DESIGNING AND COMMISSIONING SCHOOLS TO MEET BUILDING BULLETIN 93: 2014 REQUIREMENTS

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1 ABSTRACT

Building Bulletin 93 was revised in December 2014, and became referenced in Building Regulations with the revision to Approved Document E in April 2015. Some of the first schools designed to the revised performance criteria have now been built and commissioned. This paper discusses design and commissioning issues encountered in meeting the new criteria.

Some of the most significant changes from the previous requirements concern the assessment of noise with ventilation provision. This paper reviews the classification of the ventilation system, assessment of manufacturer’s claims for the noise levels emitted from their ventilation units, and noise levels measured in classrooms from a wide range of purpose-designed ventilation units. Issues with acoustic commissioning of ventilation units that do not have a set point at the design criterion are discussed.

While there have been only small changes to the reverberation time criteria, the standard design of schools that comply with the Education Funding Agency’s new criteria for thermal comfort generally adopt exposed concrete soffits. The potential to accurately calculate reverberation times based on formulae or modelling is discussed. The variation in measured values in classrooms using exposed concrete soffits, various types of suspended rafts, and wall panels is described.

2 INTRODUCTION

This paper discusses design and commissioning issues encountered in meeting the criteria in Building Bulletin 93: 2014 (BB 93)[1]. In most cases the acoustic criteria do not appear to differ much from those in the 2004 edition of Building Bulletin 93 or the interim Acoustic Performance Standards for the Priority Schools Building Programme versions 1.1 and 1.7. However, the context in which the criteria apply has changed significantly. This paper focuses on two specific areas of change. The reasons for the changes are due to the establishment of other environmental design criteria, and the necessary changes in the building design that these other criteria require.

The first area of change concerns the indoor ambient noise level (IANL). Although the A-weighted noise levels to be achieved remain broadly the same as previously, the levels are now associated with indoor air quality (IAQ) and overheating criteria. These radically change the context of, and requirements for the assessment. There are different exceptions for “natural” and for “mechanical” ventilation systems, as well as different air quality requirements for each system type. The implications for system adoption, classification, design and commissioning are discussed.

The second area of change concerns the reverberation time criteria. Again, the values to be achieved are little changed, but typical classroom design has significantly changed to meet the thermal comfort criteria required by the Education Funding Agency’s (EFA) Facilities Output Specification[2]. The near-universal adoption of exposed concrete soffits to provide exposed thermal mass means that classrooms have a larger volume and suspended ceilings are not an acceptable solution for sound absorption. This paper reviews different methods for the prediction of reverberation times and compares predicted and measured results in a range of classrooms.

3 INDOOR AMBIENT NOISE LEVELS

3.1 System classification

The first design issue concerns the classification of the ventilation system; as there are different criteria depending on whether a system is classified as being “natural”, “mechanical”, or “hybrid”; this classification is critical in determining the duty and performance requirements. The upper limits for Indoor Ambient Noise Levels (IANL) are described in Table 1 of BB 93; it is Table 2 of BB 93 that summarises the ventilation condition, system type and associated IANL tolerance. There are detailed notes to Table 2 of BB 93, see Figure 1, and also the diagrams associated with this table in BB 93.

For example, a ventilation unit containing fans that mixes internal air with external air and recirculates this into the classroom is typically classified by the EFA as a “hybrid” system, whereas a ventilation unit that exchanges the heat between the extracted air and supply air is classified as “mechanical” ventilation. These two systems have different ventilation flow rate requirements as well as different acoustic performance criteria to meet.

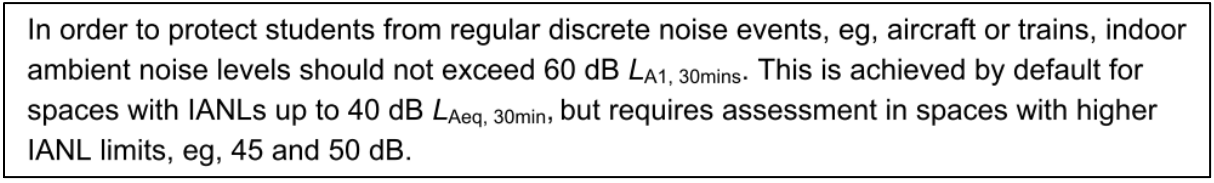
The classification of systems is a crucial step in the design process, and has significant implications for performance requirements and cost. Contractors have been known to attempt to take advantage of this ambiguity, claiming that there are small vents providing a very small amount of ventilation to supplement the heat recovery unit, and that therefore it is a “hybrid” system. This would imply the mechanical system need only provide 5 l/sec/person rather than 8 l/sec/person (assuming no material contribution from the perfunctory inclusion of vents), which also makes it easier to comply with the noise level limits, as fans can run slower. Clearly it is not the intention of the document to provoke this type of creative response to the criteria.

3.2 Performance criteria

It may be noted that BB 93 Table 2 indicates that for a hybrid system, the noise from the mechanical system alone should comply with BB 93 Table 1, whereas for a solely mechanical system, the IANL includes both mechanical system noise and external noise break in simultaneously. This means that when measuring the mechanical noise from a hybrid system, it may be appropriate to measure the background noise and make corrections to the measured noise level, following the guidance of ISO 16032[3] as described in the ANC GPG for Acoustic Testing of Schools[4]. For other ventilating conditions and criteria this correction would not be appropriate.

There is also an ambiguity over the L_{A1} criterion, from page 21 of BB 93, as shown in Figure 1.

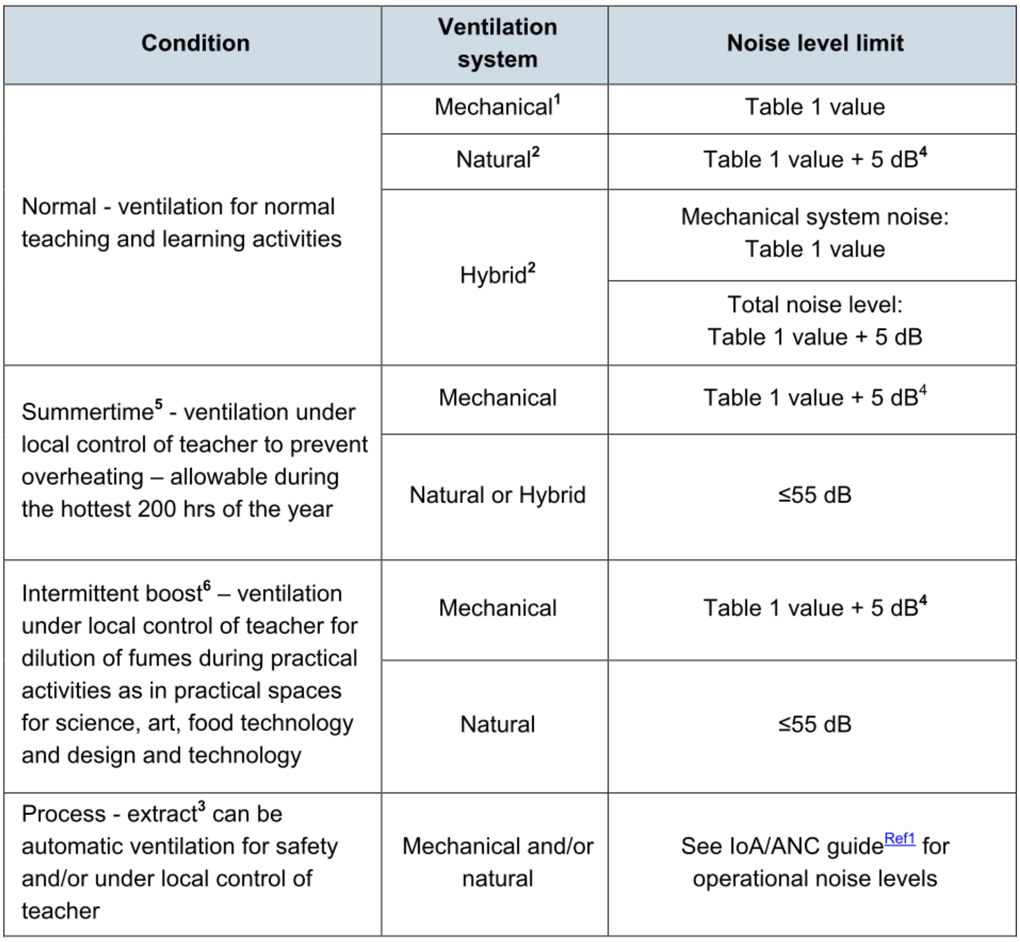
Figure 1: Extract from page 21 of BB 93



In order to protect students from regular discrete noise events, eg, aircraft or trains, indoor ambient noise levels should not exceed 60 dB $L_{A1,\ 30mins}$. This is achieved by default for spaces with IANLs up to 40 dB $L_{Aeq,\ 30min}$, but requires assessment in spaces with higher IANL limits, eg, 45 and 50 dB.

It is not clear whether any tolerances apply to this criterion during the “Summertime” condition, or if it applies under “Normal” ventilation conditions only. This can be the limiting factor in the façade performance requirement, and should be clarified.

Figure 2: BB 93 Table 2, showing a summary of ventilation condition, system type and associated IANL tolerance



Condition	Ventilation system	Noise level limit
Normal - ventilation for normal teaching and learning activities	Mechanical[1]	Table 1 value
	Natural[2]	Table 1 value + 5 dB[4]
	Hybrid[2]	Mechanical system noise: Table 1 value
		Total noise level: Table 1 value + 5 dB
Summertime[5] - ventilation under local control of teacher to prevent overheating – allowable during the hottest 200 hrs of the year	Mechanical	Table 1 value + 5 dB[4]
	Natural or Hybrid	≤55 dB
Intermittent boost[6] – ventilation under local control of teacher for dilution of fumes during practical activities as in practical spaces for science, art, food technology and design and technology	Mechanical	Table 1 value + 5 dB[4]
	Natural	≤55 dB
Process - extract[3] can be automatic ventilation for safety and/or under local control of teacher	Mechanical and/or natural	See IoA/ANC guide[Ref1] for operational noise levels

3.3 Performance criteria – “hybrid” systems

An ambiguity in BB 93 Table 2 concerns the limit for noise from a hybrid system during the hottest 200 hours, or “Summertime” condition. The table can be read to imply that the total noise level from a hybrid system should not exceed 55 dB(A), including mechanical system noise. This was not the intention of the document; the intention was that mechanical system noise as part of a hybrid system should be limited to +5 dB, in the same way as under normal ventilation conditions. BB 93 Table 2 should therefore be amended to make this clear.

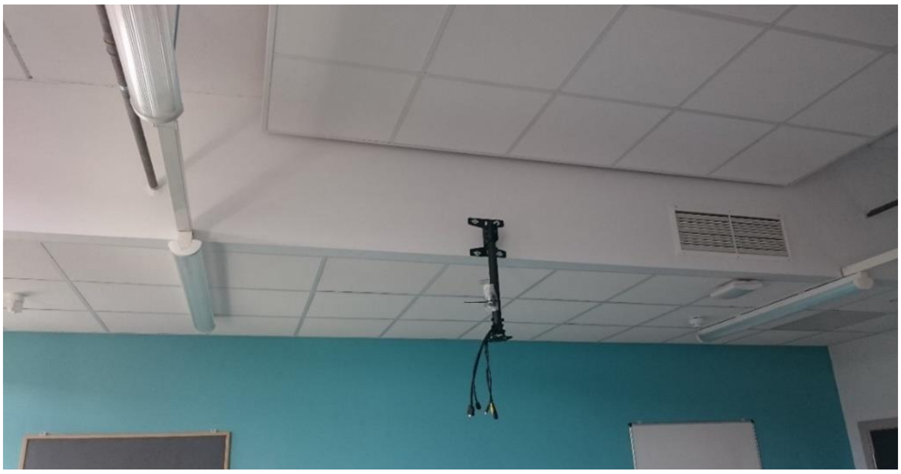
3.4 Design issues – “mechanical” systems

Design issues concern the use of exposed heat recovery units (i.e. without an enclosure) within the classroom. Despite claims by many manufacturers that their units are “BB 93 compliant”, many manufacturer’s test data has been reviewed, along with and tests undertaken by Apex within classrooms.

Based on the manufacturer’s reported test data, simple sound power calculations according to BS EN 12354-5[5] were carried out. With an assumed “realistic worst case” compliant reverberation time spectrum, it is calculated that the casing sound level emission should not exceed around 19 dB(A) @ 3 m, in the terms favoured by many fan manufacturers, presumably because it makes their products appear “quiet”. This is equivalent to a sound power level of 40 dB L_{WA}. At the time of investigation, the lowest manufacturer claimed casing sound emission that could be found was 23 dB(A) @ 3m. This would suggest that no manufacturer’s products can be used without a bulkhead or other casing noise reduction.

On this basis many options for bulkheads were developed. The range of bulkheads considered included a plasterboard encasement, a plasterboard or MDF upstand with ceiling tiles to the horizontal portion, to fully encasing on all sides and base with ceiling tiles. The sound insulation of the ceiling tiles was important, depending on the unit sound emissions; absorption within the bulkhead was also considered necessary to achieve the sound reduction required. An illustration of this arrangement is shown in Figure 3.

Figure 3: Bulkhead formed with MDF on upstand and ceiling tiles on room soffit



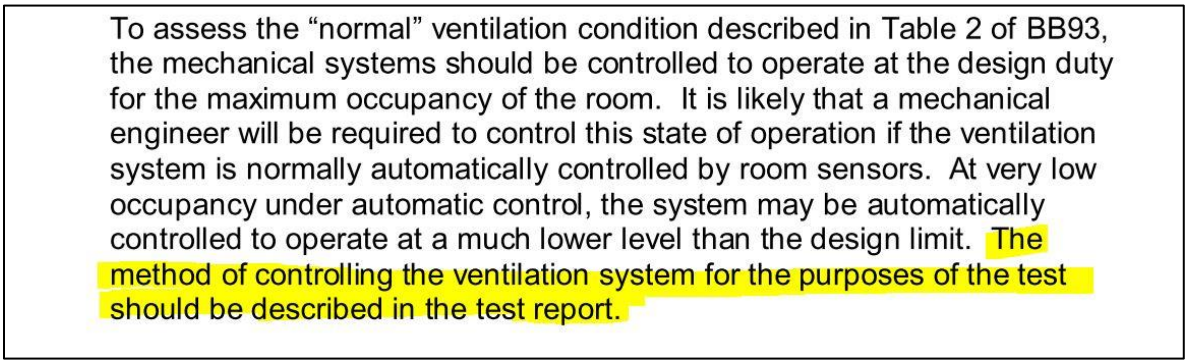
The next significant noise emission route was duct borne noise. Consideration was given to use of the bulkhead as a plenum for return air, as well as ducting the return air from a grille; this was considered to be an approximately neutral design issue for the units considered. Noise from the supply air duct was the most problematic in practice; although the manufacturer’s data suggested compliance, it was found that further mitigation was required to this noise path to sufficiently control the overall noise levels in the room.

3.5 Commissioning issues

Commissioning ventilation systems against the performance is a significant minefield. The design assessment conditions – e.g. “during the hottest 200 hrs”, and “normal” are not typically set points for operation. Controlling the system to operate in the defined conditions for the acoustic assessment is a complicated process, and as we found, unlikely to be a concept that is understood by either the site manager or mechanical services engineer. Our experience, repeated on many occasions, was that it was necessary to convey the requirements with the mechanical designers as well as the mechanical contractors in order to assemble the necessary people on site to control the ventilation systems as required..

Air flow commissioning involves ensuring that at set control voltages the units provide a certain level of air flow. When the HVAC commissioning engineer walks away, the units may be ready for normal operation. This means that within set occupied times, the unit will be controlled on temperature or air quality (usually carbon dioxide) sensor inputs to try and prevent poor air quality or overheating. It is because of this complication that the ANC Good Practice Guide for Acoustic Testing of Schools[4] makes the requirement reproduced in Figure 3.

Figure 3: Extract from ANC GPG for testing schools



To assess the “normal” ventilation condition described in Table 2 of BB93, the mechanical systems should be controlled to operate at the design duty for the maximum occupancy of the room. It is likely that a mechanical engineer will be required to control this state of operation if the ventilation system is normally automatically controlled by room sensors. At very low occupancy under automatic control, the system may be automatically controlled to operate at a much lower level than the design limit. The method of controlling the ventilation system for the purposes of the test should be described in the test report.

4 REVERBERATION TIMES

4.1 Performance requirements

Reverberation time criteria are little changed, although formally they are required to be “≤” the upper limits, rather than “<” as stated in the original version of BB 93. It is noted that the standards relate to rooms in their normal state of furnishing, such that the diffusing effect of furniture may be included when undertaking testing. Although clearly this will add a little absorption and some much needed diffusion in typical classrooms, loose furniture is often not present or available at the time of testing, which complicates the testing procedure.

4.2 Current classroom designs

Previous classroom designs contained the majority of the absorption in a suspended ceiling. Current designs lead to rafts comprising either individual boards, typically 1.2 * 1.2 m or 1.2 * 2.4 m, spaced and arranged around other high level fittings such as structural elements, bulkheads, the lighting layout, mechanical services such as ventilation ducts, sprinklers for fire suppression, all while allowing natural daylight to penetrate the space. Illustrations of typical classrooms are shown in Figure 4 and Figure 5. Rafts may also be comprised of ceiling tile grids, as visible in Figure 3.

It is well known that the sound field in classrooms can be significantly non-diffuse – there is no current definition or quantification for the “degree of diffuseness” of a sound field, and therefore this cannot be evaluated. Sound fields may be non-diffuse in rectangular rooms where there is a non-even distribution of absorption.

Figure 4: Small primary classroom with bulkhead for ventilation unit, rafts and wall panels

Figure 5: Typical primary classroom with bulkhead for ventilation unit, rafts and wall panels

4.3 Reverberation time predictions in non-diffuse spaces

It has been noted by many researchers that reverberation times are often not well predicted using the classical Sabine formula when the absorption is concentrated on one room surface. Neubauer[6] in particular provides a thorough review of the history of reverberation time formulae, and proposes a "New Formula" for calculation where there is a non-uniform distribution of absorption. Neubauer compares measured results with the predictions of the formulas proposed by Sabine, Eyring, Eyring-Kuttruff, Fitzroy, Tohyama, Arau, Millington-Sette and the method in Annexe D of BS EN 12354-6. Neubauer concludes:

The aim of this paper is first to review the best known reverberation time formulae and then to show that the reverberation time cannot be thereby predicted accurately in cases mostly encountered in practice, where the sound field is not diffuse.

The limitations of traditional reverberation time formulae have been noted by Bradley et al[7], who also compare predictions with the Sabine, Eyring, Millington, Cremer, Kuttruff, Fitzroy and Arau-Puchades formaulae. Bradley also reviews the potential of ray-tracing modelling in two commercial software packages to predict reverberation times. None of the formulae or software packages could predict reverberation times to within 10% of the measured values, with average errors between 17 % and 25 %.

More sophisticated analytical models have been proposed by Erling Nilsson, such as in Building Acoustics journal articles[8,9] and subsequent conference papers[10]. Nilsson describes the grazing sound field as that which is parallel to the absorbent ceiling, and the non-grazing part which comprises those modes that more significantly impinge on the absorbent ceiling. In his two-part energy model the decay processes in the grazing and non-grazing sound field are considered separately. Nilsson concludes in his 2007 ICA conference paper[10]:

In rooms with absorbent ceiling treatment there is a need for supplementary descriptors besides the reverberation time for a relevant characterisation of the acoustical conditions. It is shown that the steady state sound pressure levels and the reverberation times are not related according to the classical diffuse field theory and hence has to be evaluated separately since they depend on different components of the sound field. The reverberation time is mainly determined by sound waves propagating almost parallel to the ceiling and is to a large extent affected by non-absorbing objects in the room. In that respect the reverberation time is a configuration parameter not only related to the sound absorption but also to the amount of sound scattering objects and the location of the absorbers. The steady-state sound pressure level is related to the diffuse part of the sound field, mainly determined by the total amount of sound absorption in the room, and much less influenced by sound scattering objects.

4.4 Alternative descriptors to reverberation time

Alternative descriptors proposed include Sound Strength, G; Clarity, C_{50}; and the Unfavourable ratio, U_{50}. These parameters are more likely to correlate with the aspect of the room acoustic response that is important to the users, which are speech intelligibility for the listeners, speech comfort for the talker, and control of noise build up. These parameters have been investigated and developed by Nilsson[11,] Nijs & Rychtáriková[12], Pelegrin-Garcia & Brunskog[13], and Harvie-Clark, Dobinson & Larrieu[14]. The potential uncertainty with modelling reverberation times in non-diffuse spaces such as sports halls has also been investigated by Apex Acoustics[15].

While there certainly appears to be potential for these parameters to more effectively assure the type of acoustic conditions that the rooms users require, they are not yet embodied in standards and regulations. Thus the problems with predicting and measuring reverberation time remain for the time being.

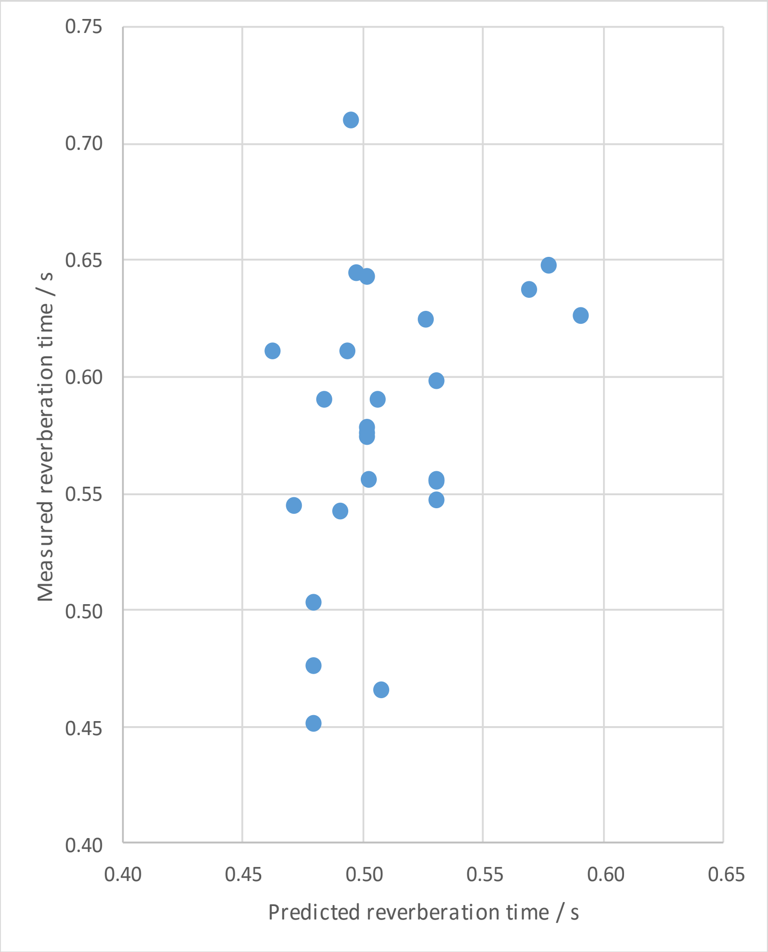
4.5 Comparing measured and predicted values in primary school classrooms

The problem of sufficiently accurate predictions for regulatory purposes remains. In these situations, the contractor wishes to install the minimum possible absorption to comply with the regulatory requirements. The acoustic consultant needs a sufficiently robust and yet resource-effective method to determine the quantity of absorption required in each room. Curiously, it is often more difficult to justify a single test failure with all other tests “just passing” than it is to justify over-designing and reducing the risk of any test failures. This is the judgement that every acoustic consultant must make when determining a suitable calculation method.

Following measurements in a batch of primary and secondary schools, with similar implementation of absorption across the different rooms and sites, the measured values of the mid-frequency reverberation time, T_{mf}, are compared with predicted values. The predicted values here are based simply on a Sabine calculation according to BS EN 12354-6[16], disregarding air absorption and furniture, as the rooms were largely unfurnished at the time of testing.

The calculations are based on the quantities of absorption observed in the rooms at the time of testing, which differed from that in the design. Many variations in the installation of the absorption were noted such as the distance of the rafts from the concrete soffit, spacing between rafts and mounting of wall panels above the level of rafts. These are examples of variations that would be likely to affect the effectiveness of the absorption, but go beyond available laboratory data. As such the closest applicable laboratory data is used in these calculations. The results are shown in Figure 6 for a sample of data from five primary schools.

Figure 6: Comparison of measured and predicted reverberation times in primary schools



4.6 Observations and discussion

In almost all cases the measured reverberation time is longer than that calculated in this manner, but it is notable that in a few cases the measured value is shorter. It can also be seen that if the limit was 0.6 seconds, then all but one of these results represents a “pass”, when rounded to one decimal place and compared with the value for a primary school classroom, 0.6 seconds. The data does not suggest any approximate relation between calculated and measured reverberation time.

It will be interesting to compare the measured and predicted reverberation times using other formulae, and also to compare with current geometric room acoustic modelling software. This will form the basis of future work, to determine if a more accurate method can be developed to predict reverberation times in practice for this type of room.

5 CONCLUSIONS

It is illustrated that although many of the changes to the acoustic performance standards in the revised version of BB 93 appear minor, the manner of current school design to meet the government’s strict environmental criteria mean that many of the previous default design solutions are no longer appropriate. Assessment of ventilation systems to meet the various performance criteria at different environmental design points is complex; acoustic commissioning of the systems properly can be extremely difficult in practice. Reverberation times remain as difficult to predict accurately as in previous schemes with suspended ceilings; the change in approach to absorption requires a further learning exercise to appropriately determine the amount of absorption required.

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