Proceedings of the Institute of Acoustics & Belgium Acoustical Society
Noise in the Built Environment, Ghent, 29-30 April 2010

CASE STUDY EVALUATIONS ON THE INFLUENCE OF BB 93 ON THE ACOUSTIC DESIGN OF SCHOOL BUILDINGS

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1 INTRODUCTION

The University of Exeter has undertaken a review of the acoustic design of schools for the UK Government. The study investigated the influence of current UK Building Regulations (esp. Building Bulletin 93[1]) on school design. The project looked at six schools (both primary and secondary), and considered current acoustic conditions using both quantitative and qualitative approaches. Members of the design team were questioned to examine the level at which acoustics had been considered in each design. A detailed report was produced for each school and conclusions drawn regarding the influence of BB 93 on the design process and the consequent satisfaction, or otherwise, of pupils and staff.

2 CASE STUDIES

2.1 Overview

The six case studies described in this report are based on studies of schools built since the introduction of *Building Bulletin 93 'Acoustic Design of Schools'* (BB 93) in the UK. BB 93 came into force in July 2003, defining acoustic requirements for new and refurbished schools and covers noise levels, sound insulation and room acoustics. Although standards are law, post construction testing is not mandatory and, in our experience, not often enforced. Given this, six case studies were undertaken to assess levels of compliance, satisfaction of users, and how acoustics were considered during the design process. The assessment was undertaken jointly by the University of Exeter and RPS Gregory, Birmingham.

2.2 The Schools

Six schools were chosen to include a variety of construction methods, architectural features and geographic locations. All were built after the introduction of BB 93 (Table 1).

Table 1: Schools included in the case study

School	*Location*	*Type*	*Number of Pupils (approx.)*	*Age Range*
Leigh Technology Academy	Dartford, Kent	Secondary	1500	11-18
St James	Exeter, Devon	Secondary	650	11-16
Bluecoat Children's Centre	Torrington, Devon	Primary and Nursery	170	3-7
Redbrook Hayes	Rugely, Staffordshire	Primary	230	3-11
Halewood Centre for Learning	Halewood, Merseyside	Secondary	1400	11-18
Thomas Deacon Academy	Peterborough, Hertfordshire	Secondary	2200	11-18

Each school underwent a programme of acoustic testing that included sound insulation, ambient noise, and reverberation tests. Surveys were distributed to teachers, students and members of the design team to assess the end user satisfaction and design procedure respectively. The following sections do not detail individual test results, but will give an overview of the most significant results drawn from the project.

2.3 Overview of Compliance

BB 93 requires that all schools meet set standards upon commissioning and, in theory, all schools tested should have 100 % compliance rates. Experienced consultants may suspect that this may not always be the case. The following table gives an overview of the compliance rates for the tests undertaken at each school.

Table 2: Overview of Results

School	*No. of Tests*	*Pass Rate*[1]
Bluecoat Centre	18	100 %
Leigh Academy	12	83 %
St James	22	79 %
Halewood Centre for Learning	17	73 %
Thomas Deacon Academy	21	72 %
Redbrook Hayes	14	67 %

It is clear that compliance rates vary significantly with some schools meeting the requirements in all cases (Bluecoat Centre), and others exhibiting poor standards of compliance (Redbrook). With different numbers of each test type being carried out at each school, a breakdown by test type is useful in analysing in which areas requirements have been successfully met (Table 3).

Table 3: Breakdown of results by test

School	*Pass Rate*			
	Airborne Sound Isolation	*Impact Sound Isolation*	*Reverberation*	*Ambient Noise*
Bluecoat Children's Centre	100 %	100 %	100 %	100 %
Leigh Technology Academy	100 %	100 %	67 %	100 %
St James	86 %	100 %	82 %	63 %
Halewood Centre for Learning	75 %	100 %	78 %	60 %
Thomas Deacon Academy	36 %	100 %	91 %	100 %
Redbrook Hayes	14 %	-	86 %	100 %

Table 3 reveals some interesting patterns in the results. Clearly schools have all performed well in impact sound tests, but have variable results for airborne, reverberation and ambient noise measurements. Airborne isolation test results show a particularly wide range of results. A closer inspection sheds some light on the variation in success between tests.

1 Where alternative performance standards (APSs) have been applied, compliance with these standards is judged to have passed.

2.3.1 Airborne Sound Tests

The results of the airborne sound tests show the most variation between schools (between 14 % and 100 % compliance). Experienced acoustic consultants will not be surprised to learn that some of the most significant failures were due to folding partitions and operable walls. The majority of other failures were due to flanking sound paths and poor junction detailing. For illustration purposes, Table 4 shows constructions of partitions that failed to meet the requirements.

Table 4: Failing wall constructions

School	*Failing wall constructions (reason in brackets)*
Leigh Technology Academy	-
St James	Folding partition (passes via alternative performance standard)
Bluecoat Children's Centre	-
Redbrook Hayes	Single Metal Stud (doors, crosstalk via ventilation ducts and folding partitions in walls)
Halewood Centre for Learning	Independent Stud Partition (low reverberation times in small volume receiving rooms)
Thomas Deacon Academy	140 mm Blockwork (insufficient specification and poor flanking details)

Subjective observations indicated that failures of folding partitions were primarily due to underspecified partitions and degraded acoustic seals (a common failure). This was evident at Redbrook Hayes where all but one of the partitions met the required standards. Damaged acoustic seals and significant crosstalk between spaces significantly degraded the acoustic performance at Redbrook. One test showed sound insulation of 34 dB $D_{nT(Tmf,max)w}$ between spaces, 11 dB below the 45 dB $D_{nT(Tmf,max)w}$ requirement. At St James in Exeter the folding partition met the requirement set by the Alternative Performance Standard but would have otherwise fell short of the BB 93 requirement.

Failures at Halewood were between music practice rooms are thought to have occurred due to the small room size. For sound insulation between music practice rooms, requirements are high (55 dB $D_{nT(Tmf,max)w}$), and reverberation times in the rooms low (due to small room volumes). Since reverberation times in these spaces were lower than required by BB 93, the reverberation normalisation process used in calculating $D_{nT(Tmf,max)w}$ has the effect of making the sound isolation appear poorer. For this reason, normalisation of $D_{nT(Tmf,max)w}$ to $T_{mf,max}$ may be confusing to designers since it may lead them to believe that similar constructions can be used between both large and small rooms. In this case, using non-normalised weighted level differences (D_w) may provide more intuitive guidance to the sound insulation required by the partition.

Other notable failures included blockwork partitions at Thomas Deacon. Impressions were that these failures were due to direct sound transmission and significant flanking paths with the partition head and window mullion details being significant weaknesses. Additionally, the 140 mm concrete block used for the partition was only expected to perform to 51 dB R_w (based on laboratory measurements) and could not meet requirements even without flanking transmission. Reasons for failure here are purely design based with insufficient partitions and poor flanking details causing the problems.

2.3.2 Impact Sound Tests

Impact sound insulation requirements were met in all cases. In all but one case these were met by greater than 6 dB. The Bluecoat Centre was the exception where results were equal to requirements (see Table 5).

Table 5: Summary of results for impact sound insulation (floors)

School	*No. of Tests*	*Average Improvement (dB)*	*Pass Rate*	*Alternative Performance Standards Applied?*
Leigh Technology Academy	1	19.0 dB	100 %	No
St James	3	9.3 dB	100 %	No
Bluecoat Children's Centre	1	0.0 dB	100 %	No
Redbrook Hayes	-	-	-	-
Halewood Centre for Learning	1	29.0 dB	100 %	No
Thomas Deacon Academy	1	19.0 dB	100 %	No

The Bluecoat Centre was the only timber frame construction tested and the closest to failing requirements. Feedback from the school indicated that impact noise was occasionally a problem here.

2.3.3 Reverberation Time Tests

Like the airborne sound test results, the results of the reverberation time tests were also mixed. Table 6 shows the room types that failed the reverberation tests along with their respective reverberation times.

Table 6: Room types failing the reverberation tests (Reverberation times in seconds)

School	*Failing room types*
Leigh Technology Academy	Sport Hall (3.3 s), Atria / "Learning Plazas" (1.1 s)
St James	Gymnasium (1.7 s), Assembly Hall (1.4 s)
Bluecoat Children's Centre	-
Redbrook Hayes	Multi-purpose hall (1.4 s)
Halewood Centre for Learning	Central Atrium (2.7 s), Sports Hall (1.8 s)
Thomas Deacon Academy	Indoor Sports Hall (2.4 s)

Without exception, all the failing spaces are either large halls or open plan teaching spaces. For both types of rooms this is a concern, but particularly for open plan teaching areas. The reasons for failures are insufficient absorption and absorption distribution. These spaces all have ceiling heights above 4 m and as such are particularly prone to flutter echo effects. It is suspected, that due to their absorption strategies (i.e. applying absorption only to the ceiling) absorption was not sufficiently distributed throughout the space, and hence reverberation times are extended beyond those predicted by the Sabine equation[2].

One area where appropriate absorption appears not to have been considered at all is the Central Atrium at Halewood Centre for Learning. On a visit to this site, no acoustic absorbers were observed anywhere in the space. This explains the excessive reverberation time of 2.7 seconds.

It should be noted that all of the above reverberation times were measured in furnished spaces; however, sports halls were generally empty and could be considered to be unfurnished. This was not the case for the open plan learning areas which all had a significant amount of furniture.

2.3.4 Ambient Noise Tests

Results of the ambient noise tests show that the rooms were generally successful in meeting the requirements of BB 93. Site conditions occasionally made some measurements impossible to evaluate (*e.g.* rain noise on roofs) and as such have been omitted from the statistics. Table 7 shows the levels of compliance at each school.

Table 7: Pass rates for ambient noise tests

School	*No of Tests*	*Pass Rate*
Bluecoat Children's Centre	6	100 %
Leigh Technology Academy	3	100 %
St James	8	63 %
Halewood Centre for Learning	5	60 %
Thomas Deacon Academy	6	100 %
Redbrook Hayes	7	100 %

Ambient noise criteria have been met in most cases; however, Halewood and St James showed poor levels of compliance.

St James is a partially mechanically ventilated school and measurements there were taken with and without ventilation in operation. A number of APSs were also set for ambient noise levels (from noise due to ventilation), and exceedances of these were also counted in the failures. Naturally ventilated areas of St James were assessed using the trickle vent concession (some of these areas would be non-compliant with windows open). All other failures were due to noisy ventilation. In the computer suite, an APS of 41 dB was set to allow for noise from computer equipment. This was met with the ventilation off, but not with ventilation on (an exceedance of 13 dB above the APS). Similar problems were also met a Halewood Centre for Learning where mechanical ventilation in the recording studio and the theatre led to ambient levels of 42.5 and 39.7 dB $L_{Aeq,30min}$ respectively.

3 DISCUSSION

The various types of schools surveyed and assessment methods used mean that limited statistical significance can really be taken from the results. However, test results do provide an interesting snapshot of post-BB 93 schools. A worrying finding, for some schools at least, is the poor levels of compliance. Given that each design team considered the acoustics in detail during the design, why have the standards of BB 93 not been met in all cases? As might be expected, there are many answers to this question. Reasons appear to vary from design errors (*e.g.* reverberation times in large spaces) to workmanship issues (*e.g.* unsealed service penetrations). It is useful to consider the pattern of results; Table 8 shows the breakdown of results by test type.

Table 8: Breakdown of results by test type

Test Type	*No of Tests*	*Pass Rate*
Impact	7	100 %
Reverberation	51	84 %
Ambient	35	86 %
Airborne	39	59 %

Clearly there is significant variation here with better results being more easily achieved for impact sound isolation than for airborne. The important question is how these poorer results have impacted on teaching and learning at each school. To help determine this, questionnaires were distributed among teachers and pupils. Results from the pupil questionnaires did not have any significant correlation with the acoustic test results. This is thought to have been largely due to the varying numbers of pupils willing to take part at each school (ranging from 10 pupils to around 140). This made it difficult to draw out any significance from the results. Feedback from teachers was however more enlightening. Each teacher surveyed was asked to rate the following environmental features in order of importance (acoustics related terms are marked with an *):

- Lots of wall display space
- Fresh and cool (not stuffy) air
- Lots of natural lighting
- Ease of use of linked spaces
- Having activity areas linked to teaching spaces
- Low background noise levels*
- Flexibility of space for different arrangements*
- Quiet / private space (for 1-to-1 / small groups) nearby*
- Ease of seeing pupils in other teaching and related spaces
- Carpeted floors in most classrooms

Factors were rated by each school as follows (1 = most desirable, 10 = least desirable).

Table 9: How teachers rated environmental factors

Test Type	*St James*	*Bluecoat Children's Centre*	*Leigh Academy*	*Redbrook Hayes*	*Thomas Deacon Academy*	*Halewood Centre for Learning*
Low background noise levels	1	4	1	-	4	1
Flexibility of space for different teaching arrangements	6	1	2	-	3	3
Quiet / private space (for 1-to-1 / small groups) nearby	7	3	5	-	5	5

Clearly, flexible teaching spaces and low levels of background noise seem to be desirable by teachers. Teachers were also asked whether they prefer open plan or more traditional cellular classrooms:

Table 10: Teacher preferences regarding classroom layout (**less than 5 responses)

Test Type	*St James***	*Bluecoat Children's Centre***	*Leigh Academy*	*Redbrook Hayes*	*Thomas Deacon Academy*	*Halewood Centre for Learning*
Traditional enclosed classroom and a door leading from a corridor	50 %	100 %	80 %	100 %	75 %	87.5 %
Open plan / semi open plan teaching spaces, for more than one whole class.	50 %	0 %	16 %	0 %	25 %	12.5 %

The surveys show a strong bias towards more traditional cellular classrooms as opposed to open-plan spaces. If we assume that the data presented is a fair representation of teachers' attitudes, a problem is presented; how is the desire for flexible teaching spaces balanced with the preference for more traditional cellular classrooms? There is no easy answer to this. There is also the question of whether the survey data is an accurate representation of teachers' views and whether more survey data is required to draw such conclusions. Analysis of educational benefits of certain acoustic conditions have been carried out in detailed studies elsewhere[3-11] and have no doubt informed the standards in BB 93, so attention should therefore be drawn to the lack of compliance in the schools tested.

The key area of failure has been that of airborne sound insulation. It could be argued that airborne sound isolation is the most difficult to achieve since the large number of possibilities of flanking sound paths and types of construction available preclude a one-size-fits-all method. But why have some schools succeeded more than others? Members of the design teams (particularly acousticians) pointed out that they were strongly in favour of mandatory PCT as they felt that this would improve acoustic standards. Due to workmanship and other construction issues, a partition may not always perform as expected on site. The role of PCT in this instance is clear, but due to the cost and often considerable inconvenience of testing and remedial works, both the client and contractor may be reluctant to carry out the work required for compliance. It will therefore be essential to ensure that expensive mistakes are avoided. To achieve this, the buildings' acoustics should be given a high priority, with an experienced acoustic consultant being appointed as early as possible to oversee the design process. How this will be ensured in practice will clearly be a source of much debate.

4 REFERENCES

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