion was achieved for all measurement positions, implying that whole class teaching at desks may be possible under these circumstances. When the adjacent activities involved movement, the BB93 criterion was not achieved for any position in the class. For the large layout (Figure 5), the BB93 criterion was only met at the front and middle positions when activities were co-ordinated (e.g. adjacent groups involved in listening activity, with one person talking).

Figures 6 and 7 show each STI sample plotted as a function of the measured intrusive noise level for all classrooms and for those with limited layout respectively. For all classrooms (Figure 6) a strong negative correlation was obtained (the multiple correlation coefficient for the third order polynomial fit to the data was 0.92, with a standard error of 5.6%). Considering the 95% confidence intervals shown, it appears that a limiting maximum intrusive noise level of L_{Aeq} 51-55 dB is necessary to achieve the BB93 criterion of STI 0.6. This condition was achieved with reasonable activity in adjacent rooms including individual work at tables. Figure 7 shows that those classrooms where layouts were restricted to three class bases were more likely to achieve this criterion, particularly when the listening position was at the front of the class.

It is interesting to note that the L_{Aeq} maximum noise level necessary to achieve the BB93 criterion is about 10 dB less than the recommended maximum L_{A50} intrusive noise level to avoid distraction (for these purposes, it is assumed that the intrusive L_{Aeq} is very similar to the L_{A50}). It may therefore be appropriate to consider different criteria for the following situations:

- When the main class and surrounding classes are engaged in individual/group work activity, therefore listening (STI) is not as critical (i.e. consider maximum intrusive noise level of L_{A50} 65 dB to avoid distraction)
- When the main class is involved in critical listening (i.e. control of intrusive noise levels to L_{Aeq} 55 dB to obtain BB93 criterion of STI 0.6).

Figure 8 shows STI plotted as a function of A-weighted speech-to-noise ratio, S/N(A), which was calculated from the measured intrusive noise level and the measured speech level at each sample position. A third order polynomial curve was fitted to the data set (multiple correlation coefficient 0.95; standard error of 4.5%). It can be seen from the figure that an S/N(A) of around 8 dB(A) is required to achieve the BB93 criterion of STI 0.6. This condition was achieved with reasonable activity in adjacent rooms including instances of individual work at tables. Generally more active tasks that involved movement did not achieve the criterion.

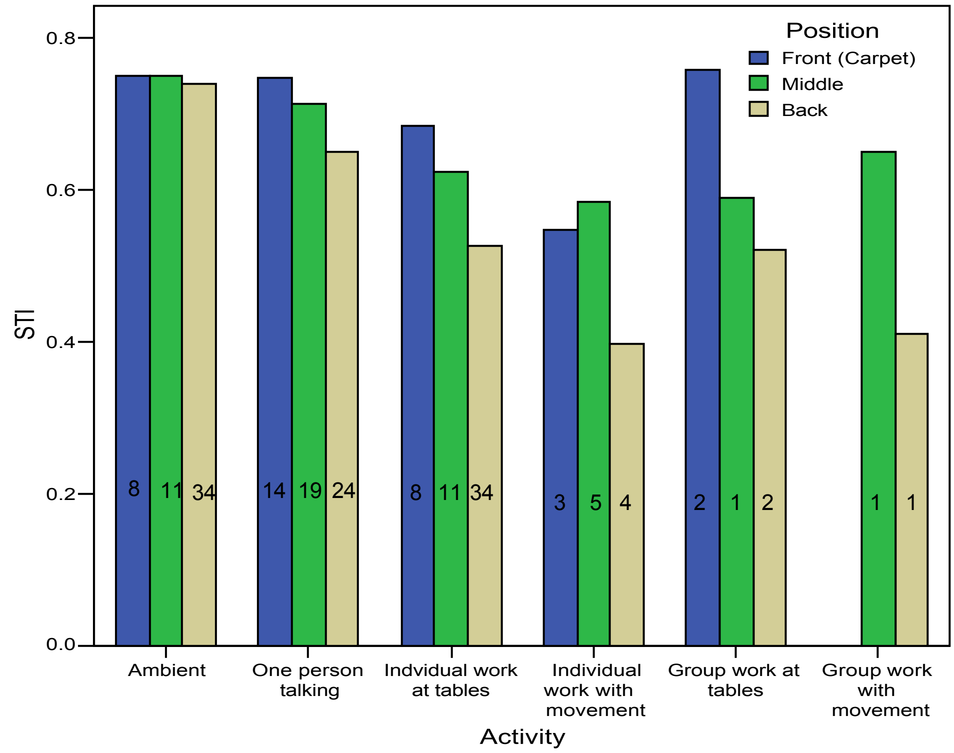

Figure 4: Mean STI: Limited layout

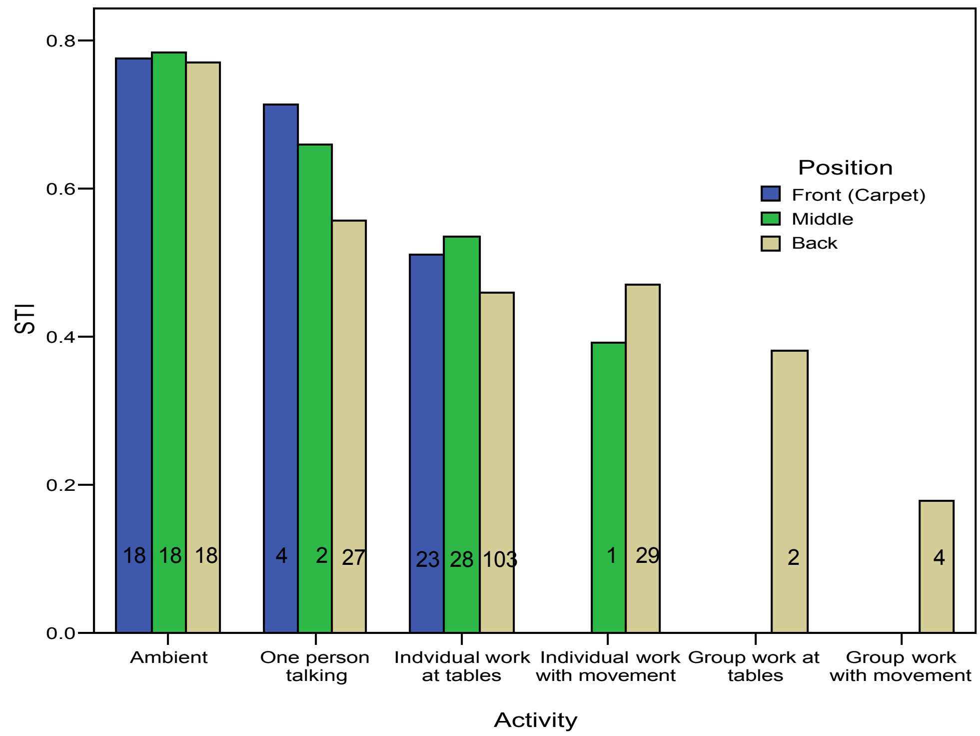

Figure 5: Mean STI: Large layout

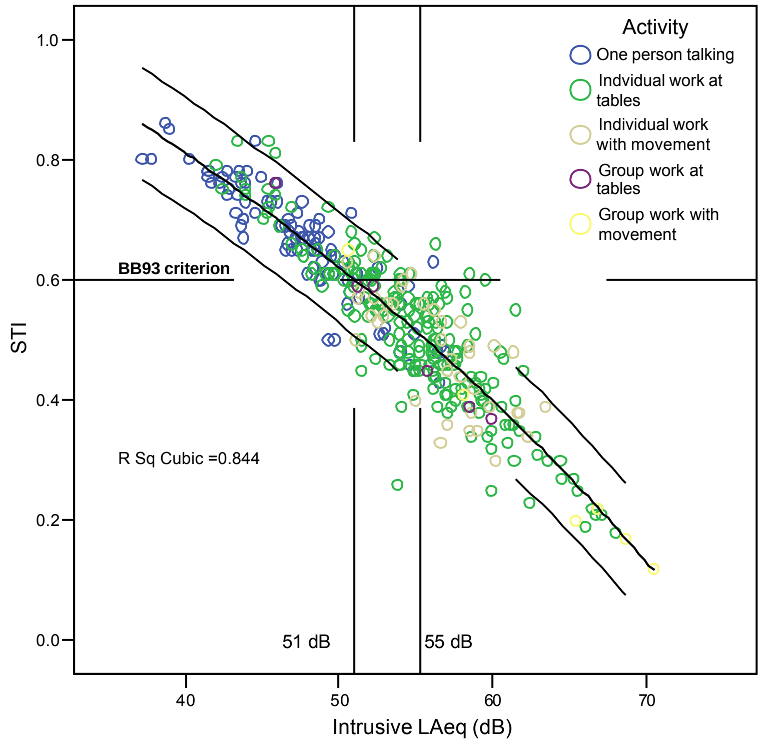

Figure 6: STI and intrusive noise level (all classrooms)

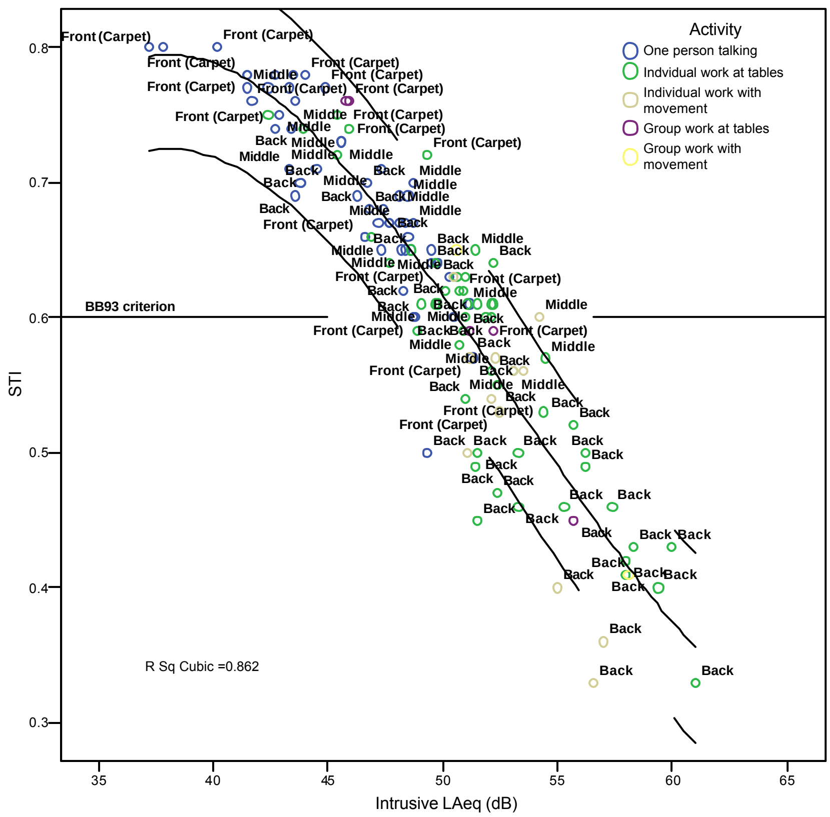

Figure 7: STI and intrusive noise level (limited layout)

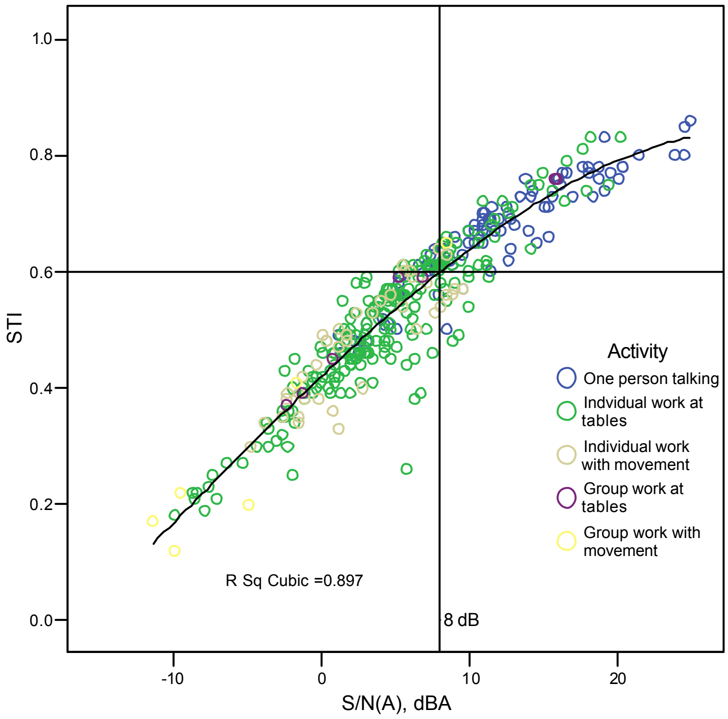

Figure 8: STI and Speech to Noise ratio

It should be noted that although a speech-to-noise ratio of around 8 dB is generally adequate for adults and older children with normal hearing[22], a greater S/N(A) is necessary for younger[23] and more vulnerable listeners[24] to achieve equivalent scores in speech intelligibility. For this reason an S/N(A) of at least 15 dB is usually recommended for classrooms[23-25].

In view of this, it could be argued that the BB93 standard of STI 0.6 is not sufficient to provide effective signal to noise ratio, which could result in additional strain on both talker and listeners, especially younger and more vulnerable children.

However, there is some trade off between S/N(A) and reverberation time. Bradley[15] showed that as reverberation time decreased below 0.7 seconds, some increase in background noise levels could be tolerated whilst still expecting 100% speech intelligibility scores for normal hearing children.

4.3 Reverberation time

The mid-frequency reverberation times were very low (mean T_{mf} less than 0.4 s) and consistent between classrooms in each school (s.d. <10%) except for two schools (schools 2 and 6) which did not have acoustic ceilings or fully carpeted floors (marked with asterisk * in Figure 9). All classrooms measured met the BB93 requirement for open-plan teaching areas (maximum 0.8 seconds) and all except those in school 2 met the BB93 requirement for primary school classbases (maximum 0.6 seconds). Classrooms were measured with furniture and fittings in place. The reverberation time is likely to be slightly higher when measured without fixtures and fittings (as required by BB93). However those rooms with full ceiling and floor treatment are still likely to meet requirements.

Figure 9 shows reverberation time plotted against ambient STI (measured in unoccupied classrooms). The third order polynomial line of best fit in Figure 9 indicates that the optimum maximum reverberation time (for classrooms measured in situ with furniture and fittings) is around 0.4 - 0.5 seconds. After this point a steep drop off in STI can be observed.

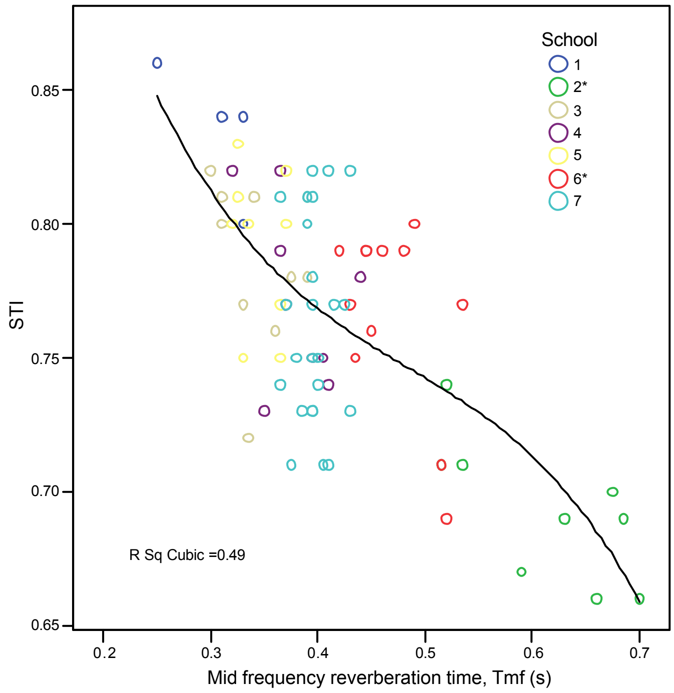

Figure 9: Reverberation times and ambient STI

In Figure 10 the STI was plotted as a function of S/N(A) for classrooms with a T_{mf} of 0.4 s or less. Here the tolerated increase in background noise for shorter reverberation times can be observed, with a reduced S/N(A) of 7 dB necessary to achieve the criterion. Layouts with smaller volumes generally appear to perform better, as shown by the number of classrooms in the layout.

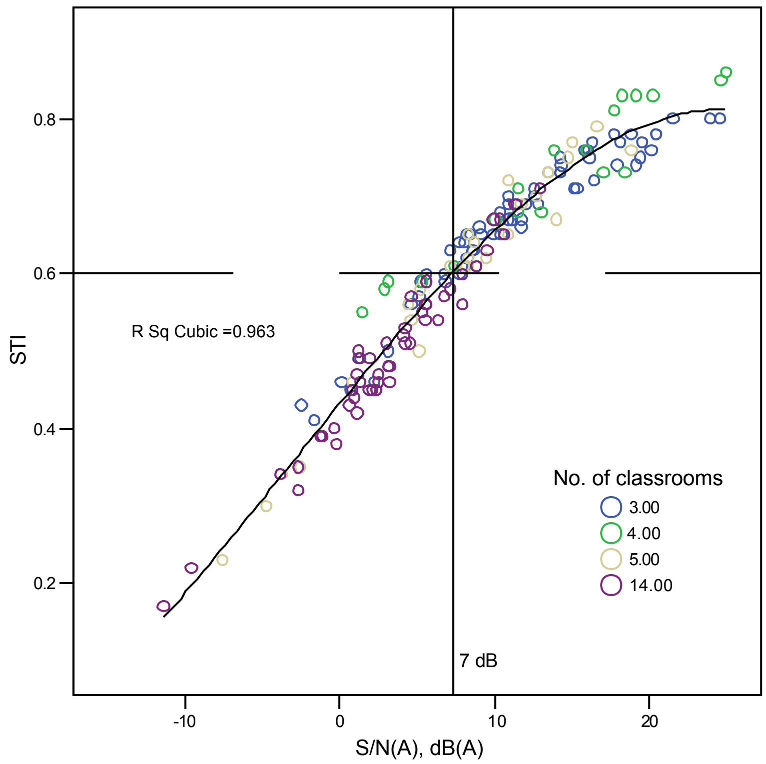

Figure 10: STI and Speech-to-noise ratio for T_{mf} 0.4 seconds or less

5 CONCLUSIONS

The conclusions from the preliminary results of this research are concerned as much with classroom organisation and management as acoustic design and layout. In order to achieve the BB93 performance standard of STI 0.6, some recommendations are set out below. It should be noted that these recommendations are applicable for normal hearing listeners. Alternative standards may be applicable for other groups of listeners (e.g. children with special needs, haring impairments or English as a second language).

- The open plan layout should be limited to three class bases or less, to control the number of children sharing the space, and consequently the intrusive noise levels experienced in each class base. This recommendation could also be set out in terms of a minimum floor area per student.
- The unoccupied and furnished classroom reverberation time, T_{mf}, should not exceed 0.4 seconds. This allows for some trade off of increased background (intrusive) noise level to achieve the same level of speech intelligibility. Note that current BB93 guidance may need to be reviewed in light of this evidence.
- Absorption should be provided to the entire ceiling and floor area in order to achieve the recommended reverberation time. Note that limiting the size of the layout as above would also control the room volume and hence reverberation time.
- Activities should be co-ordinated as far as possible to avoid conflicting noise levels and conditions. Provided that activities are co-ordinated and the layout is limited to three class bases with controlled reverberation time, most types of activity may take place in adjacent classrooms without causing annoyance and distraction (see section 4.1 – note that analysis of further results is necessary to make firm conclusions about the more active classroom tasks).
- Speech intelligibility may be considered critical where listening tasks take place in the main classroom (as opposed to individual/group work, for example). When activities are co-ordinated (i.e. all classrooms in the open plan space engaged in listening with one person talking at any time), the BB93 criterion for speech intelligibility may generally be achieved at any position in the room.
- When activities are not co-ordinated and a critical listening task is taking place in the main room, the teacher should gather the whole class around him or her, preferably on a “carpet space” away from the opening, to facilitate better speech intelligibility. Adjacent activities should also be limited to activities not involving movement.
- If higher impact activities involving movement are sought during a period when an adjacent class is involved in critical listening, this should be discussed with the other teachers, and activities should be moved to an enclosed space (e.g. enclosed quiet room off the main layout if necessary.

It should also be noted that the methods in this study rely on standard levels of vocal effort for teachers. Teachers who shout or use a loud voice level may cause distraction or annoyance, and may interfere with speech intelligibility in other classrooms. For this reason, most teachers in open plan classrooms tend to use visual or other noiseless cues to attract the attention of the class. Further recommendations regarding behaviour and management in the classroom will be possible following analysis of the subjective data gathered for this project.

6 ACKNOWLEDGEMENTS

This work has been funded by the Engineering and Physical Sciences Research Council. The authors would like to thank the schools, teachers and children that have taken part in the research project to date.

7 REFERENCES

1. N. Bennett *et al,* "Open plan schools: Teaching, curriculum, design". Schools Council Publications, NFER Publishing Company Ltd (1980).
2. C. Weinstein, "Noise and reading performance in an open space school", *Journal of Educational Research* 72 (March/April) pp.210-213, (1977).
3. B.L. Kyzar: "Comparison of instructional practices in classrooms of different design", Final Report' (1971).
4. D. P. Walsh, "Noise levels and annoyance in open plan educational facilities", *Journal of Architectural Research* 4(2) pp. 5-16, (1975).
5. H. Kingsbury & D. Taylor, "Acoustical conditions in open plan classrooms," *Sound and Vibration* May 1970 pp. 19-23 (1970).
6. J Yerges, "Development and utilization of open plan educational facilities," *Sound and Vibration* June 1972 pp.19-23 (1973).
7. B Schellenberg, "Noise and sound control in open plan schools", National Institute of Education, U.S. Dept. of Health Education and Welfare, (1975).
8. School Facilities and Transportation Division, "School sound level study", California State Department for Education, USA (1986).
9. Department for Education and Skills, "Building Bulletin 95: Schools for the Future", The Stationery Office, London (2002).
10. Department for Education and Skills, "*Schools for the Future - Exemplar Designs: Concepts and Ideas*", The Stationery Office, London (2003).
11. Department for Education and Skills, "*Classrooms of the Future*", The Stationery Office, London (2002).
12. Department for Education and Science, "Building Bulletin 51: Acoustics in Educational Buildings", HMSO London (1975).
13. Department of Education and Employment, "Building Bulletin 87: Guidelines for environmental design in schools", HMSO London (1997).
14. Department for Education and Skills, Building Bulletin 93, "Acoustic Design of Schools", The Stationery Office, 2003.
15. J.S. Bradley, "Speech intelligibility studies in classrooms", *Journal of the Acoustical Society of America*, 80, pp.846-854, (1986).
16. J. Dockrell and B. Shield, "Acoustical barriers in classrooms: The impact of noise on performance in the classroom", *British Educational Research Journal* (in press).
17. B. Shield & J. Dockrell, "External and internal noise surveys of London primary schools", *Journal of the Acoustical Society of America*, 115 (2), pp. 730-738, (2004).
18. British Standard BS EN 60268-16, "Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index", (1998).
19. Bradley, Reich & Norcross, "A just noticeable difference in C50 for speech", *Applied Acoustics* 58 pp. 99-108, (1999).
20. D. Rife, "Modulation transfer function measurement with maximum length sequences", *J. Audio Engineering Society* 40(10) pp. 779-790, (1992).

21 J. Edwards, "The classroom as a microcosm of the world", In *Spaces for Children*, Ed. Mark Dudek, Architectural Press (2005).

22. J.S. Bradley & H. Sato, "Speech intelligibility studies in grades 1, 3 and 6 children in real classrooms", in *Proceedings of the ICA,* Kyoto, (2004).
23. M. Picard & J.S. Bradley, "Revisiting speech interference in classrooms", *Audiology,* 40, pp. 221-244 (2001).
24. P. Nelson, "Sound in the classroom – why children need quiet", *ASHRAE Journal* February 2003 pp. 22-25 (2003).
25. B. M. Shield ,J. E. Dockrell, "The effects of noise on children at school – a review", *J. Building Acoustics 10(2), 2003.*