DESIGN STRATEGIES FOR LINEAR SEMI-OPEN PLAN CLASSROOMS: CASE STUDY ON IMPROVING THE ACOUSTIC ENVIRONMENT IN A MODERN PRIMARY SCHOOL

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1 INTRODUCTION

The modern primary school pertained for this paper is a past exemplary primary school in Scotland with linear semi-open plan classrooms. Its acoustic environment was viewed as unsatisfactory by the school, despite the acoustic design being generally aligned with recommendations given in some well-recognised documents. This school was looking for improvements, while maintaining its open-plan nature was not compromised. This paper describes the assessment of the acoustic environment by onsite measurements and a 3D acoustic modelling for speech intelligibility. It investigates a series of possible improvement measures individually, and compares their effectiveness and efficiency in improving Speech Transmission Index (STI) scores. The analysis results in some general design strategies for linear semi-open plan classrooms to achieve satisfactory speech intelligibility and privacy.

2 BACKGROUND

2.1 A Brief History of Open Plan Classrooms

Open-plan classrooms first became fashionable during progressive educational reforms in the 1950s and 1960s, that moved schools towards child-centred pedagogic approaches[1]. However, many experienced excessive intrusive noise from adjacent classrooms. Research found there was a significant negative relationship between noise levels, learning attainment[2,3], and teacher stress levels[4]. This was the primary reason that many open-plan classrooms returned to traditional layouts, after the 1980s.

In recent years, flexible learning spaces have again been trending towards open-plan environments in the UK, the US, the Nordic countries, New Zealand, Australia, Canada, and Japan[1,5]. This movement is stimulated by fast advances in digital-based teaching, which have been rapidly changing classroom methods. Many educators believe that 21st century education will ultimately depart from textbook-based, teacher-centred schooling to more project-driven, student-centred pedagogic approaches[6]. Education stakeholders nowadays often require the design of learning spaces to promote multiple modes of student learning, supporting both individual and group work, providing space for presentation and exploration, promoting interaction and a sense of community, and fostering both formal and informal learning.

Open-plan classrooms are the architectural response to these requirements. Returning to traditional four-wall classrooms is not a preferred option for solving noise issues associated with the learning environment for many education stakeholders.

Research shows that fully open classrooms can achieve less than 10 dB attenuation between classbases[7,8], meaning they are not encouraged. Semi-open classrooms with a linear layout rather than square or cluster arrangement has been shown to be the most beneficial for noise attenuation[9,10], and thus are encouraged.

2.2 Project Background

The school building in question was first viewed as an exemplary design after its completion in 2004 as measured by the third International Compendium of Exemplary Educational Facilities (2006), prepared by Organisation for Economic Co-operation and Development (OECD)[11]. The design is generally aligned with the recommendations given in some well-recognised paper[1] (refer to Figure 1 for the floor layout and Figure 2 for internal view), which are:

- adopting linear layout to achieve speech intelligibility and privacy, and reduce visual distraction;
- separating semi-open classrooms using a storage wall with Perspex panels on top, extending to steel beams to maximise sound insulation
- providing enclosed quiet rooms within each unit, to allow withdrawal for quiet or noisy activities;
- installing sound absorbent ceilings and carpeted floor coverings in classrooms to minimise cumulated reverberant noise and control footfall/impact noise.

Despite including these in the design, the school complained that noise levels in the semi-open plan classrooms were still too high. In each classroom, individual had to raise their voices to be heard due to intrusive noise from other classrooms. This resulted in spiraling increases in noise levels. The Council and the school were looking for improvements, via a refurbishment.

Meanwhile, the school still preferred to use the open-plan layouts, and emphasised that “the open-plan nature of the building cannot be compromised by any proposed solutions/improvements”.

To provide suitable solutions to combat the noise issue, while still preserving its flexible learning and teaching environment, a detailed acoustic study was carried out for improving the acoustic environment.

3 ASSESSMENT OF CURRENT ACOUSTIC ENVIRONMENT

3.1 Site Survey

A detailed site survey including measurements of reverberation time, sound insulation between adjacent classrooms, indoor ambient noise levels, classroom activity noise levels, background noise levels (comprising combination of the indoor ambient noise levels and transmitted noise from adjacent spaces), and overall noise levels (comprising combination of the background noise levels and teaching and learning activity noise levels) was conducted in some typical classrooms. The measured results are summarised in Table 1 against the criteria defined in Building Bulletin 93:2015 (BB93) and its supporting document *Acoustic of Schools: a design guide* (The DG) by the Institute of Acoustics (IOA) and the Association of Noise Consultants (ANC).

It was not practical for us to measure STI onsite. STI scores were given, based on the layout and acoustic properties of the interior finishes using a proprietary 3D acoustic modelling software EASE ® (Enhanced Acoustic Simulator for Engineers).

The primary school includes a Nursery block, an Early Years Learning block and a Primary block. For simplicity, this paper only presents studies of the acoustics in Room 2 in Figure 1, a typical room in the Early Years Learning block, adjacent to Room 1 to the left and Room 3 to the right. Studies of the acoustics in other blocks have followed similar methodology.

Table 1. The results of site measurements

Measured parameter	Results	BB93/DG criteria
Indoor ambient noise levels	29 -38 dBA	40-45 dBA
Background noise levels (only one adjacent classroom active)	53-58 dBA	-
Classroom activity noise levels	68 dBA	-
Total noise levels including activity noise levels	63-73 dBA	-
Sound insulation between classrooms	14 – 16 dBA	20 dBA
Reverberation time in classrooms	0.5 – 0.7 s (Rooms 1&2:0.5s)	≤ 0.5 s

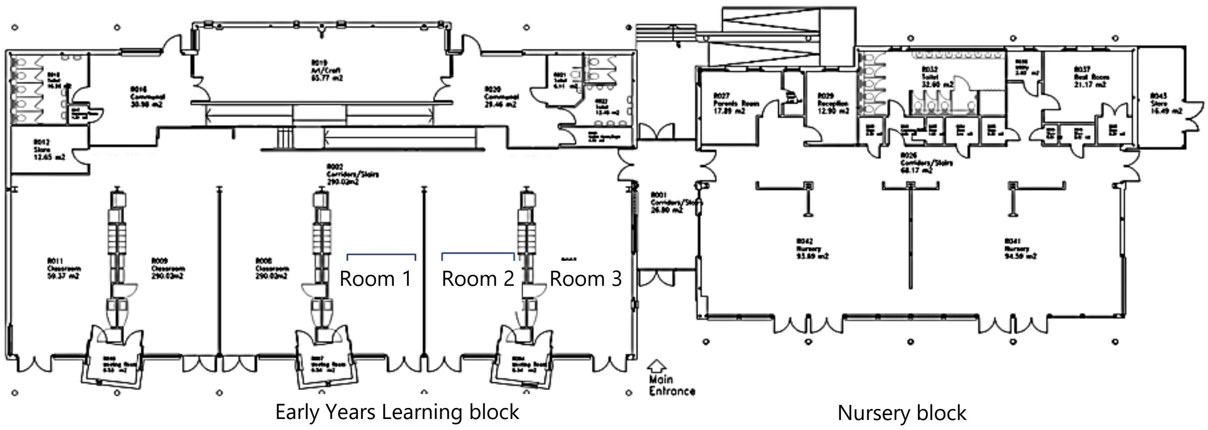
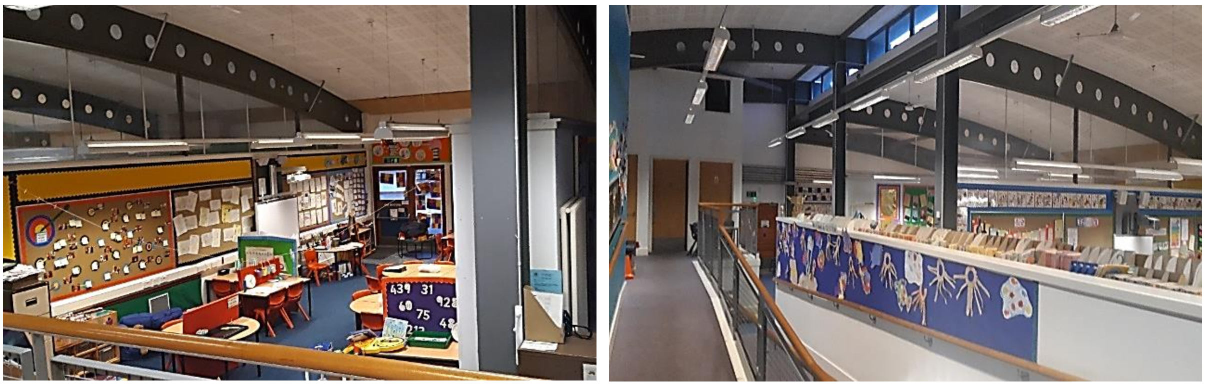


Figure 1. Nursery and Early Years Learning Floor Layout

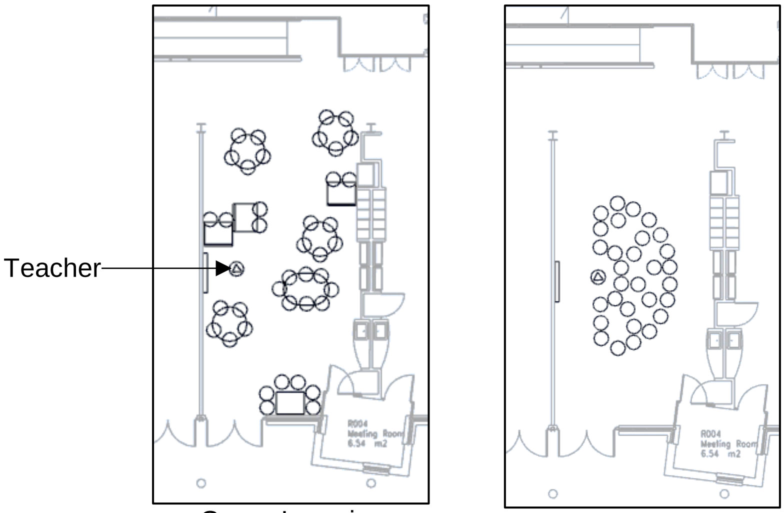


Figures 2. The Interior View of Early Years Learning Space
(Note the storage wall with Perspex panels on top)

3.2 Calculation of Speech Intelligibility STI Scores

The EASE models for deriving STI in Room 2 have followed the suggested source-receiver heights, orientation, vocal effort and the procedure described in *Appendix 6 Acoustic modelling of open plan spaces* described in the DG.

During the survey, two main teaching/learning modes were observed: group learning and story-telling. The typical seating layouts are illustrated in Figure 3. The observed positions of the teacher and pupils have been used in the model as the source and the worst-case receiver positions.



Group Learning   Story Telling

Figure 3. Typical seating layouts of two main teaching/learning modes

The model was calibrated to ensure that the predicted RT in the classrooms, and sound insulation between the adjacent classrooms, diverged by no more than 10% from the measured results. The measured activity noise levels were used as source levels in the source rooms, Room 1 and Room 3. The background noise levels in Room 2 were predicted, assuming both adjacent classrooms host teaching activities.

3.3 Assessment Results

It can be seen in Table 1 that the ambient noise levels are low as the classrooms are naturally ventilated. When only two or three classrooms are active, the ambient noise levels may be too low to mask sound from adjacent classrooms. When multiple classrooms are active, it may not be a concern as activity noise from other classrooms can be masking noise. The reverberation times in some classrooms were higher than the criteria defined in BB93, but the classrooms investigated in particular to in this paper meet the BB93 criteria. The sound attenuation between the adjacent classroom are substantially lower than the minimum value recommended in the DG.

The calculated STI scores for the worst-case scenario are listed in Table 2 against the criteria defined in the DG.

Table 2. Predicted STIs at different locations against performance criteria stated in BB93

Source	Receiver	Distance	STI	Criteria
Within a Classroom				
Teacher – Group learning	Student near window	4.3 m	0.34	≥ 0.6
	Student near corridor	5.6 m	0.27	
Teacher – Story telling learning	Furthest student	2.5 m	0.42	
Student near corridor – Group learning	Teacher	5.6 m	0.31	
	Student near window	6.8 m	0.29	
Student near window –	Teacher	4.3 m	0.35	

Source	Receiver	Distance	STI	Criteria
Group learning	Student near corridor	6.8 m	0.24	
	Student in the middle	4.3 m	0.35	
Student near window – Story telling	Student close to corridor	4.5 m	0.30	
Between Classrooms				
Teacher	Students in adjacent classrooms	-	0.01 – 0.05	≤ 0.3

It can be seen from Table 2 that the STI scores between adjacent classrooms are low, indicating that speech privacy is acceptable. However, the STI scores within the same classroom are significantly lower than the required limit, indicating that speech intelligibility in the classrooms was very poor.

4 COMPARISON OF POSSIBLE IMPROVEMENT MEASURES

The possible practical measures for reducing background noise and subsequently improving speech intelligibility within classrooms were identified as follows (refer to Figure 5 for clarity of the locations of these treatments):

a) Seal the holes in the steel beams between classrooms using 6mm thick Perspex;
b) Introduce a 2.5m high screen between openings of adjacent classrooms with either of the following widths and material:
   b-1) 0.6m wide Class A material on both sides, treatment area 1.5 m^2 per classroom
   b-2) 1.2m wide Class A material on both sides, treatment area 3 m^2 per classroom
   b-3) 1.8m wide Class A material on both sides, treatment area 4.5 m^2 per classroom
   b-4) 1.8m wide reflective on both sides, treatment area 4.5 m^2 per classroom
c) Cover plasterboard walls/furniture facing the openings of classrooms with 2.5m high absorptive material, based on one of the following absorption classifications:
   c-1) Class A material, treatment area 14.5 m^2 per classroom
   c-2) Class B material, treatment area 14.5 m^2 per classroom
   c-3) Class C material, treatment area 14.5 m^2 per classroom
d) Upgrade existing Class C perforated plasterboard ceiling to Class A ceiling panels. Treatment area is 60 m^2 per classroom;
e) Replace vinyl flooring in the circulation and breakout areas to carpet. Treatment area is 23 m^2 per classroom;
f) Cover over the Perspex panels at upper level between classrooms with Class A wall panels. Treatment area is 11 m^2 per classroom.

The interior wall within the classrooms below 2.5 m are working surfaces for display. It is impractical to cover these surfaces by acoustic material.

STI scores take into account both noise and reverberation times to provide an ultimate guide of the quality of the speech transmitted. The evaluation of the effectiveness and efficiency of each measure for improving speech quality focuses on the study of STI scores.

The speech intelligibility parameter STI across Room 2 in a grid of 1 m x 1 m excluding positions within 0.5 m from walls (50 points in total) were predicted for each measure using the EASE. The location of the teacher is shown in Figure 3. The statistical results are summarised in Figure 4, showing the averaged values with standard deviation, and minimum and maximum values for each of the options discussed.

It can be seen in Figure 4, the most effective measure is to cover the walls facing the openings of the classrooms with absorptive material. Most sound energy escaping from classroom is from these openings. The walls facing these openings perform as reflectors of sound energy into other classrooms.

The second most effective measure is to introduce an absorptive screen between the openings of adjacent classrooms. Even a panel as narrow as 0.6 m wide can provide notable improvement in STIs. If the screen is too wide, the openness of the open plan nature would be compromised. Although reflective screens do not lower reverberation time, it is interesting to note that using a 1.8 m wide reflective panels, such as glass, is more efficient for improving STI than upgrading ceilings, covering Perspex panels with absorptive material, and changing vinyl floor in circulation areas to carpet. As glass screens do not hamper the view, it may be a preferred option than an absorptive screen for some cases.

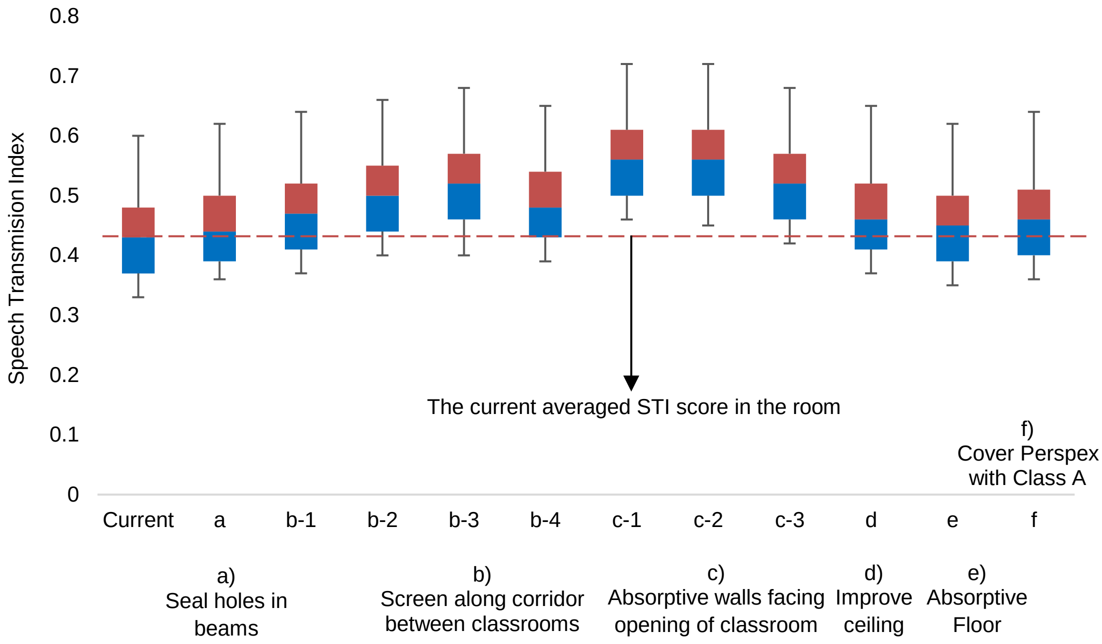


Figure 4. Comparison of STI scores using different treatments
(Averaged values with standard deviation, and minimum and maximum values)

Some research suggests that Class A's ceiling should be used for open-plan classrooms[12,13]. However, for this particular case it is not an efficient solution to upgrade the existing Class C ceiling to Class A, as indicated in Figure 4. Despite the largest treatment area involved among the listed measures, the improvement in STI score is very limited. Upgrading the ceiling can reduce reverberation time and consequently reduce the build-up of noise. However, the dominant noise transmission path from one classroom to another in this case is from the open side of the classrooms, as the separation walls extend up to the beams.

Another treatment within the classrooms' space, covering the Perspex panels above the cabinet wall with Class A material, provides just as limited improvement as upgrading the ceiling to Class A panels, with less treatment areas involved. This method, however, only offers limited improvements at expense of compromising the feeling of openness.

Replacing vinyl flooring in the circulation and breakout areas to carpet does not lead to a significant improvement of predicted STI. It has been noticed that many schools do not want to install carpets in such areas for the ease of maintenance. The results shown in Figure 4 indicate that it carpets could be acceptable for controlling intrusive noise from neighbouring classrooms. However, it has been observed that pupils sometimes jump and run to the toilet through these areas during class hours, and cause disruptive impact noises. Carpeted floors can help reduce footfall/impact noise. If carpet is not preferred, then vinyl with a resilient underlay could be adopted.

It seems that sealing the holes in the beams with Perspex panels offers minimum improvement. The advantage of this measure is that it has minimum impact on the openness of the classrooms, and cost is low if it is convenient to install.

5 RECOMMENDATIONS

Balancing the effectiveness/efficiency of the treatments found in the above analysis, cost, convenience of installation, and maintenance of openness, the treatments given in Figure 5 were recommended for the refurbishment of the Early Years Learning block.

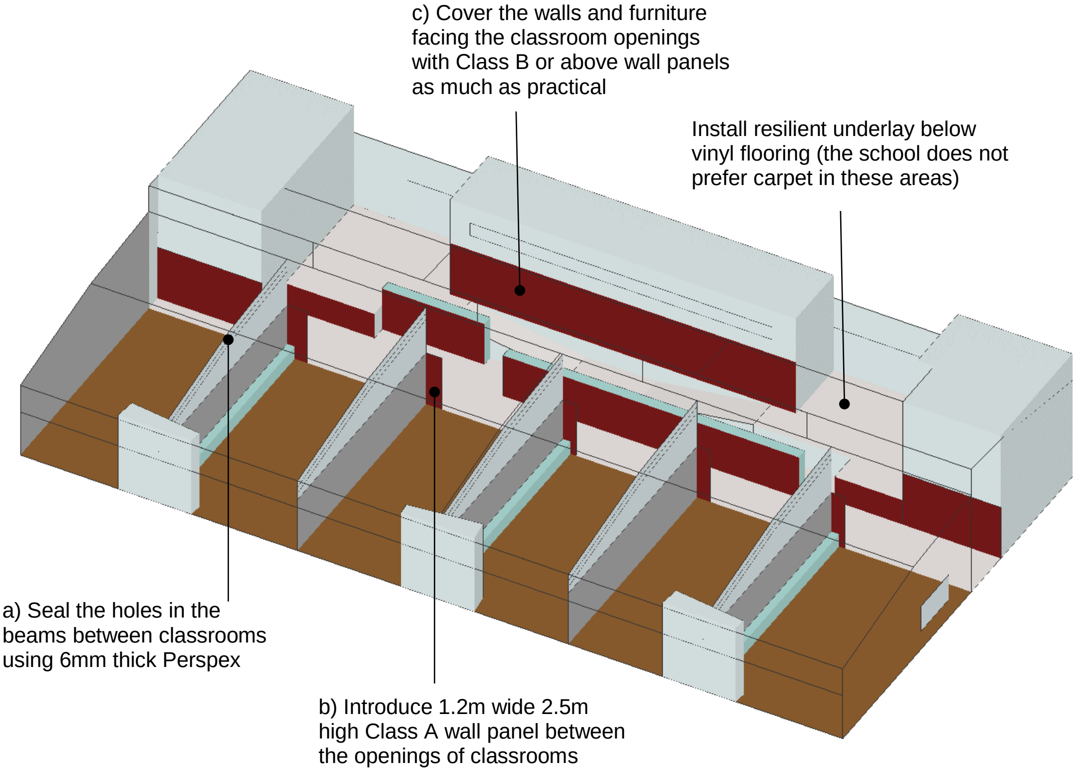


Figure 5. Recommendations for the Early Years Learning block
(Where the colour is similar this indicates the material has similar absorptive properties. The numbering is corresponding to the numbering of the treatments in Section 4)

Predicted STI scores for the worst-case scenario have been provided in Table 3 below. A summary of all the predicted acoustic parameters are listed in Table 4, together with criteria defined in BB93 and the DG.

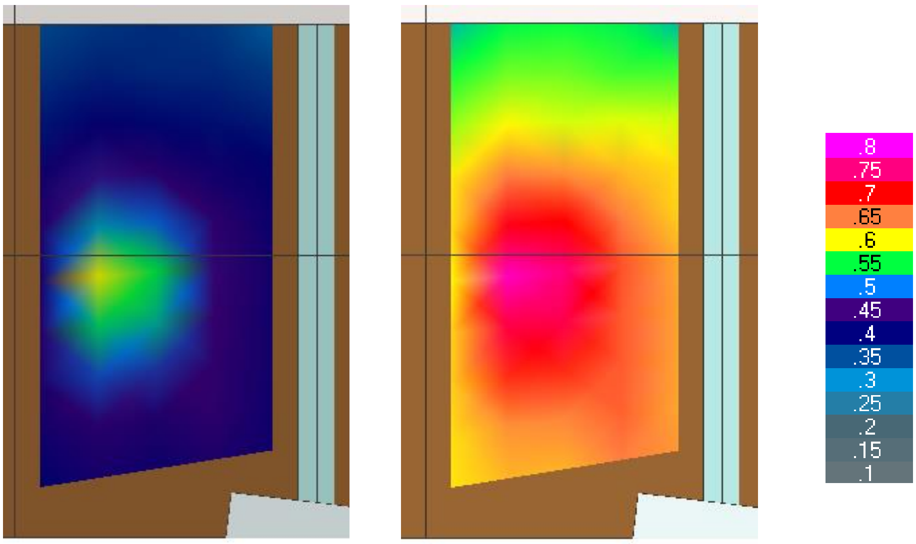
Table 3. Predicted STI scores for Early Years Learning Space – with recommended treatments

Source	Receiver	Distance	STI
Within a Classroom			
Teacher– Group learning	Student near window	4.3 m	0.64
	Student near corridor	5.6 m	0.56
Teacher – Story telling	Furthest student	2.5 m	0.70

Source	Receiver	Distance	STI
learning			
Student near corridor – Group learning	Teacher	5.6 m	0.59
	Student near window	6.8 m	0.57
Student near window – Group learning	Teacher	4.3 m	0.65
	Student near corridor	6.8 m	0.54
Student near window – Story telling	Student close to corridor	4.5 m	0.68
Between Classrooms			
Teacher	Students in adjacent classrooms	-	0.04-0.07

Table 4. Comparison of predicted results against performance criteria after recommended treatments

Indicator	After recommendations	BB93/DG Criteria	
Reverberation Time T_{mf}	0.4	Teaching area	≤ 0.5 s
	≤ 1.2 s	Resource/breakout areas	≤ 1.2 s
Sound attenuation between classrooms	22 dBA	20 dBA	
Speech Transmission Index STI	Except 0.54 between furthest student, all others ≥ 0.55	Instruction or critical listening activity within a classroom	≥ 0.6
	0.15	Between classrooms during critical listening activities	≤ 0.3



Current After recommendations

Figure 6. Comparison of distribution of STI across the room of before and after recommendations (Teacher with raised voice as source)

It can be seen from Table 4 that the performance criteria defined in BB93 and the DG have generally been achieved.

Figure 6 illustrates clearly that after recommended treatments are incorporated in the model, the predicted STI scores across the room have been improved significantly. The only areas which pupils may not have sufficient speech intelligibility is around 1 m from the boundary line, defined by the ends of separating walls. It is desirable that no seats be arranged in these areas. It has been witnessed onsite that some seats were extended into the circulation areas. These seats have the worst speech intelligibility, and the activity noise generated by the pupils seating in these areas would also affect adjacent classrooms. Therefore, this seating arrangement should be avoided. Such an arrangement of seating implies that the area of the classrooms may not be sufficient to accommodate the current number of pupils. This would indicate that when designing an open-plan classroom, the layout should provide 1 m buffer zone at the boundaries of classroom spaces.

6 CONCLUSIONS

A typical semi-open classroom building block, which received unsatisfactory feedback on its acoustic environment, has been investigated. It has been found that the reverberation times in the rooms investigated in particular in this paper meet the BB93 criteria, and indoor ambient noise levels are also low. Onsite measurements show that sound insulation between classrooms is low, and results in low speech intelligibility.

A series of possible practical measures have been investigated in terms of STI using the 3D modelling tool EASE. Through the case study using computer models and onsite observations, with a balance of the effectiveness/efficiency of the treatments, cost, convenience of installation, and maintenance of openness, the following design strategies are recommended for semi-open classrooms with a linear layout:

- The walls facing the openings of classrooms should be absorptive, preferably Class B or above;
- A minimum 1.2m-wide screen should be introduced between the openings of adjacent classrooms, preferably absorptive;
- A minimum 1m-deep buffer zone in classrooms to the boundaries of classrooms formed by the end line of separating walls should be free of any pupil seating;
- Not only classrooms' floor, but also circulation areas - especially those leading to toilets - should have carpet installed. If carpet is not preferred for maintenance purpose in circulation areas, other types of resilient flooring, such as vinyl with a resilient underlay, should be installed, to minimise footsteps/impact noise;
- It is acceptable to use glass or Perspex on top of separating cabinet walls to separate classrooms to help maintain the feeling of openness when providing suitable sound insulation;
- It is beneficial that the ceilings of classrooms are a Class A material. However, if separating elements between classrooms extend to the ceiling, Class C ceilings are acceptable. This will allow the architects more freedom to choose material to express visual inspirations.

This study mainly looks at activities in adjacent classrooms as noise sources. It would be difficult to control noise from circulation and breakout areas facing the openings of classrooms. Therefore, a noise management plan is still essential for achieving satisfactory speech intelligibility. The activities in the breakout and circulation areas should be minimised when instruction and critical listening activities are carried out in the classrooms.

The study of STI presented in this paper is based on computer modelling. The refurbishment work has been postponed due to the Coronavirus lockdown. The predicted results need to be verified after the refurbishment is completed.

7 ACKNOWLEDGEMENTS

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