# Acoustics of Schools: a design guide




November 2015

# Acknowledgements

This document is published jointly by the Institute of Acoustics (IOA) and the Association of Noise Consultants (ANC).

The document is designed to accompany the revised performance standards for the acoustic design of schools published by the Department for Education in December 2014, and is a revision of the guidance previously published in 2003 as Sections 2 to 7 of Building Bulletin 93: Acoustic Design of Schools.

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# Contents

# Chapter 1 Introduction

This document has been produced by the Institute of Acoustics and the Association of Noise Consultants to provide supporting guidance and recommendations on the acoustic design of new and refurbished schools. It replaces the guidance previously published in the 2003 edition of Building Bulletin 93: Acoustic Design of Schools.

The revised constructional acoustic performance standards for new and refurbished school buildings are given in the Department of Education publication Acoustic Design of Schools: Performance Standards, Building Bulletin 93, published in 2014[1].

The performance standards in Building Bulletin 93 provide the normal means of compliance with the following:

- Requirement E4 of Part E of the Building Regulations;
- The School Premises Regulations 2012.
- Independent Schools Standards 2013.

For pupils and staff with special communication needs it may be necessary to make reasonable adjustments under the Equality Act of 2010 and Part M of the Building Regulations.

To meet the Building Regulations school buildings must comply with the performance standards in Building Bulletin 93 for indoor ambient noise levels, reverberation time and sound insulation.

The School Premises Regulations (SPR) and Independent Schools Standards (ISS) govern the performance in use of school buildings, including speech intelligibility in teaching areas and operational noise levels. To comply with the SPR and ISS, open plan spaces must meet the performance standards in Building Bulletin 93 for the Speech Transmission Index.

Further information on the requirements of the regulations, and on the educational establishments to which they apply, are given in Building Bulletin 93.

## 1.1 Aims of the performance standards and regulations

The overall objective of the performance standards is to ensure that the design and construction of school buildings provide acoustic conditions that enable effective teaching and learning. There has been a large body of research over the past 50 years showing that noise and poor acoustic design have a detrimental effect upon pupils' academic performance and teachers' vocal health. Pupils with additional learning needs and hearing impaired pupils are particularly susceptible to the negative effects of poor acoustic design.

The introduction in 2003 of performance standards for acoustics in schools under the Buildings Regulations led to a general improvement in the acoustic environment of new school buildings. Prior to the introduction of the standards, remedial work was often required to new buildings in order to provide acoustic conditions suitable for teaching and learning. Such remedial work is much more expensive than providing good acoustics as part of the original building work and is usually much less effective.

## 1.2 Revision of the standards

The performance specifications have been revised in the light of 12 years' experience of applying the standards. A major change is that the previous standards published in 2003 gave performance criteria for new school buildings only. The current standards also include requirements for refurbishments and changes of use of buildings. Furthermore, in general, where Alternative Performance Standards are required, they must not be less stringent than the refurbishment standards.

The standard for speech intelligibility in open plan teaching and learning areas has been removed from the requirements for meeting the Building Regulations, and hence from the need for assessment by the Building Control Body. However the speech intelligibility standard must be met in order to comply with the School Premises Regulations.

The performance criteria represent minimum standards which must be achieved to provide a suitable acoustic environment for teaching and learning.

Table 1.1 summarises where the main changes to the performance standards have occurred.

**Table 1.1 Summary of changes to performance standards**

| Topic | Change |
|---|---|
| Regulations | More emphasis on School Premises Regulations, Independent School Standards and Equality Act |
| Refurbishment and change of use | New mandatory standards where Part E of the Building Regulations applies, and guidance where it does not apply |
| Room conditions | Standards apply to rooms furnished for normal use |
| Pupils with special hearing or communication needs | Category expanded from hearing impaired pupils only |
| | More emphasis on design of classrooms for these pupils |
| Room types | List simplified and updated |
| Noise tolerance | Number of categories reduced to three |
| Rain noise | To be calculated using BS EN ISO 140-18 |
| | Noise from heavy rain not to exceed 25 dB above indoor ambient noise level limit |
| Indoor ambient noise level | New limits for ambient noise depending on ventilation condition and type of ventilation system |
| | New standard for noise from window actuators |
| | Limit for individual noise events increased to 60 dB $L_{A1,\ 30min}$ |
| Equipment noise | Has to be controlled to satisfy School Premises Regulations and Independent School Standards |
| Sound insulation | Units simplified to $D_{nT,w}$ and $L'_{nT,w}$ |
| | $D_{nT,w}$ requirements table simplified |
| | $D_w$ allowed for commissioning testing, but not for design |
| | More room types require higher performance corridor wall and door |
| | Standards for classroom to corridor ventilators relaxed |
| Reverberation time | Standards for rooms for pupils with special hearing or communication needs more stringent and apply across frequency range 125 Hz to 4 kHz |
| | Standard for sports halls dependent on size; relaxed for large halls |
| | Compliance for activity spaces can be demonstrated by use of 'deemed to satisfy' design procedure |
| Alternative performance standards | APS not to be a lower standard than the performance standard for refurbishment |
| | Certain exceptions allowed without need for APS |
| STI in open plan spaces | STI removed from Building Regulation requirement but criteria must be met to comply with School Premises Regulations and Independent School Standards |
| | Two STI criteria for critical listening activities |
| | More information given on design and modelling of open plan spaces |

## 1.5 Overview of contents of design guide

This document is arranged as described below.

**Chapter 2:** Noise Control describes how to conduct a site survey and plan the school buildings to control noise. It also includes recommendations for maximum external sound levels on playing fields, recreational areas and areas used for outdoor teaching. Guidance is also given on the design of roofs and the external façade, on ventilation strategies to reduce the ingress of external noise, and on the control of noise from equipment.

**Chapter 3:** Internal Sound Insulation outlines the general principles of sound insulation including airborne and impact sound insulation and flanking transmission. Typical wall and floor constructions capable of meeting the required performance standards for sound insulation are discussed.

**Chapter 4:** Design of Rooms for Speech describes the factors that need to be considered to ensure that a room provides good conditions for clear speech communication between teachers and pupils and between pupils. The particular requirements of different types of teaching space (e.g. classrooms, sports facilities, drama rooms) are considered.

**Chapter 5:** Design of Rooms for Music gives guidance on the acoustic design of different types of room used for music teaching, recording and performance, including appropriate sound insulation and room acoustic requirements.

**Chapter 6:** Acoustic Design and Equipment for Pupils with Special Hearing Requirements addresses the needs of pupils with permanent or temporary hearing impairments, with visual impairments, and with other speech, language or communication difficulties. Different types of assistive technology for use in the classroom are discussed.

**Chapter 7:** Design of Open Plan Teaching Spaces discusses the design of open plan spaces to meet the required STI standards. Options for open plan layout are described, together with the need for activity management plans.

**Chapter 8:** Refurbishment and Integrated Design outlines appropriate strategies and factors to consider in the acoustic design of refurbished spaces, and discusses the importance of considering other design factors which may have an impact on the optimum acoustic design, such as thermal comfort, ventilation and daylighting.

Additional information is contained in appendices which provide brief explanations of general acoustic principles and those specific to room acoustics and sound insulation. Further appendices give more detailed information on the design of unfurnished activity spaces, the calculation of equipment noise, acoustic modelling of open plan spaces and the assessment of noise from window actuators.

## References

1. Department for Education. Acoustic Design of Schools: Performance Standards, Building Bulletin 93, 2015.

# Chapter 2 Noise control

This chapter gives recommendations and guidance concerning noise control, starting with the choice of a site and the control of external noise. Local government planning policy will be influenced by the recommendations on maximum external noise levels in playing fields and other external areas used by the school. This chapter also includes discussion of the means of controlling indoor ambient noise including attenuation by the façade and the roof, and the influence of the ventilation strategy on external noise ingress.

## 2.1 Choosing a site

The acoustic design of a school starts with the selection of the site. An assessment typically includes a noise survey, and planning the layout of the school buildings. Financially viable sites for new schools with easy access to transport often suffer from transport noise and pollution. Many of the acoustic problems in existing schools result directly from the school's location in a noisy area. Noise from road traffic is a common problem, but in some areas noise from railways or aircraft is intrusive. Noise from such sources has been shown to affect pupils' cognitive performance and attainments[1].

School sites affected by transport noise may require the use of zoning, noise screening and, if necessary, sound insulating building envelopes, together with mechanical ventilation or acoustically designed passive ventilation.

## 2.2 Recommendations for external noise levels outside school buildings

Although Requirement E4[2] does not apply to external noise, the following recommendations are considered good practice for providing suitable acoustic conditions outside school buildings.

For new schools, 60 dB $L_{Aeq,30min}$ should be regarded as an upper limit for external noise at the boundary of external areas used for formal and informal outdoor teaching and recreation.

It may be possible to meet the specified indoor ambient noise levels on sites where external noise levels are as high as 70 dB $L_{Aeq,30min}$ but this will require considerable building envelope sound insulation, or screening.

Playgrounds, outdoor recreation areas and playing fields are generally considered to be of relatively low sensitivity to noise. Indeed, playing fields may be used as buffer zones to separate school buildings from busy roads where necessary. However, where used for teaching, for example sports lessons, outdoor ambient noise levels have a significant impact on communication in an environment which is already acoustically less favourable than most classrooms. Noise levels in unoccupied playgrounds, playing fields and other outdoor areas should not exceed 55 dB $L_{Aeq,30min}$ and there should be at least one area suitable for outdoor teaching activities where noise levels are below 50 dB $L_{Aeq,30min}$. If this is not possible, due to a lack of suitably quiet sites, acoustic screening should be used to reduce noise levels in these areas as much as practicable, and an assessment of noise levels and options for reducing these should be carried out. Noise levels can be reduced by up to 10 dBA at positions near an acoustic screen.

All external noise levels specified in this section apply to measurements made at approximately 1.5 m above the ground and at least 3 m from any other reflecting surface.

## 2.3 Noise survey

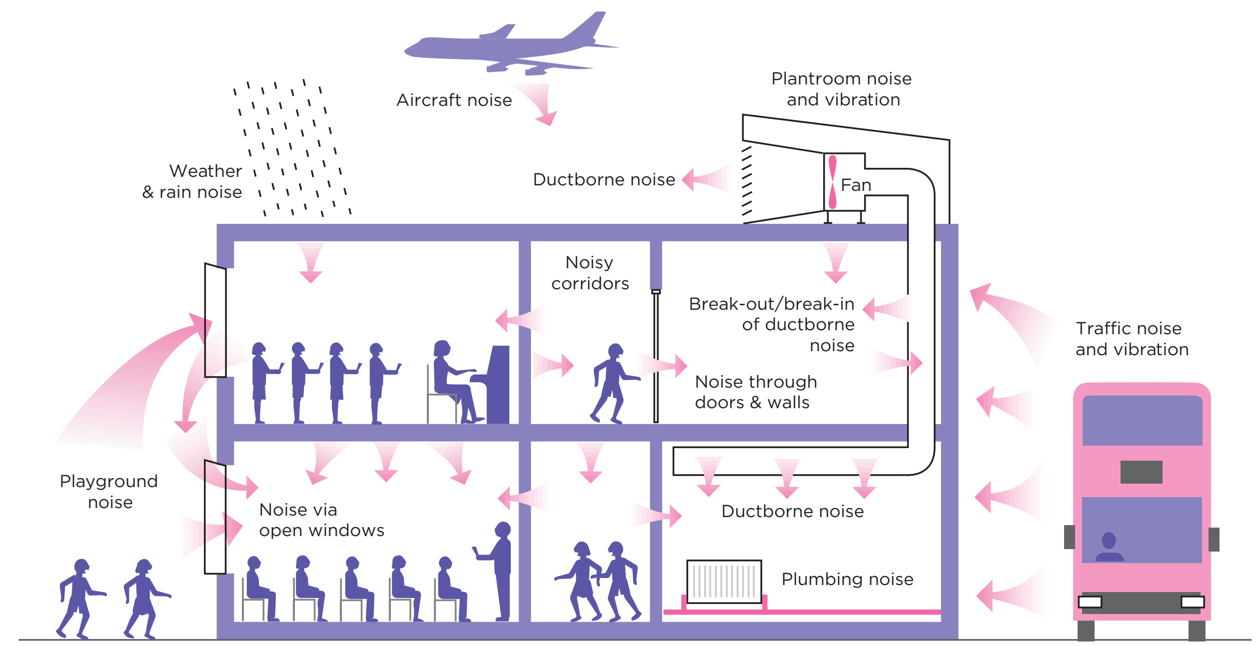



**Figure 2.1: Typical sources of noise.**

Figure 2.1 shows typical external and internal sources of noise which can affect noise levels inside a school. In order to satisfy the limits for the indoor ambient noise levels in Table 1 of Building Bulletin 93, it is usually necessary to know the external noise levels at the site so that the building envelope can be designed with the appropriate sound insulation. The external noise level can be established by carrying out a noise measurement survey. The measurements should be taken during school hours over a suitable time period to be able to quantify the representative A-weighted sound pressure level, $L_{Aeq,30min}$, likely to occur during teaching hours and should include noisy events (e.g. road traffic at peak hours, worst-case runway usage in the case of airports, etc). The measurements should exclude intermittent or occasional events associated with the school operation (e.g. mowing of school lawns, traffic movements associated with school drop off and pick-up, etc). The measurements must also take account of the weather conditions. For long-distance propagation of noise, the measured level is affected by wind, temperature gradients and turbulence. The noise level is generally increased under downwind conditions and reduced under upwind conditions. Whilst temperature inversion can radically change noise propagation, this normally only occurs at night-time and, therefore, outside school hours.

A noise measurement survey should include measurement of octave or one-third octave frequency band levels. This is because the attenuation of sound, for example by a sound insulating element or a noise barrier, depends upon the frequency of sound. In general, building materials and barriers are less effective at controlling low frequency noise than mid and high frequency noise. Although noise levels and performance standards can be quoted as overall A-weighted levels, calculations must be carried out in octave or one-third octave bands and the results then converted into A-weighted levels.

## 2.4 Assessment of external noise and vibration

If the noise measurement survey shows that the ambient external noise levels on the site are below 45 dB $L_{Aeq,30min}$, and prediction work shows that they will remain below 45 dB $L_{Aeq,30min}$ in the future, no special measures are likely to be necessary to protect the buildings or playing fields from external noise. However, consideration should be given to any potential increases in noise levels due to future developments (e.g. increases in traffic flows, new transport schemes, changes in flight paths). The local highway authority should be able to advise whether significant changes in road traffic noise are expected in the future. This is likely to be relevant for developments near new or recently improved roads. Where road traffic noise levels are likely to increase, it is reasonable to base the sound insulation requirements on the best estimate of noise levels in 15 years' time. Similar information is likely to be available from railway operators and airports. The prediction[3,4] of future external noise levels should be carried out by an acoustics consultant.

### 2.4.1 Road and railway noise

Road and railway noise require individual assessment because of their different characteristics. Road traffic noise is a function of traffic flow, percentage of heavy goods vehicles, traffic speed gradient (rate of acceleration), road surface and propagation path of the noise, while railway noise is a function of train type, number, speed, rail type and propagation path.

In general it is advisable to locate a school away from busy roads and railways, but in towns and cities this is often not possible. However, the use of distance alone is a relatively ineffective way to reduce noise. A simple rule of thumb is that the noise level from a road with constant traffic decreases by 3 dBA for a doubling of distance from the road, assuming propagation over hard ground.

### 2.4.2 Aircraft noise

Where a school is to be located in an area affected by aircraft noise, special measures may be necessary and an acoustics consultant should be appointed.

### 2.4.3 Vibration

Railways, plant and heavy vehicles close to a school can lead to vibration within the school buildings. This vibration can re-radiate as audible noise, even when the vibration itself is not perceptible in the building. The propagation of vibration depends on ground conditions but, when planning a new school building, it is generally advisable for the noise survey to include vibration measurements when there is a railway within 30 m of a building, or a road with significant HGV traffic within 20 m. In these cases airborne noise is also likely to be a problem.

## 2.5 Noise barriers

Noise barriers can be much more effective than distance in reducing noise from road or rail traffic. In its simplest form a noise barrier can be a continuous close-boarded wooden fence, with a mass of not less than 16 kg/m$^2$. There is relatively little point in increasing the weight of the barrier beyond this because a significant proportion of the noise passes over the top, or round the ends, of the barrier. However, the particular requirements should be checked with an acoustics consultant.

The attenuation of a barrier is a function of the path difference, that is, the extra distance that the sound has to travel to pass over the top of the barrier, relative to the direct sound path from the source to the receiver, as shown in Figure 2.2. Barriers are less effective at reducing low frequency noise than mid and high frequency noise. Hence, to calculate the effectiveness of a noise barrier it is necessary to know the source noise levels in octave or one-third octave bands (see Figure 2.2).

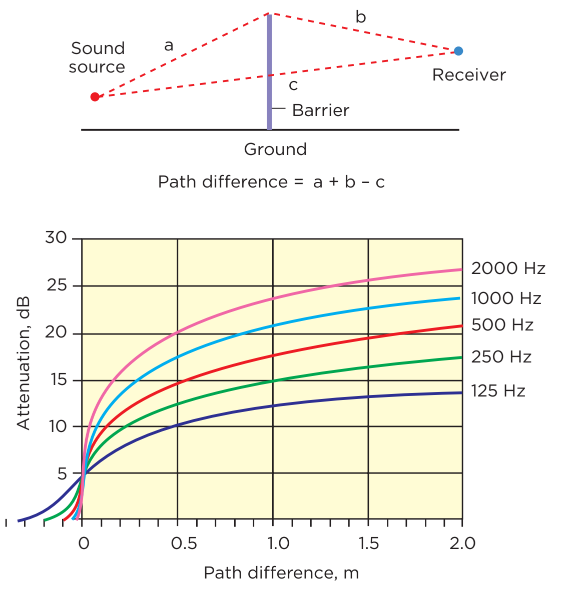



**Figure 2.2 Attenuation by a noise barrier as a function of path difference**

Hedges or single trees (or rows of trees) do not, in themselves, make effective noise barriers, although a noise barrier can be located within a band of trees to create an acceptable visual effect. Barriers can also be formed by other buildings, or by landscaping using earth bunds, as shown in Figure 2.3. The path difference and, hence, the attenuation of a barrier will be affected by whether the road or railway is in a cutting or on an embankment.

## 2.6 Noise from schools to surrounding areas

Noise from schools to the surrounding area can also be a problem and consideration should be given to nearby residential and other noise-sensitive developments that could be disturbed by noise from playgrounds, playing fields, music rooms and halls used for events outside normal school hours, such as concerts and discos. Noise from plant, deliveries and other activities associated with the operation of the school should also be considered. The local planning authority will normally consider this when assessing any planning application for new schools or extensions to existing premises.

The effect of playground noise on children inside the school should also be considered as part of the design.

## 2.7 Planning and layout

Noise transfer between rooms is one of the most common problems found in schools. This can be designed out to a large extent, without resort to very high performance sound insulating walls or floors, by good planning and zoning of the building at the

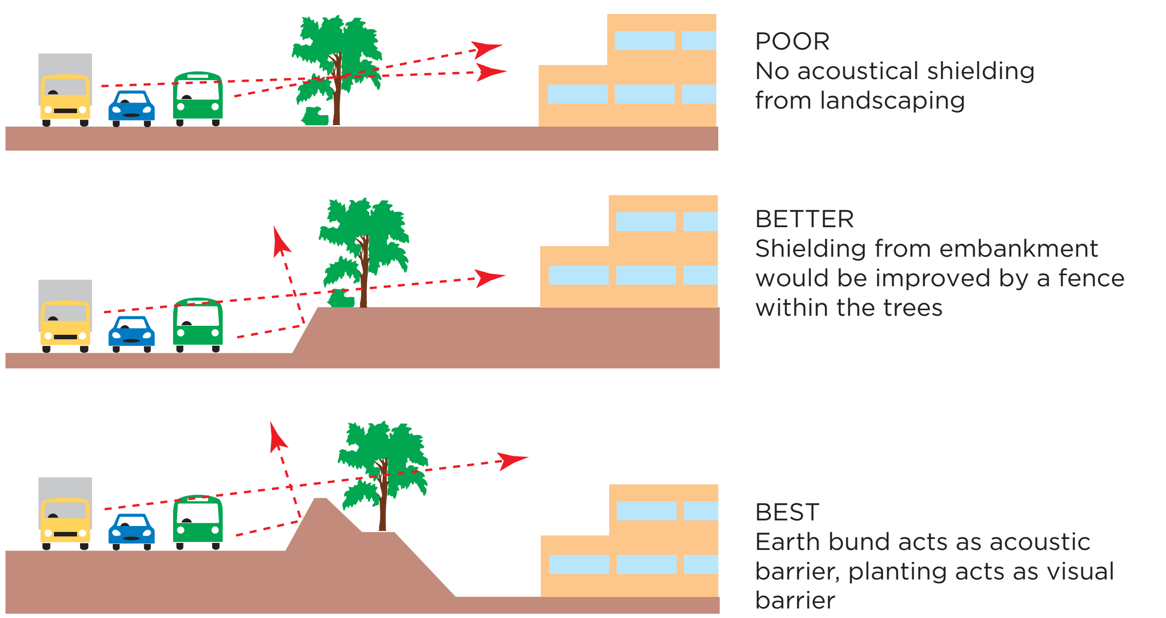



**Figure 2.3 Traffic noise barriers**

earliest stage of design. At this stage it is possible to identify noise-sensitive areas and to separate these from noisy areas using buffer zones such as storerooms, corridors or less sensitive rooms, and by separating buildings by a suitable distance. Figure 2.4 shows an example of the room layout in a music department that uses buffer zones.

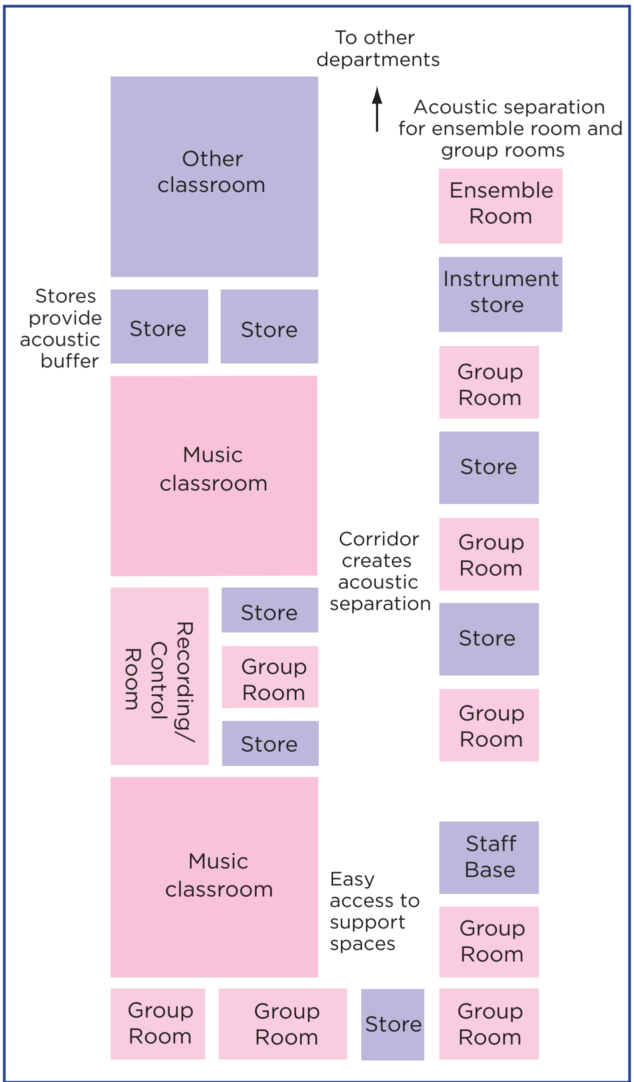



Figure 2.4 Planning acoustic 'buffer zones'

It is also advisable to locate noise-sensitive rooms, such as classrooms, away from sources of external noise wherever practicable. Mechanically serviced spaces such as sports halls, assembly halls, and drama halls with sealed facades can be used to form a buffer between external noise sources and naturally ventilated classrooms.

Tables 1, 3a and 3b of Building Bulletin 93 give the required maximum indoor ambient noise levels and minimum sound insulation levels between rooms. The performance standards in these tables should be used in the early planning stages of a project to determine (a) the layout of the school (b) the constructions needed to provide sound insulation and (c) the compatibility of school activities in adjacent rooms.

## 2.8 Limiting indoor ambient noise levels

The total indoor ambient noise level is determined by combining the noise levels from all relevant sources. The indoor ambient noise level due to external sources such as traffic must be added to the noise from mechanical ventilation, heating systems, lighting and other classroom building services. Unless care is taken, these individual sources can be loud enough to cause disturbance, particularly in spaces where low noise levels are required.

## 2.9 Impact noise

Impact noise from footfalls on balconies, stairs and circulation routes, or from movement of furniture or other class activities, can be a significant distraction to teaching and learning.

Carpets and other soft floor finishes such as resilient backed vinyl or rubber flooring materials can be useful in limiting impact noise. Resilient feet can also be fitted to furniture to reduce impact noise.

## 2.10 Corridors, entrance halls and stairwells

Noise in corridors, entrance halls and stairwells can cause disturbance to neighbouring classrooms and other teaching spaces. It is, therefore, important that reverberation in corridors, entrance halls and stairwells is kept as low as possible to minimise noise levels in these areas. The requirement is to provide sound absorption in accordance with Section 1.7 of Building Bulletin 93. Corridors outside classrooms typically need acoustically absorbent ceilings and/or wall finishes to satisfy this requirement. Carpets and other soft floor finishes can also help to reduce reverberation at higher frequencies and the noise from footfalls.

## 2.11 Masking noise

The audibility and intrusiveness of noise from other areas (break-in noise) is a function of the level of the intrusive noise, the ambient noise level in the room under consideration (the receiving room) and the sound insulation of the separating structure (floor or wall). If the ambient noise level in the receiving room is low, break-in noise will be more audible. Hence, noise from the ventilation system (where rooms are mechanically ventilated) can be used to mask the noise from activities in neighbouring rooms. In this case, ventilation noise should be not more than 5 dB below the appropriate maximum ambient noise level listed in Table 1 of Building Bulletin 93. It is also important to ensure that the ventilation noise follows a specific masking noise curve, with no tonal or intermittent characteristics, for it to be both effective and unobtrusive. Specialist acoustic advice is required before using building services noise for masking.

Other possible sources of masking noise include fan heaters and constant levels of road traffic noise, for example from distant roads. However, it should be noted that the noise from some sources, such as fans and other mechanical equipment, can be intrusive and hence be disturbing or annoying. Such masking noise can also give rise to problems for hearing impaired occupants, as discussed in Section 2.12. It should also be noted that some building services systems may only operate at certain times of the year.

## 2.12 Low frequency noise and hearing impaired pupils

Many hearing impaired pupils make use of low frequencies below 500 Hz to obtain information from speech. Therefore, for hearing impaired pupils to be included in classes with pupils having normal hearing, special care should be taken to minimise low frequency indoor ambient noise levels. Given the prevalence of infections leading to temporary hearing loss, it is advisable to minimise low frequency indoor ambient noise levels in all classrooms, especially those used by younger pupils.

The indoor ambient noise levels in Table 1 of Building Bulletin 93 are given in terms of $L_{Aeq,30min}$, which is an A-weighted noise level. This is a convenient and widely-used parameter, but is not a good indicator of low frequency noise. There are other rating systems in use to assess indoor noise which address low frequency content, but these are beyond the scope of this document. Specialist advice from an acoustics consultant should be sought in cases where low frequency noise is likely to be a problem. Such cases include schools exposed to high levels of external noise, in excess of 60 dB $L_{Aeq,30min}$ (see Section 2.2), where sound insulation may reduce upper frequency noise while leaving comparatively high levels of low frequency noise. More information on this can be found in CIBSE Guide B5 Noise and Vibration Control for HVAC[5].

## 2.13 Roofs

The sound insulation of a pitched roof depends upon the mass of the ceiling and the roof layers and the presence of a sound absorbing material in the roof space. Mineral wool, used as thermal insulation in the ceiling void, will also provide some acoustic absorption, which will have a small effect on the overall sound insulation of a roof. A denser specification of mineral wool, as commonly used for acoustic insulation, would have a greater effect on the overall sound insulation of the roof.

Where it is necessary to ventilate the roof space, improvements to the sound insulation of the construction can be achieved by increasing the mass of the ceiling layer over the teaching space rather than acoustically sealing and increasing the mass of a (pitched) roof.

### 2.13.1 Rain noise

The impact noise from rain falling on the roof can substantially increase the indoor noise level; in some cases the noise level inside a school due to rain can be as high as 70 dBA. Although rain noise is excluded from the definition of indoor ambient noise in Section 1.1.1 of Building Bulletin 93, it is a potentially significant noise source which must be considered at an early stage in the roof design to minimise disturbance inside the school.

Excessive noise from rain on the roof can occur in spaces such as sports halls and assembly halls where the roof has a large surface area and is constructed from profiled metal cladding with no sealed roof void to attenuate the noise before it radiates into the space below. Suitable treatments that can be used in combination to provide sufficient resistance to impact sound from rain on the roof are:

- damping of the profiled metal cladding (e.g. using commercial damping materials)
- use of dense mineral wool insulation in the roof build-up
- independent ceilings below the lightweight roof.

Profiled metal cladding used without mineral wool insulation or without an independent ceiling is unlikely to provide sufficient resistance to impact sound from rain on the roof. Reference can be made to manufacturers' data to assess the effect of 'Heavy' rain noise (measured in accordance with BS EN ISO 140-18[6]) for a range of lightweight roof constructions.

Consideration should also be given to any glazing (e.g. roof lights) when designing to attenuate noise due to rain on the roof. As there is a wide variety of roof constructions, advice should be sought from an acoustics consultant who can calculate the sound pressure level in the space resulting from 'Heavy' rainfall on the proposed roof construction.

## 2.14 External walls

For masonry walls, such as a solid brick wall, a brick/block cavity wall or a brick-clad timber frame wall, the sound insulation of the wall will normally be sufficiently high that the windows, ventilators and, in some cases, the roof will dictate the overall sound insulation of the building envelope.

Timber frame walls with lightweight cladding and other lightweight systems of construction normally provide limited sound insulation at low frequencies, where road traffic and aircraft often produce relatively high levels of noise. This can result in poor airborne sound insulation against these sources, unless the cladding system has sufficient low frequency sound insulation. The airborne sound insulation of such constructions should be assessed using data from laboratory measurements carried out according to BS EN ISO 10140-2:2010[7].

## 2.15 Ventilation

The method of ventilation, as well as the type and location of ventilation openings, will affect the overall sound insulation of the building envelope. The main choices for natural ventilation of typical classrooms are shown in Figure 2.5. Under normal operating conditions, single-sided ventilation typically requires a greater opening area in the façade (and therefore requires lower external noise levels to achieve suitable internal ambient noise levels), than cross-ventilation or stack ventilation.

Natural ventilation is typically provided by opening windows or by ventilators that penetrate the building envelope. Many proprietary ventilation products are designed for the domestic sector and in some cases they do not have large enough openings for classrooms and other large rooms found in schools. However, proprietary products with a sufficiently large open area to be suitable for classroom ventilation, with or without acoustic attenuation, are now more widely available. The use of acoustically attenuated ventilators, instead of opening windows, can enable natural ventilation to be used where school façades are exposed to high external noise levels.

The acoustic performance of a ventilator can be assessed with laboratory sound insulation test data measured according to BS EN ISO 10140-2[7]. The assessment of the acoustic performance of a ventilator can be complex and advice may be needed from a specialist acoustics consultant. It is essential that the effective area of the ventilator be considered, as it may be smaller than the free area required to maintain adequate ventilation (see BS EN 13141-1[8]).

It is important, particularly in the case of sound-attenuated products, that a good seal is achieved between the penetration through the wall, or window, and the ventilator unit. Where through-the-wall products are used, the aperture should be cut accurately and the gap around the perimeter of the penetrating duct should be packed with sound insulating material prior to application of a continuous, flexible, airtight seal on both sides.

Bespoke ventilator designs, such as that shown in Figure 2.6, may be needed in some schools.

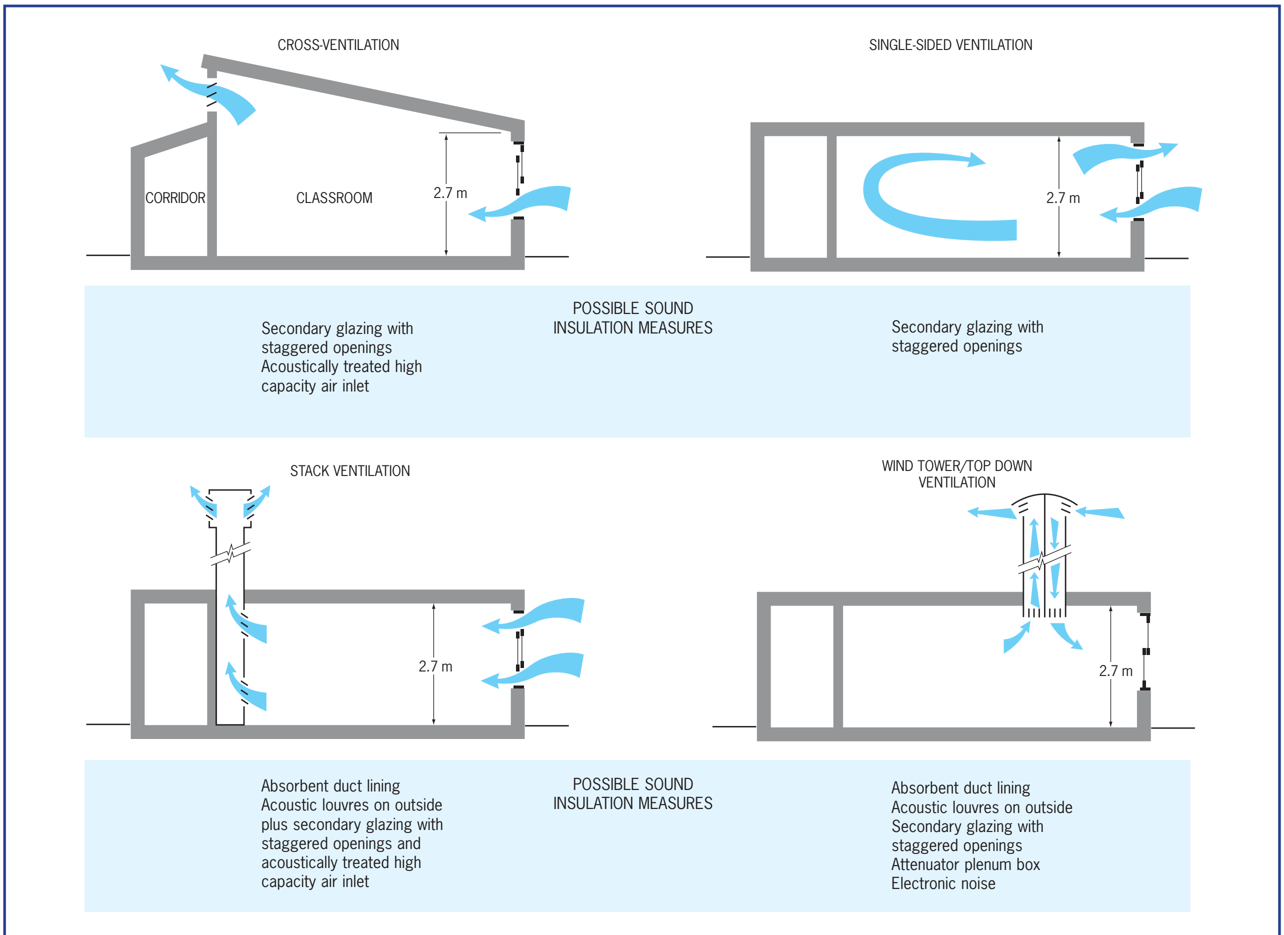



**Figure 2.5 Possible types of natural ventilation**

## 2.16 External windows

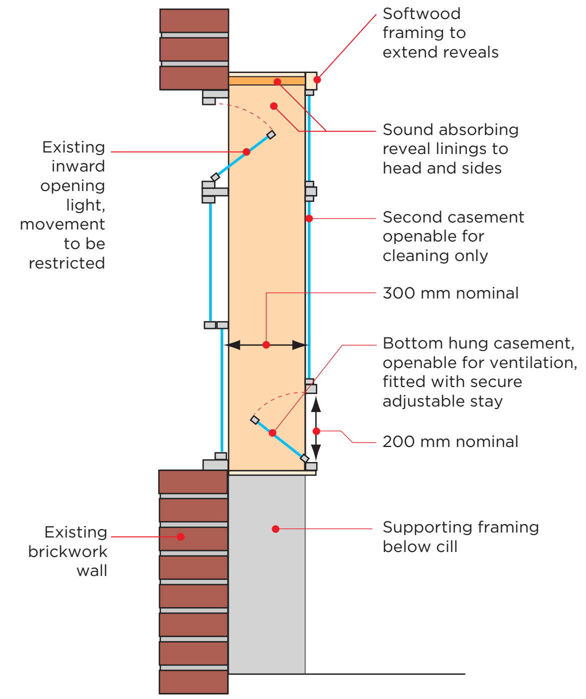
The airborne sound insulation of windows can be assessed from laboratory measurements of the sound reduction index according to BS EN ISO 10140-2[7]. Care must be taken to differentiate between measured data for glazing (i.e. the glass element only) and measured data for windows (i.e. the assembly of glazing in the frame) when choosing suitable windows on the basis of measured data. The reason for this is that the overall sound insulation performance of a window is affected by the window frame and the sealing, as well as the glazing.

It is often necessary to use two panes of glass separated by an air (or other gas) filled cavity to achieve the required sound insulation. In theory, the wider the gap between the panes, the greater the sound insulation. In practice, the depth of the cavity in double glazing makes relatively little difference for cavity widths between 6 mm and 16 mm. Deeper cavities perform significantly better.

Secondary glazing may be installed in existing buildings as an alternative to replacing existing single glazing with double glazing. The effectiveness of secondary glazing will be determined by the thickness of the glass and the width of the air gap between the panes. Another alternative may be to fit a completely new double-glazed window on the inside of the existing window opening, leaving the original window intact. The use of sound absorbing reveal linings improves the performance of double-glazed windows, but the improvement is mainly in the middle to high frequency region, and has little effect on road traffic and aircraft noise.

It is essential that the glazing has an airtight seal with the frame, and that opening lights have effective seals around the perimeter of each frame to achieve the optimum performance. Neoprene compression seals will provide a more airtight seal than brush seals. The framing of the window should also be assembled to achieve an airtight construction. It is also important that an airtight seal is achieved between the perimeter of the window frame and the opening into which it is to be fixed. The opening should be accurately made to receive the window, and the perimeter packed with sound insulating material prior to application of a continuous seal on both sides.

The laboratory measured airborne sound insulation of partially open single-glazed windows, or double-glazed windows with opposite opening panes, is approximately 10-15 dB. This increases to 20-25 dB for a partially open secondary glazing system where the openings are staggered on plan or elevation and the window reveals are lined with absorbent materials (see Figure 2.6). The effectiveness of an open window at attenuating noise also depends on the spectrum of the noise and the geometry of the situation.




Retrofit secondary glazing producing a staggered air flow path. Designed to limit aircraft noise intrusion to science laboratories at a secondary school near an airport.

A sound reduction of approximately 20-25 dB $R_W$ was achieved using this design.

**Figure 2.6 Secondary glazing producing a staggered air flow path**

### 2.16.1 Window actuators

Section 1.1.4 of Building Bulletin 93 identifies the upper limit for noise from window actuators when installed and operating to be no more than 5 dB above the IANL from Table 1 of Building Bulletin 93. It refers to ISO 16032[9] for the measurement of noise from these installations and indicates that assessment of a reference installation may be used to demonstrate suitability as there is currently insufficient design data to determine in-situ levels at the design stage.

Appendix 7 gives guidance on the assessment of actuators and the use of a reference installation.

## 2.17 External doors

The airborne sound insulation of external doors is determined by the door set, which is the combination of the door and its frame. The quality of the seal achieved around the perimeter of the door is crucial in achieving the potential performance of the door itself. Effective seals should be provided at the threshold, jambs and head of the door frame.

It is also important that an airtight seal is achieved between the perimeter of the door frame and the opening into which it is to be fixed. The opening should be accurately made to receive the door frame and any gaps around the perimeter packed with insulating material prior to application of a continuous, airtight seal on both sides.

A high level of airborne sound insulation is difficult to achieve using a single door that is practicable for use in schools. Where a high level of insulation is required it is best achieved using a lobby with two sets of doors, as is often provided for energy efficiency.

## 2.18 Subjective characteristics of noise

The indoor ambient noise levels in Table 1 of Building Bulletin 93 provide a reasonable basis for assessment, but some noises have tonal or intermittent characteristics which make them particularly noticeable or disturbing, even below the specified levels. This is most common with industrial noise. At some sites, achieving the indoor ambient noise levels in Table 1 of Building Bulletin 93 will not prevent disturbance from external sources, and additional noise mitigation may be required. In these cases advice from an acoustics consultant should be sought.

The potentially beneficial masking effect of some types of continuous broadband external noise (e.g. road traffic noise and some industrial noise) must also be borne in mind (see Section 2.11). Continuous broadband noise can mask other sounds, such as those from neighbouring classrooms, which would otherwise be more disturbing than the external noise. There are acoustic benefits, as well as cost benefits, in ensuring that the level of insulation provided is not over-specified, but is commensurate with the level and character of the external noise.

## 2.19 Variation of noise incident on different façades

It may be convenient to determine the external noise level at the most exposed window (or part of the roof) of a building, and to assume this exposure for other elements too. This may be suitable at the early design stage for large schools. However, where external noise levels vary significantly, this approach can lead to over-specification and unnecessary cost.

## 2.20 Calculations

A calculation of the internal noise level according to BS EN 12354-3[10] can be used to estimate whether, for the levels of external noise at any particular site, a proposed construction will achieve the levels in Table 1 of Building Bulletin 93. By estimating the internal levels for various different constructions, designers can determine the most suitable construction in any given situation. BS EN 12354-3 allows the effects of both direct and flanking transmission to be calculated, but in many cases it is appropriate to consider only direct transmission.

## 2.21 Noise from equipment in teaching and learning spaces

The internal ambient noise level limits include contributions from noise sources outside the school premises and noise from building services. These limits exclude the noise made by equipment used in the space. Installations such as process extract ventilation may be considered as equipment rather than classified as building services. The School Premises Regulations and Independent Schools Standards require consideration of noise from equipment associated with teaching.

### 2.21.1 Types and classes of equipment and typical uses

For the purposes of assessing noise from teaching equipment, sources that may be in use during teaching or learning activities should be included in the assessment. Two classes of equipment, A and B, may be considered, as shown in Table 2.1, the classes having different noise limits as explained in section 2.21.2.

**Table 2.1: Characteristics of the different classes of noise sources**

| Class of noise source | Characteristics |
|---|---|
| A | Operates continuously or intermittently under automatic control during teaching periods |
| B | Operates during teacher demonstration, under teacher control, or during teaching and learning activities as necessary to enable those activities |

Table 2.2 gives typical examples of equipment whose noise emission should be assessed. This list is not exhaustive and the assessor will need to determine which items of equipment should be included.

**Table 2.2: Types of equipment and suggested classes of noise sources**

| Room type | Typical equipment to consider | Class of noise source |
|---|---|---|
| Classroom | Stand alone projectors<br>Interactive white boards with built in projectors<br>Laptop and desktop PCs<br>Printers | A |
| Design Technology, Electronics, Graphics | Dust extraction systems<br>Fume/combustion extraction systems<br>CAD/CAM machines<br>Compressors | B |
| Food Technology | Cooker extraction hoods<br>Ovens<br>Microwaves<br>Dishwashers<br>Washing machines | B |
| | Refrigerators<br>Freezers | A |
| ICT | PCs/servers/printers | A |
| Science Laboratories | Fume cupboards | B |
| | Compressors | B |

If the equipment is to provide ventilation and is part of the fixed building installation it should normally be considered under the requirements for ventilation described in Building Bulletin 93. If the service is process extract and only required during some teaching activities, for example fume cupboards and local exhaust ventilation, then it may be considered as equipment.

Noise from activities associated with the use of the spaces, such as playing of musical instruments, banging of pots and pans, hammering, welding etc., need not be considered as these sources will normally be under the control of the teacher.

Dust and fume extraction plant should be located outside teaching spaces, otherwise it is unlikely to be practical to meet the noise level limits.

### 2.21.2 Noise level limits

In order to prevent excessive disturbance to teaching activities, the noise level in the teaching space, due to equipment related to teaching activities, should not exceed the limits shown in Table 2.3. These are described in terms of the excess, X dB, over the IANL limit for appropriate room types in new buildings from Table 1 of Building Bulletin 93. The noise from equipment is denoted $L_{p,equipment}$, such that:

$$L_{p,equipment} \leq \text{IANL (for room type in new buildings)} + X \text{ dB}$$

Values of X are given in Table 2.3.

**Table 2.3: Noise limits for equipment**

| Class of noise source | Limit, X dB, in excess of IANL for new buildings from Building Bulletin 93 Table 1 |
|---|---|
| A | + 3 |
| B | + 10 |

Noise from external sources and building services is assessed against the IANL limits in Table 1 of Building Bulletin 93; if this is at or near the upper limit for IANL, and there is also noise producing equipment in use during teaching then the overall noise level in the room may exceed the limits indicated in Table 2.3.

The time period for the assessment of equipment noise should be for a normal cycle of operation. There is guidance on assessing the cycle of operation in the Annexes of ISO 16032[9]. It is not intended that the noise level from short duration events should be averaged or assessed over a 30 minute period.

Although it is desirable that the cumulative effect of all equipment meets the limits indicated, it may not be practical to determine this, for example, when one new item of equipment is added to a room that already contains a range of other noise producing equipment.

This noise level limit should apply at all normally occupied positions in the teaching space. It is not intended to be a limit for spatially averaged levels, nor for noise levels at positions that would normally be unoccupied. There is more information on calculating noise from both new and legacy equipment in Appendix 5.

## References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6. ISO 140-18: 2006. Acoustics: Measurement of sound insulation in buildings and of building elements - Part 18: Laboratory measurement of sound generated by rainfall on building elements.
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# Chapter 3 Internal sound insulation

General principles of sound insulation and typical constructions are discussed in this section. Space does not allow all details for each type of construction to be shown. Many such details are illustrated and discussed in greater detail in manufacturers' literature for proprietary materials and systems.

This section describes constructions capable of achieving the different levels of sound insulation specified in Building Bulletin 93. Appendix 3 describes basic principles of sound insulation between rooms.

## 3.1 General principles

The airborne sound insulation of building elements is principally controlled by the mass of the element, although the stiffness of the element also influences sound insulation at low frequencies. For single leaf elements (e.g. single leaf walls, single glazing, solid core doors), doubling the mass of the element will give an increase of 5 to 6 dB in the sound insulation of the element (known as the mass law). In general, double-leaf constructions such as double-glazing, cavity masonry or double-leaf plasterboard partitions of a given mass provide better sound insulation than the mass law would indicate. The separation of the two leaves of double-leaf constructions provides improved sound insulation, particularly at medium and high frequencies, with performance increasing with the width of the air gap between the leaves. A further improvement in sound insulation, for a given separation width, can be achieved by avoiding a rigid connection between the leaves.

Figure 3.1 shows values of the sound insulation of some typical building elements, expressed in terms of the weighted sound reduction index, $R_w$. The solid red line shows the theoretical value based purely on the mass law.

Impact sound is normally controlled by the use of soft floor coverings (to limit the generation of impact sound) or by the use of double-leaf constructions (a floating floor or independent ceiling below a void). In critical cases, both techniques may be used.

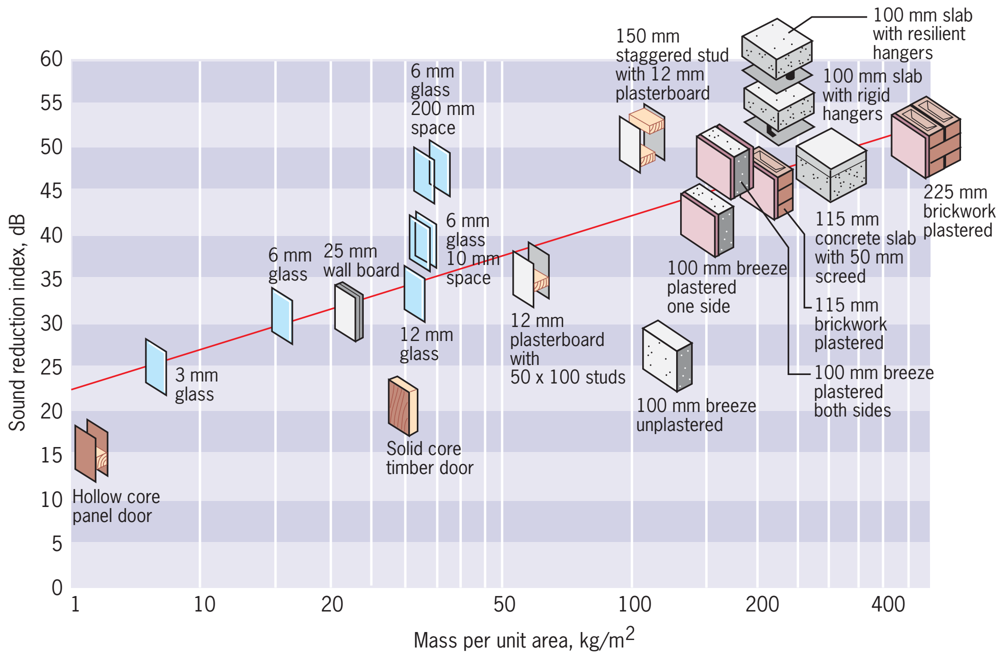



Figure 3.1 Typical sound reduction indices for construction elements

The specification, construction and detailing of sound insulating partitions for walls and floors is discussed in detail in the following sections.

## 3.2 Specification of sound insulation

The airborne and impact sound insulation of partitions (walls and floors) and of building elements is normally expressed in terms of a single figure value, based on measurement of the sound insulation over a range of frequencies (typically 100 Hz to 3.15 kHz, although this may be extended under special circumstances). The measured values are then compared to a standard reference curve and a single figure "weighted" value of the sound insulation derived. The rating procedure is given in the British Standards BS EN ISO 717-1[1] and 717-2[2].

The sound insulation of a built partition is normally different from the sound insulation of the building element when tested in a laboratory, because the measured sound levels are affected by the partition area, the volume of the receiver room and the sound absorption in that room (usually defined by its reverberation time). The sound level measured in the receiving room is also influenced by sound travelling through other common elements (walls, the floor and the ceiling); this flanking sound will reduce the expected sound insulation of the as-built partition. Typical airborne and impact flanking paths are shown in Figure 3.2.

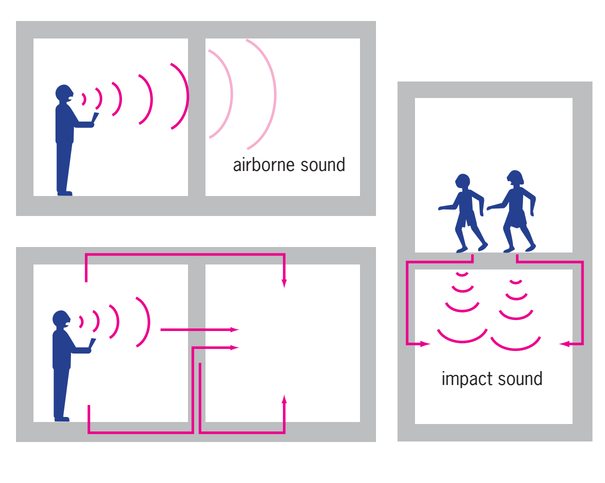



**Figure 3.2 Direct and flanking sound transmission paths between adjacent rooms**

The relationship between the airborne and impact sound insulation values specified in Tables 3a and 3b of Building Bulletin 93 is discussed in Sections 3.2.1 and 3.2.2 to enable the designer to select appropriate building elements to meet the required as-built sound insulation criteria.

Details of how flanking transmission may be controlled are presented in Section 3.3.

### 3.2.1 Specification of the airborne sound insulation between rooms

Tables 3a and 3b in Building Bulletin 93 describe the minimum weighted sound level difference between rooms in terms of $D_{nT,w}$. This value includes not only the direct sound transmitted through the separating partition itself (the wall or floor), but also the flanking sound. However, manufacturers' information tends to be based on laboratory airborne sound insulation data for a sample element on its own, measured according to BS EN ISO 10140-2[3] and presented as the weighted sound reduction index, $R_w$.

The test procedure eliminates any significant flanking sound transmission. The $R_w$ value is a fundamental property of the building element itself (like its density), while the $D_{nT,w}$ value specified in Tables 3a and 3b will vary according to the as-built conditions, that is the common partition area, the receiving room volume, the acoustic conditions (reverberation time) in the receiving room and the flanking sound transmission.

This section provides some basic guidance for the designer on how to use laboratory measured $R_w$ values to choose a suitable separating wall or floor for the initial design. However, specialist advice should always be sought from an acoustics consultant early on in the design stage to assess whether the combination of the separating partition and the flanking elements is likely to achieve the performance standards in Tables 3a and 3b. An acoustics consultant can use advanced methods of calculation to predict the sound insulation, such as BS EN 12354-1[4]. The correct specification and detailing of flanking walls, ceilings and floors is of high importance to prevent substantial reductions in the expected level of sound reduction (see Section 3.3).

The following procedure can be used to choose an appropriate type of separating wall or floor before seeking specialist advice on relevant flanking details.

1. From Table 3a or 3b determine the required minimum weighted standardized level difference between rooms, $D_{nT,w}$.

2. Estimate the required weighted sound reduction index for the separating wall or floor, as follows:

   a. Use the following formula to provide an initial estimate of the measured sound reduction index ($R_{w,est}$) that should be achieved by the separating wall or floor in the laboratory:

   $$R_{w,est} = D_{nT,w} + 10 \lg \left(\frac{S \times T}{V}\right) + 8 \text{ dB}$$

   where

   $D_{nT,w}$ is the minimum weighted standardized level difference between rooms from Table 3a or 3b

   S is the surface area of the separating element ($m^2$)

   T is the maximum mid-frequency reverberation time allowed for the receiving room from Table 6, applied to all frequency bands for the purposes of the calculation.

   V is the volume of the receiving room ($m^3$).

   b. Estimate the likely reduction, X dB, in the airborne sound insulation that would occur in the field, to account for less favourable mounting conditions and workmanship than in the laboratory test. X can be assumed to be 5 dB provided flanking walls and floors are specified with the correct junction details. However, if flanking walls and floors are not carefully designed, poor detailing can cause the airborne sound insulation to be reduced by a substantial amount. To allow the designer to choose a suitable separating wall for the initial design it is recommended that X is taken as 5 dB and an acoustics consultant is used to check the choice of separating element and ensure that the correct flanking details are specified.

   c. Calculate the final estimate for the weighted sound reduction index $R_w$ that should be used to select the separating wall or floor from laboratory test data from:

   $$R_w = R_{w,est} + X \text{ dB}$$

### 3.2.2 Specification of the impact sound insulation between rooms

Table 5 of Building Bulletin 93 describes the minimum impact sound insulation between rooms in terms of $L'_{nT,w}$, which includes contributions from flanking sound, via the paths shown in Figure 3.2.

Again, manufacturers usually provide information for floors based on laboratory impact sound insulation data measured according to BS EN ISO 10140-3[5], in terms of the element $L_{n,w}$, which does not allow for the flanking components.

This section provides some basic guidance for the designer on how to use laboratory $L_{n,w}$ values to design a suitable separating floor. However, specialist advice should always be sought from an acoustics consultant early on in the design process to assess whether the combination of the separating floor and flanking walls is likely to achieve the performance standard in Table 5. An acoustics consultant can use advanced methods of calculation to predict the sound insulation, such as BS EN 12354-2[6].

The following procedure can be used to choose an appropriate type of separating floor before seeking specialist advice on flanking details from an acoustics consultant.

1. Determine the maximum weighted standardized impact sound pressure level, $L'_{nT,w}$ from Table 5.

2. Estimate the required weighted normalized impact sound pressure level for the separating floor, as follows:

a. Use the following formula to provide an initial estimate of the weighted normalized impact sound pressure level ($L_{n,w,est}$) that should be achieved by the separating floor in the laboratory:

$L_{n,w,est} = L'_{nT,w} + 10 \lg\left(\frac{S \times T}{V}\right) - 18$ dB

where $L'_{nT,w}$ is the maximum weighted standardized impact sound pressure level from Table 5

S is the surface area of the separating element (m$^2$)

T is the maximum mid-frequency reverberation time for the receiving room from Table 6, applied to all frequency bands for the purposes of the calculation.

b. Estimate the likely increase, Y dB, in the impact sound pressure level that would occur in the field to account for less favourable mounting conditions and good workmanship than in the laboratory test.

Y can be 5 dB assuming that flanking walls are specified with the correct junction details. However, if flanking walls are not carefully designed, the impact sound pressure level can increase by up to 10 dB. To allow the designer to choose a suitable separating floor for the initial design it is suggested that a value for Y of 5 dB is assumed and an acoustics consultant is used to check the choice of separating floor and ensure that the correct flanking details are specified.

c. Calculate the final estimate for the weighted normalised impact sound pressure level $L_{n,w}$ that should be used to select the separating wall or floor from laboratory test data using the formula

$L_{n,w} = L_{n,w,est} - Y$ dB

## 3.3 Flanking details

Specific guidance on appropriate flanking details for products may be found in manufacturers' data sheets, or be available from manufacturers' technical advisers. Some products have been tested in accordance with BS EN ISO 10848[7], so that flanking sound transmission may be calculated in accordance with BS EN 12354-1[4].

Examples of problematic flanking details are given in the following sections.

### 3.3.1 Junctions between walls and floors

In some buildings it is considered desirable to lay a floating screed (e.g. a sand-cement or fibre-reinforced screed over a resilient material) across an entire concrete base floor and build lightweight partitions off the screed to form the rooms, see Figure 3.3(a). This allows the flexibility to change the room spaces. However, a continuous lightweight floating screed can transmit significant structure-borne flanking sound from one room to another.

To illustrate the significance of the flanking sound component, a lightweight partition with a sound reduction index of 54 dB $R_w$ built off a continuous floating screed could result in a level of sound insulation as low as 40 dB $D_{nT,w}$. Increasing the sound insulation of the partition to, say, 64 dB $R_w$, with a consequent increase in cost, would not improve the sound insulation significantly from 40 dB $D_{nT,w}$, because most of the sound is being transmitted via the screed, which is the dominant flanking path. This demonstrates the importance of detailing the junction between the screed and the lightweight partition correctly. To reduce the flanking transmission, the floating screed should stop at the lightweight partition, as shown in Figure 3.3(b), with sole plates set on either the structural floor, or an independent batten.

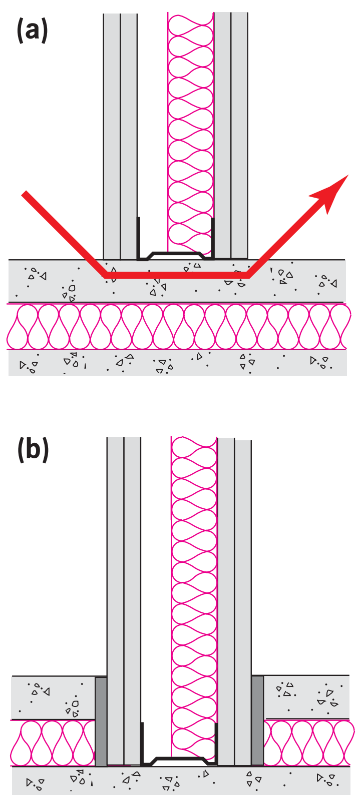



Figure 3.3 Flanking transmission via floating screed (a) Sound insulation may be limited by continuous screed (b) Higher sound insulation performance possible

### 3.3.2 Junctions between internal walls and ceilings

Ceilings should be designed in relation to internal walls to achieve the required combined performance in respect of sound insulation, fire compartmentation and support. In the case of suspended ceiling systems the preferred construction is one in which partitions or walls pass through the suspended ceiling, do not require support from the ceiling system and combine with the structural soffit above to provide fire resisting compartmentation and sound insulation. The alternative construction in which partitions or walls terminate at, or just above, the suspended ceiling limits the potential sound insulation; the scale and frequency of access to engineering services in the ceiling void through the ceiling and any insulation may be incompatible with maintaining the required sound insulation standards.

### 3.3.3 Junctions between partitions and the soffit

Where a non-load bearing partition abuts the structural soffit, a deflection head or movement joint is generally required, so that the movement of the structural element above does not cause loading to be applied to the partition, which may in turn cause cracking or failure of that element. The joints that permit movement must be suitably sealed to control noise transmission, such that this flanking path does not undermine the performance requirement between rooms. Where the soffit is exposed, the deflection head detail may be visible within the room, such that it may need to have architectural merit as well as functional performance.

Manufacturers of proprietary products can often provide standard details for deflection heads to achieve different performance requirements. A lightweight suspended ceiling can also provide some additional control of flanking noise via the deflection head detail.

Another flanking detail that can cause problems is where a lightweight profiled metal roof deck runs across the top of a separating partition wall. With profiles such as trapezoidal sections, it is very difficult for builders to ensure that they do not leave air paths between the top of the partition wall and the roof. Shaped plasterboard infill panels and proprietary packers shaped to match the roof profile can be used to reduce flanking, although lightweight roofs may limit the overall sound insulation achievable due to flanking noise through the roof itself. Most lightweight roofs, when combined with a suspended ceiling, provide sufficient control of flanking noise to achieve a sound insulation performance of 45 dB $D_{nT,w}$ between classrooms, but not enough to achieve 50 dB $D_{nT,w}$ or higher.

### 3.3.4 Flanking transmission through windows

Flanking transmission can occur between adjacent rooms via open windows in the external walls. Side-opening casement windows near the separating wall should have their hinges on the separating wall side to minimise airborne sound transmitted from one room to another. Where possible, windows in external walls should be located away from the junction between the external walls and the separating wall or floor. In particular, windows in the external walls of noise-sensitive rooms and in the external walls of rooms adjacent to them should be as far as possible from the separating wall or floor.

### 3.3.5 Curtain walling

Detailing of curtain walling may be important to ensure that flanking transmission does not undermine the level difference required between rooms. Flanking transmission paths can include direct transmission through the frame elements, transmission along frame elements, combination flanking paths through the glazing and frame, and airborne paths between the other building elements and the curtain walling. For example, flanking noise transmission routes that may need to be considered can include:

- Horizontally through the mullion, including the effect of any mullion filling or cladding
- Horizontally/vertically across a single transom/mullion, limited by the inner pane of glass
- Vertically through mullions, which may be continuous between storeys
- Airborne sound paths between the partition/slab edge and curtain walling

Some manufacturers have extensive test data of different configurations, which may have been tested before ISO 10848 was established but can be interpreted in terms of the parameters in BS EN 12354-1[4].

### 3.3.6 Flanking transmission of impact sound through floors

Control of the flanking component of impact sound is usually achieved using a soft floor covering, such as carpet or a resiliently backed vinyl, or particularly where a higher performance is required, a floating floor construction that will be isolated from the walls as well as the structural floor using a resilient material.

## 3.4 Internal walls and partitions

### 3.4.1 General principles

Typical values of the sound reduction index ($R_w$) for various building elements, including walls, doors, glazing and floors are shown in Figure 3.1. The sound insulation of all partitions can, however, be reduced from the expected value if the partitions are not airtight. Partitions should be well sealed, as small gaps, holes, etc. significantly reduce sound insulation. Note that this also applies to porous materials, e.g. porous blockwork, which can transmit a significant amount of sound energy through the pores.

The performance of plasterboard partitions at low frequencies is limited by the mass and stiffness of the partition. Masonry walls can provide better low frequency sound insulation because of their higher mass and stiffness. This is not obvious from the $R_w$ figures, as the $R_w$ rating system lends more importance to insulation at medium and high frequencies than at low frequencies. This is not normally a problem in general classroom applications where sound insulation is mainly required at speech frequencies. However, it can be important in music rooms and other cases where increased low frequency sound insulation is needed. A combination of masonry with a sealed face, such as a parge coat beneath dry lining or a wet plaster finish, can be very effective in providing reasonable low frequency performance with good sound insulation at higher frequencies. Independent or semiindependent dry linings on frames with appropriate void sizes containing quilt can effectively increase the sound insulation of masonry walls. While partition walls may be provided as a means of achieving adequate sound reduction, it should be remembered that the sound insulation will be limited by that of the weakest element. This is discussed in detail in section 3.4.4.

### 3.4.2 Sound insulation of common constructions

The approximate weighted sound reduction index $R_w$ values for typical masonry and plasterboard constructions are shown in Figure 3.4. The values shown are necessarily approximate and will depend on the precise constructions and materials used. Many blockwork and plasterboard manufacturers provide more accurate data for specific constructions. Sound reduction data should be sought from laboratories that have carried out tests according to BS EN ISO 10140-2[3]. The procedure given in Section 3.2.1 can then be used to select suitable constructions that are capable of meeting the required sound insulation for a room pair, expressed as the $D_{nT,w}$.

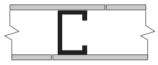
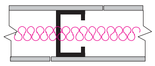
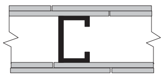
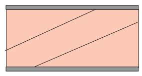
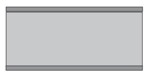
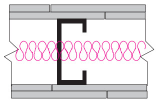
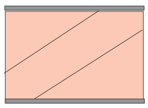
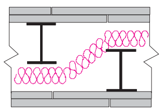
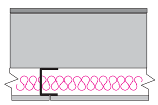
| Walls - typical forms of construction | | Performance $R_w$ (dB) |
|---|---|---|
| 1x12.5 mm plasterboard each side of a metal stud (total width 75 mm) |  | 35-40 |
| 100 mm block (low density 52 kg/$m^2$) plastered/rendered 12 mm one side |  | |
| 1x12.5 mm plasterboard each side of a 48 mm metal stud with glass fibre/mineral wool in cavity (total width 75 mm) |  | 40-45 |
| 100 mm block (medium density 140 kg/$m^2$) plastered/rendered 12 mm one side |  | |
| 2x12.5 mm plasterboard each side of a 70 mm metal stud (total width 122 mm) |  | 45-50 |
| 115 mm brickwork plastered/rendered 12 mm both sides |  | |
| 100 mm block (medium density 140 kg/$m^2$) plastered/rendered 12 mm both sides |  | |
| 2x12.5 mm plasterboard each side of a 150 mm metal stud with glass fibre/mineral wool in cavity (total width 198 mm) |  | 50-55 |
| 225 mm brickwork plastered/rendered 12 mm both sides |  | |
| 215 mm block (high density 430 kg/$m^2$) plastered/rendered 12 mm both sides |  | |
| 2x12.5 mm plasterboard each side of a staggered 60 mm metal stud with glass fibre/mineral wool in cavity (total width 178 mm) |  | 50-60 |
| 100 mm block (high density 200 kg/$m^2$) with 12 mm plaster on one side and 1x12.5 mm plasterboard on metal frame with a 50 mm cavity filled with glass fibre/mineral wool on other side |  | |

**Figure 3.4 Walls – airborne sound insulation for some typical wall constructions**

### 3.4.3 High performance constructions

High-performance plasterboard partitions or masonry walls with independent linings can provide airborne sound insulation as high as 70 dB $R_w$ in the laboratory. However, to achieve high performance in practice (i.e. above 50 dB $D_{nT,w}$), flanking walls/floors with their junction details must be carefully designed. Airborne sound insulation in excess of 55 dB $D_{nT,w}$ can be achieved on-site using high performance plasterboard partitions, or masonry walls with independent linings. Lightweight isolated floors and independent ceilings can be used to control flanking transmission. This will require specialist advice from an acoustics consultant.

It may be possible to use circulation spaces, stores and other less noise-sensitive rooms to act as buffer zones between rooms that would otherwise need high-performance partitions. Partitions with lower levels of sound insulation can then be used.

### 3.4.4 Composite partitions

Where a partition is a composite construction and includes, for example, a glazed screen, door, or other opening, the sound insulation will tend to be limited by the weakest element. The sound insulation values and areas of the component parts can be used to estimate the overall sound reduction of the composite partition using the method shown in Figure 3.5.

Alternatively, the equation below may be used to calculate the composite weighted sound reduction index, $R_{w,composite}$:

$$R_{w\ composite} = -10\lg\left(\frac{\left(\Sigma_{i=1}^{n}[S_i \times 10^{(-R_{wi}/10)}]\right)}{\Sigma_{i=1}^{n} S_i}\right)\ \text{dB}$$

where

$S_i$ is the area of an individual element

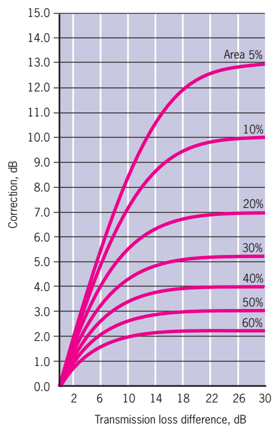
$R_{wi}$ is the weighted sound reduction index of that element

n is the number of elements.

It should be noted that the above approach based on the weighted sound reduction index, $R_w$, of each element is only an approximation of the true calculated composite value. The true composite weighted value may be calculated by following the procedure above for each element in each frequency band, to determine the composite frequency band sound reduction indices. It is then necessary to apply the procedure in ISO 717-1[1] to fit the reference curve to the frequency band sound reduction values calculated, to determine the composite weighted sound reduction index.

Typical details and sound reduction values for doors and glazing are given in Section 3.5. Note that composite walls separating teaching spaces from corridors need special consideration and are discussed in Section 3.5.4.

In general, rooms which require acoustic separation of at least 35 dB $D_{nT,w}$ should not have doors or standard glazing in the separating wall or partition to the adjoining room.




The percentage of the total area of the wall occupied by the element with the lower transmission loss, e.g. a door, and the difference between the higher $R_w$ and the lower $R_w$, are used to calculate the correction in dB which is added to the lower $R_w$ to give the $R_w$ of the whole wall.

**For example:** Assume a classroom to corridor wall has an $R_w$ of 45 dB and a door in the wall has an $R_w$ of 30 dB. If the area of the door is 0.85 m x 2.1 m = 1.785 m$^2$ and the area of the wall is 7 m x 2.7 m = 18.9 m$^2$, then the percentage of the wall occupied by the door is 1.785/18.9 x 100 = 9.4%

The difference in $R_w$ = 15 dB.

Therefore reading from the chart gives a correction of about 9 dB to be added to the lower $R_w$, giving a composite $R_w$ of 39 dB.

If a higher performance door of say 35 dB had been used, the composite $R_w$ would be 35 + 7 = 42 dB.

**Figure 3.5 Chart to estimate $R_w$ for a composite wall consisting of two elements with different transmission losses**

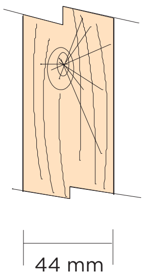
## 3.5 Doors, glazing and partitions

### 3.5.1 Doors

The choice of appropriate doors with good door seals is critical to maintaining effective sound reduction and controlling the transfer of sound between spaces. Internal doors of lightweight hollow core construction may achieve only around 15 dB $R_w$ ,which is about 30 dB less than for a typical masonry wall.

Figure 3.6 shows the sound insulation of some typical door constructions. Manufacturers should be asked to provide test data to assist in the specification and selection of doorsets.

**30 dB $R_w$**




44 mm thick timber door, half hour fire rated

This acoustic performance can be achieved by a well-fitted solid core door-set where the door is sealed effectively around its perimeter in a substantial frame with an effective stop. A 30 minute fire doorset (FD30) can be suitable.

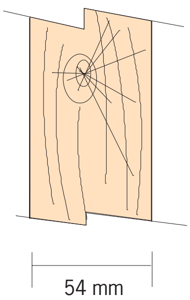
Timber FD30 doors often have particle cores or laminated softwood cores with a mass per unit area ≈ 27 kg/m$^2$ and a thickness of ≈ 44 mm.

Frames for FD30 doors often have a 90 mm x 40 mm section with a stop of at least 15 mm.

Compression or wipe seals should be used around the door's perimeter along with a threshold seal beneath. A drop-down or wipe type threshold seal is suitable.

Doors incorporating 900 mm x 175 mm vision panels comprising 7 mm fire resistant glass can typically meet this acoustic performance.

**35 dB $R_w$**




54 mm thick timber door, one hour fire rated

This acoustic performance can be achieved by specialist doorsets although it can also be achieved by a well-fitted FD60 fire doorset where the door is sealed effectively around its perimeter in a substantial frame with an effective stop.

Timber FD60 doors often have particle core or laminated softwood cores with a mass per unit area ≈ 29 kg/m$^2$ and a thickness of ≈ 54 mm. Using a core material with greater density than particle or laminated softwood can result in a door thickness of ≈ 44 mm.

Frames for FD60 doors can have a 90 mm x 40 mm section with stops of at least 15 mm.

Compression or wipe seals should be used around the door's perimeter along with a threshold seal beneath. A drop-down or wipe type threshold seal is suitable.

Doors incorporating 900 mm x 175 mm vision panels comprising 7 mm fire resistant glass can typically meet this performance.

**Figure 3.6: Airborne sound insulation for some typical door constructions**

Gaps between door frames and the walls in which they are fixed should be no more than 10 mm and should be filled to the full depth of the wall with ram-packed mineral wool and sealed on both sides of the wall with a non-hardening sealant.

The sound insulation of an existing door can be improved by increasing its mass (e.g. by adding two layers of 9 mm plywood or steel facings) as long as the frame and hinges can support the additional weight. However, it is often simpler to fit a new door. The mass of a door is not the only variable that ensures good sound insulation. Good sealing around the frame is crucial. Air gaps should be minimised by providing continuous grounds to the frame which are fully sealed to the masonry opening. There should be a generous frame rebate and a proper edge seal all around the door leaf. Acoustic seals can eliminate gaps between the door and the door frame to ensure that the door achieves its potential in terms of its airborne sound insulation. Seals should be inspected regularly and replaced when worn.

Care should be taken to ensure that the force required to open doors used in schools is not excessive for children. The opening force at the handles of doors used by children aged 5 to 12 years should comply with relevant access requirements. Doors should be fitted correctly, good quality hinges and latches used and door closers selected with care, to minimise opening forces.

### 3.5.2 Twin leaf doors

Twin leaf doors are often used where access for large furniture, instruments or equipment is required, for example for music/drama spaces. Maximum performance is likely to be limited to 30 dB $R_w$. It is suggested that one leaf should normally be fixed closed and the meeting stiles should be rebated and fitted with good seals.

As a rule of thumb, even a good quality acoustically sealed door in a 55 dB $R_w$ wall between two classrooms will limit the sound insulation between spaces so that the $D_{nT,w}$ is only 30-35 dB. Two such doors, separated by a door lobby, would be necessary to maintain the sound insulation of the wall. Figure 3.7 shows the effect of different doors on the overall sound insulation of different types of wall. In a conventional layout with access to classrooms from a corridor, the corridor acts as a lobby between the two classroom doors.

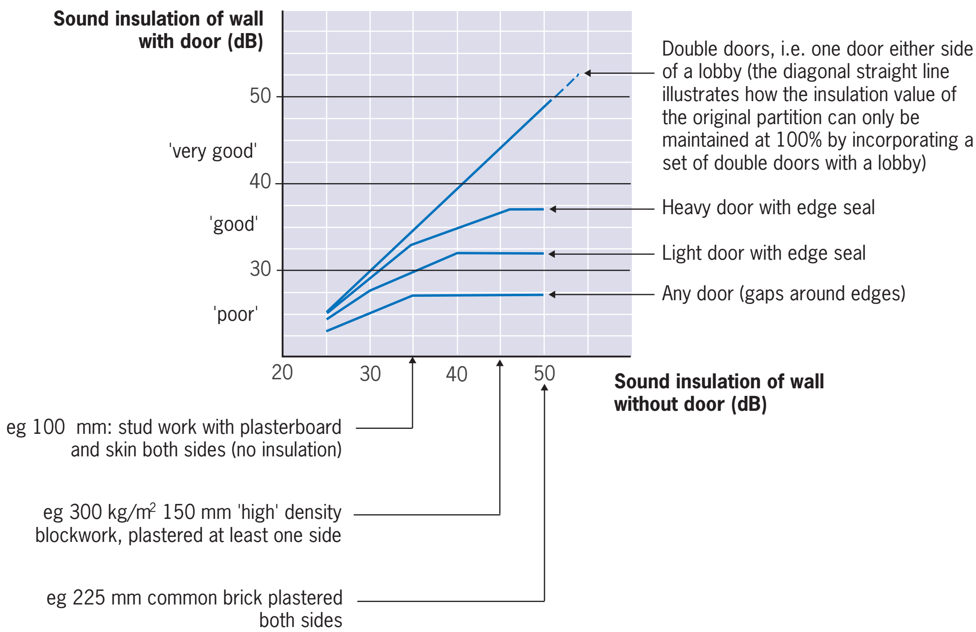



**Figure 3.7: Reduction of sound insulation of a wall incorporating different types of door**

Where a high performance is required, and space permits, lobbied doors should be used. A lobby is useful between a performance space and a busy entrance hall and lobbied doors should be used between adjoining music spaces where interconnecting doors are required.

The greater the distance between the lobbied doors, the better the sound insulation, particularly at low frequencies. Maximum benefit from a lobby is associated with offset door openings as shown in Figure 3.8(a) and acoustically absorbent wall and/or ceiling finishes. An acoustically attenuated transfer air vent may need to be provided in order to prevent build-up of air pressure within the lobby, which increases the opening forces required.

Where limitations of space preclude a lobby, a double (back-to-back) door in a single wall will be more effective than a single door; this configuration is illustrated in Figure 3.8(b).

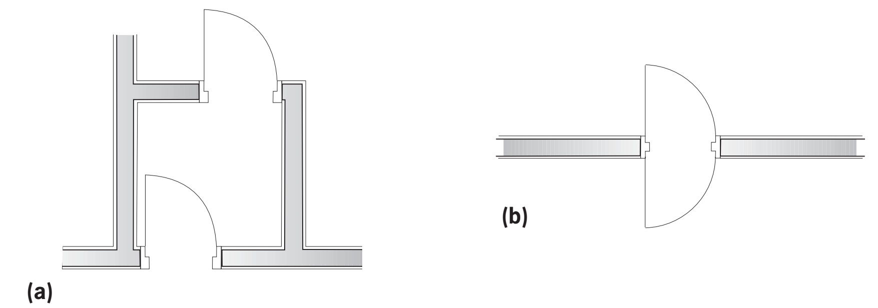



Figure 3.8: Use of lobbies and double doors (a) Lobbied doorway (b) Double (back-to-back) door

## 3.5 3 Glazing

Figure 3.9 gives the airborne sound insulation for some typical glazing constructions. Manufacturers' data should be consulted for the performance of different combinations of glass and separation distances.

| Performance $R_w$ (dB) | Glazing - typical forms of construction |
|---|---|
| 25 | 4 mm single float (sealed) |
| 28 | 6 mm single float (sealed) |
| | 4mm glass/12 mm air gap/4mm glass |
| 30 | 6mm glass/12 mm air gap/6mm glass |
| | 10 mm single float (sealed) |
| 33 | 12 mm single float (sealed) |
| | 16mm glass/12 mm air gap/8mm glass |
| 35 | 10 mm laminated single float (sealed) |
| | 4mm glass/12 mm air gap/10mm glass |
| 38 | 6mm glass/12 mm air gap/10mm glass |
| | 12 mm laminated single float (sealed) |
| 40 | 10mm glass/12 mm air gap/6mm laminated glass |
| | 19 mm laminated single float (sealed) |
| | 10mm glass/50 mm air gap/6mm glass |
| 43 | 10mm glass/100 mm air gap/6mm glass |
| | 12mm laminated glass/12 mm air gap/10mm glass |
| 45 | 6mm laminated glass/200 mm air gap/10mm + absorptive reveals |
| | 17mm laminated glass/12 mm air gap/10mm glass |

Figure 3.9: Glazing - airborne sound insulation for some typical glazing constructions

## 3.5.4 Corridor walls and doors

The $R_w$ values in Tables 4a and 4b of Building Bulletin 93 should be used to specify wall constructions with appropriate glazing and door specifications between noise sensitive rooms and corridors, stairwells and other spaces. To ensure that the door achieves its potential in terms of its airborne sound insulation, it must have good perimeter sealing, including the threshold.

Note that a lightweight fire door will usually give lower sound insulation than a heavier, sealed acoustic door, and that the door should be selected to meet both fire and acoustic requirements.

Greatly improved sound insulation will be obtained by having a lobbied door arrangement between noise-sensitive rooms and corridors, stairwells and other spaces. However, this is often not practicable between classrooms and corridors. Some noise transmission from corridors into classrooms is inevitable, but this may not be important if all lesson changes occur simultaneously.

For some types of room, such as music rooms, studios and halls for music and drama performance, lobbied doors should generally be used, see Chapter 5.

### 3.5.5 Folding walls and operable partitions

Folding walls and operable partitions are sometimes used to provide flexibility in teaching spaces or to divide open plan areas. A standard folding partition with no acoustic seals or detailing may provide a value as low as 25 dB $R_w$. Whilst higher performance folding partitions are available that can provide up to 58 dB $R_w$, the sound insulation achievable on site depends on very careful installation, with stringent control over flanking transmission, and effective acoustic sealing. The performance also deteriorates if seals or tracks become worn or damaged in use. As a result, it can be very difficult to achieve sound insulation values greater than 45 dB $D_{nT,w}$.

It is important that the specification of folding partitions takes into account the weight, ease of opening and maintenance. Regular inspection and servicing will extend the life of a partition and ensure that it achieves the desired sound insulation.

Folding partitions are useful in many applications, but they should only be used when necessary and not as a response to a non-specific aspiration for flexibility in layout of teaching areas. The design team should be made aware that the use of the allowable exception in BB 93 for folding partitions may not provide acoustic conditions that permit simultaneous independent use of the adjacent rooms.

### 3.5.6 Roller shutters

Roller shutters are sometimes used to separate kitchens from multi-purpose spaces used for dining. Because roller shutters are only required to provide sound insulation of 18 dB $R_w$ it is common for noise from the kitchen to disturb teaching activities. Refer to Building Bulletin 93 paragraph 1.2.3 for further notes on the limitations of use that may result with low levels of sound insulation between the kitchen and dining hall.

## 3.6 Floors and ceilings

Both airborne and impact noise can be transmitted between vertically adjacent rooms through the separating floor and its associated flanking constructions.

Vertical noise transmission between classrooms can be a problem in older multi-storey buildings with wooden floors, such as traditional Victorian school buildings. Both airborne noise and impact noise can be problematic with wooden floors and both issues need to be considered when dealing with vertically adjacent spaces. Even when performance standards for impact transmission from Building Bulletin 93 are met, low frequency noise may still cause disturbance. Adding carpets or other soft coverings to wooden floors can significantly reduce mid and high frequency impact noise, but has very little effect on low frequency impact sound and airborne noise transmission.

Impact noise can also be a problem with concrete floors (although airborne noise may not be a problem); this can usually be solved by adding a carpet or resilient vinyl finish, or by the use of a floating screed.

A suspended ceiling in the room below can also provide significant airborne and impact sound reduction and may be appropriate for particularly sensitive spaces, or where impact or airborne noise levels in the room above are likely to be high.

### 3.6.1 Impact sound insulation

Impact noise on floors may arise from:

- foot traffic, particularly in corridors at break times/lesson changeover
- scraping of furniture, such as chairs and tables
- percussion rooms
- areas for dance or movement
- loading/unloading areas (e.g. in kitchens and workshops)
- machinery

Where possible, impact noise should be reduced at source through use of soft floor coverings or floating floors.

Planning and room layout can be used to avoid impact noise sources on floors above noise-sensitive rooms. Soft floor coverings and floating floor constructions and independent ceilings are the most effective means of isolation, and resilient floor finishes are also appropriate for some sources.

Typical airborne and impact noise performance values are listed for a number of constructions in Figures 3.10 to 3.13. Note that, unlike airborne sound insulation, impact sound insulation is measured in terms of an absolute sound level in the lower room, so that a lower figure indicates a better standard of insulation.

### 3.6.2 Upgrading existing wooden floors using suspended plasterboard ceilings

Figure 3.10 shows the airborne and impact sound insulation performance of a standard wooden floor with various forms of suspended plasterboard ceiling. All values are approximate guidelines and will vary between different products and constructions. Manufacturers' data, measured in accordance with ISO 10140[3,5], should be obtained for all proprietary systems and constructions. These must be installed in accordance with good practice and manufacturers' recommendations, and all gaps sealed.

Options 2 to 5 are possibly the most widely used systems for increasing both impact and airborne sound insulation, with or without the original plaster ceiling. Good results can be achieved in small rooms using timber studs fixed only to the walls, but large timber sections are needed to span wider rooms. Where resilient floor materials are used, the material must be selected to provide the necessary sound insulation under the full range of loadings likely to occur in the room and must not become over-compressed, break down or suffer from long-term 'creep' when higher loads are likely to be encountered. Where large ranges of loading are encountered, or where there are high point loads such as pianos, heavy furniture or operable partitions, the pad stiffness may have to be varied across the floor to take account of these.

In wider span rooms it is generally more convenient to suspend the plasterboard from the floor joists above using a proprietary suspension and grid system (option 4) and fixing through the existing ceiling, if this is retained (option 3). The grid can be hung from simple metal strips or, for a higher performance, special flexible ceiling hangers.

The major manufacturers of dry lining systems all provide their own systems for these options and provide sound insulation data and specifications for a variety of configurations. The performance for both airborne and impact sound insulation improves with the depth of the ceiling void, the mass of the ceiling and the deflection of the ceiling hangers due to the mass of the ceiling. Adding a layer of lightweight acoustically absorbent glass wool or mineral wool in the ceiling void increases the sound insulation, typically by 2-3 dB.

Performance on site is strongly dependent on good workmanship to avoid air gaps, so careful attention should be given to ensuring that joints are close butted, taped and filled, and that all gaps are properly sealed. A small gap should be left between the plasterboard and the perimeter walls, which should then be sealed using non-hardening mastic to allow a small amount of movement without cracking.

Penetrations through the ceiling need to be properly detailed to maintain an airtight seal, while allowing movement, and services should not be allowed to result in a rigid link between the ceiling and the floor above. This can be a particular problem with sprinkler pipes. Recessed light fittings, grilles and diffusers can significantly reduce the sound insulation, so any services should be surface-mounted or boxed in.

A plasterboard finish is acoustically reflective whereas in some rooms an acoustically absorbent ceiling is required to meet the specifications for room acoustics and reverberation times. One solution to this, if there is sufficient height, is to suspend a separate lightweight sound absorbing ceiling under the sound insulating plasterboard ceiling. This can be a standard lightweight composite or perforated metal tile system. These lightweight ceilings normally add very little to the sound insulation but do provide acoustic absorption. Lights and services can be recessed in the absorbent ceiling.

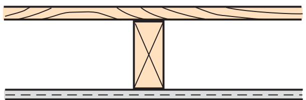
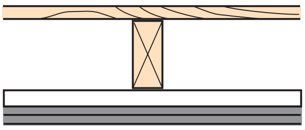
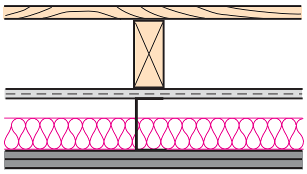
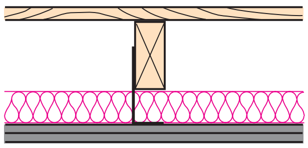
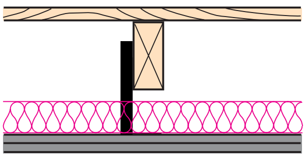
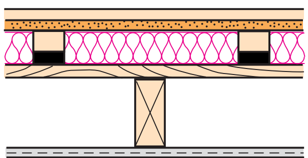
| Option Construction - timber floors | | $R_w$ (dB) | $L_{n,w}$ (dB) | Depth (mm) |
|---|---|---|---|---|
| 1. Basic timber floor consisting of 15 mm floorboards on 150-200 mm wooden joists, plasterboard ceiling fixed to joists |  | 35-40 | 80-85 | 180-230 |
| 2. As 1, ceiling consisting of either two layers of plasterboard with combined mass at least 20 kg/m² fixed to resilient bars, or typically a lathe and plaster ceiling |  | 50-55 | 65-70 | 220-270 |
| 3. As 1, ceiling retained, with suspended ceiling consisting of 2 layers of plasterboard with combined mass at least 20 kg/m², suspended on a proprietary metal ceiling system to give 240 mm cavity containing 80-100 mm mineral wool (>10 kg/m³) |  | 55-60 | 60-65 | 450-500 |
| 4. As 1, ceiling removed, with suspended ceiling consisting of 2 layers of plasterboard with combined mass at least 20 kg/m², suspended on a proprietary metal ceiling system to give 275 mm cavity containing 80-100 mm mineral wool (>10 kg/m³) |  | 55-60 | 60-65 | 450-500 |
| 5. As 1, ceiling removed, with suspended ceiling consisting of 2 layers of plasterboard with combined mass at least 20 kg/m², suspended special resilient hangers to give 275 mm cavity containing 80-100 mm mineral wool (>10 kg/m³) |  | 60-65 | 55-60 | 450-500 |
| 6. As 1, with proprietary lightweight floating floor using resilient pads or strips (eg 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board supported on 45 mm softwood battens laid on 25 mm thick foam pads). 80-100 mm mineral wool (>10 kg/m³) laid on top of existing floorboards |  | 50-55 | 60-65 | 270-320 |

**Figure 3.10: Existing timber floors - airborne and impact sound insulation for typical constructions**

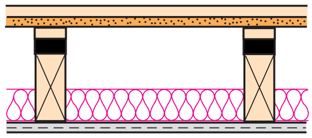
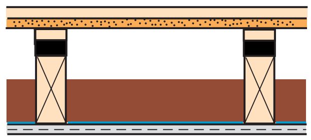
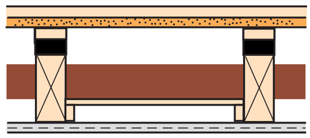
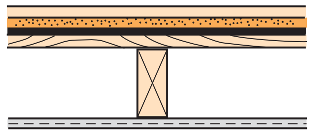
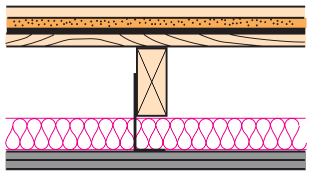
| Option Construction - timber floors | | $R_w$ (dB) | $L_{n,w}$ (dB) | Depth (mm) |
|---|---|---|---|---|
| 7. As 1, floorboards removed and replaced with 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board supported on 12 mm softwood battens laid on 25 mm thick foam pads bonded to the joists, 80-100 mm mineral wool (>10 kg/m$^3$) laid on top of existing ceiling |  | 55-60 | 55-60 | 240-290 |
| 8. As 7 but mineral wool replaced by 100 mm pugging (80 kg/m$^2$) on lining laid on top of ceiling |  | 55-60 | 50-55 | 240-290 |
| 9. As 8 but with 75 mm pugging laid on top of board fixed to sides of joists |  | 50-55 | 55-60 | 240-290 |
| 10. As 1 with proprietary lightweight floating floor using a continuous layer (e.g. 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board on 6-12 mm thick continuous foam mat) |  | 50-55 | 55-60 | 220-270 |
| 11. As 10, ceiling removed and replaced with suspended ceiling consisting of 2 layers of plasterboard with combined mass at least 20 kg/m$^2$ on a proprietary metal ceiling system to give 275 mm cavity containing 80-100 mm mineral wool (>10 kg/m$^3$) |  | 60-65 | 50-55 | 360-410 |

**Figure 3.10 continued: Existing timber floors - airborne and impact sound insulation for typical constructions**

The term ‘acoustic ceiling’ generally refers to relatively lightweight acoustically absorbent ceiling tile systems, designed to provide acoustic absorption, but only limited sound insulation. There are, however, some systems which use heavier ceiling tiles, which are designed to fit into ceiling grids to provide a reasonably airtight fit. These may consist of dense plasterboard or mineral fibre products, or perforated metal tiles with metal or plasterboard backing plates. If properly installed and maintained these can provide a useful increase in sound insulation as well as acoustic absorption. Manufacturers of these systems can provide both airborne and impact sound insulation figures, as well as acoustic absorption coefficients. If no measured sound insulation data are provided, it is better to err on the side of caution and assume that the tile will not provide a significant increase in sound insulation.

The sound insulation performance figures quoted in Figure 3.10 all assume that the floorboards are in good condition and reasonably airtight, with thin carpet laid on top. If retaining the original floorboards it is good practice to fill in any gaps with glued wooden strips, caulking or mastic, or to lay hardboard on top, to provide an airtight seal. If not retaining the original boards, 18 mm tongue-and-grooved chipboard can be used to achieve the same effect, with all joints and gaps properly sealed, especially at the perimeters.

### 3.6.3 Upgrading existing wooden floors using platform floors

Many of the systems discussed in Section 3.6.2 maintain the original wooden floor mounted directly on joists. This has the advantage of maintaining the original floor level at the expense of a loss of ceiling height below. An alternative approach is to provide a floating floor system, comprising either a floor deck on a resilient underlay over the existing floorboards, or a low profile metal deck with in-situ concrete laid on resilient material set on top of the floor joists after removing the original floor. In both cases the increase in both airborne and sound insulation relies on the mechanical isolation of the floor from the joists using resilient material. The isolating layer will typically consist of rubber, neoprene, open-cell or closed cell foams, mineral fibre or composite materials. The isolating layer can be in the form of individual pads, strips or a continuous layer of material.

The sound insulation increases with deflection of the resilient layer (up to the limit of elasticity for the material), the mass of the floating layer and the depth of the cavity. Adding a layer of lightweight acoustically absorbent glass wool or mineral wool in the ceiling void can increase the sound insulation, typically by 2 to 3 dB. In each case the deflection of the material under the permanent 'dead' load of the floating layer and the varying 'live' loads of occupants and furniture must be considered.

If the material is too resilient and the floating layer is insufficiently heavy or rigid, the floor will deflect under the varying loads as people move about the room. For this reason it is advantageous for the floating deck to be as heavy and as stiff as practicable, in some cases using ply or fibre-bond board (for mass) laid on top of the resilient layer, with tongue-and-grooved chipboard on top of this.

If there are likely to be very heavy local loads in the room (e.g. pianos) it may be necessary to increase the stiffness of the resilient material or, in the case of pads, to space the pads more closely together to support these loads. Guidance should be sought from manufacturers regarding appropriate distribution of resilient materials

Junctions with walls and at doors need to be designed to maintain an effectively airtight seal while allowing movement of the floating layer. Manufacturers generally provide their own proprietary solutions for this, with or without skirtings.

Lightweight floating floors are quite specialist constructions and achieving the correct deflection under varying live loads without overloading the resilient material can be difficult. Most materials suffer from long term loss of elasticity or 'creep' under permanent loads and this should be taken into account in the design and selection of materials. The system manufacturer should normally be provided with all the relevant information and required to specify a system to meet all of the acoustic and structural requirements over the expected lifetime of the floor. The advice of an acoustics consultant and/or structural engineer should be sought.

### 3.6.4 Concrete floors

In general, concrete floors provide much greater low frequency airborne sound insulation than wooden floors by virtue of their greater mass. There are, however, considerable variations in performance between dense poured concrete floors and comparatively lightweight precast concrete plank floors. Impact sound transmission can be a problem even in heavy concrete floors because of the lack of damping in concrete, and a soft or resilient floor covering is generally required. This may simply be carpet on suitable underlay, or vinyl with a resilient backing. Figures 3.11-3.13 show airborne sound insulation and impact sound transmission data for a number of typical concrete floor constructions, with and without suspended ceilings and floating floors.

Where reference is made to a soft floor covering, this should be a resilient material or a material with a resilient base, with an overall uncompressed thickness of at least 4.5 mm; or any floor covering with a weighted reduction in impact sound pressure level of not less than 17 dB when measured in accordance with BS EN ISO 10140-3[5] and calculated in accordance with BS EN ISO 717-2[2].

As with timber floors, any resilient floor materials used must be selected to provide the necessary sound insulation under the full range of potential loadings. The guidance given in Section 3.6.2 for timber floors also applies to concrete floors.

All sound insulation values shown are approximate guidelines and will vary between different products and constructions. Manufacturers' data, measured in accordance with ISO 10140[3,5], should be obtained for all proprietary systems and constructions. These must be installed in accordance with good practice and manufacturers' recommendations, and all gaps sealed.

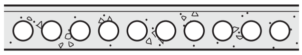
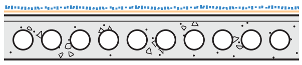
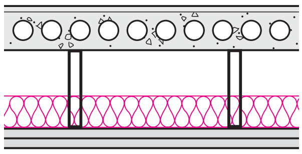
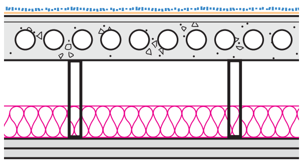
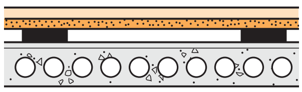
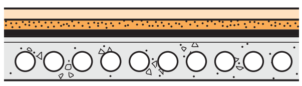
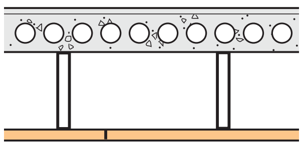
| Option Construction - concrete floors | | $R_w$ (dB) | $L_{n,w}$ (dB) | Depth (mm) |
|---|---|---|---|---|
| 1. Lightweight floor consisting of pre-cast concrete planks (solid or hollow) or beam and blocks, with 30-50 mm screed, overall weight approximately100 kg/m², no ceiling or floor covering |  | 35-40 | 90-95 | 100-150 |
| 2. As 1 with soft floor covering >5 mm thick |  | 35-40 | 75-85 | 105-155 |
| 3. As 1 with suspended ceiling consisting of 2 layers of 15 mm wallboard or 2 layers of 12.5 mm dense plasterboard, suspended on a proprietary metal ceiling system to give 240 mm cavity containing 80-100 mm lightweight mineral wool (>10 kg/m³) |  | 60-65 | 55-60 | 370-420 |
| 4. As 3 with soft floor covering >5 mm thick |  | 60-65 | 50-55 | 375-425 |
| 5. As 1 with proprietary lightweight floating floor using resilient pads or strips (e.g. 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board on 25 mm thick foam pads) |  | 50-60 | 50-60 | 155-205 |
| 6. As 1 with proprietary lightweight floating floor using a continuous layer (eg 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board on 6-12 mm thick continuous open-cell foam mat) |  | 50-55 | 55-60 | 150-200 |
| 7. As 1 with heavyweight proprietary suspended sound insulating ceiling tile system |  | 45-55 | 60-70 | 250-500 |

**Figure 3.11: Lightweight concrete floors – airborne and impact sound insulation of some typical constructions**

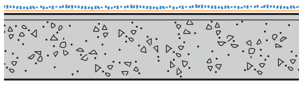
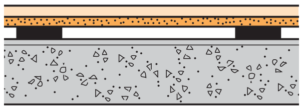
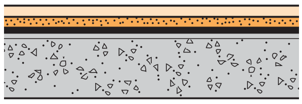
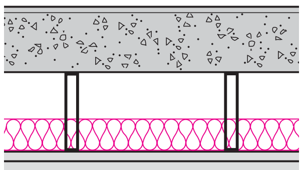
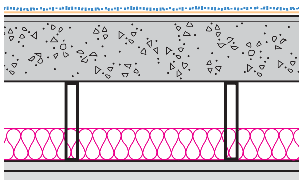
| Option Construction - concrete floors | | $R_w$ (dB) | $L_{n,w}$ (dB) | Depth (mm) |
|---|---|---|---|---|
| 1. Solid concrete floor consisting of reinforced solid cast in-situ concrete with or without shuttering, concrete beams with infill blocks and screed, hollow or solid concrete planks with screed, of thickness and density to give a total mass of at least 365 kg/m², with covering >5 mm thick |  | 50-55 | 60-65 | 150-200 |
| 2. As 1 with proprietary lightweight floating floor using resilient pads or strips (eg 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board on 25 mm thick foam pads) |  | 55-60 | 50-55 | 200-250 |
| 3. As 1 with proprietary lightweight floating floor using a continuous layer (eg 15 mm tongue-and-groove floorboards on a 15 mm plywood, chipboard or fibre-bond board on 6-12 mm thick continuous foam mat) |  | 55-60 | 50-60 | 175-230 |
| 4. As 1 with suspended ceiling consisting of 2 layers of 15 mm wallboard or 2 layers of 12.5 mm dense plasterboard, suspended on a proprietary metal ceiling system to give 240 mm cavity containing 80-100 mm mineral wool (>10 kg/m³) |  | 60-70 | 55-60 | 420-470 |
| 5. As 4 with soft floor covering >5 mm thick |  | 60-70 | 50-55 | 425-475 |

Figure 3.12: Heavyweight concrete floors – airborne and impact sound insulation of some typical constructions

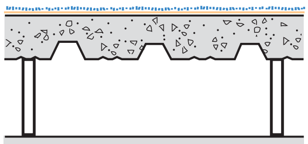
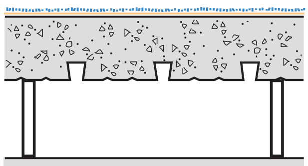
| Option Construction - steel-concrete composite floors | | $R_w$ (dB) | $L_{n,w}$ (db) | Depth (mm) |
|---|---|---|---|---|
| 1. 130 mm steel-concrete composite with trapezoidal profile and normal density concrete, with suspended ceiling tile below and carpet on top |  | 50-55 | 50-55 | 300-400 |
| 2. 175 mm steel-concrete composite with re-entrant profile and normal density concrete, with suspended ceiling tile below and carpet on top |  | 55-60 | 50-55 | 350-450 |

Figure 3.13: Steel-concrete composite floors – airborne and impact sound insulation of some typical constructions

## 3.7 Design and detailing of building elements

Important points to remember when designing constructions to achieve adequate sound insulation are:

- Weak elements (e.g. doors and glazing, service penetrations, etc) will reduce the effectiveness of the walls in which they are located.
- Impact sound will travel with little reduction through a continuous element such as a steel beam or a pipe.
- Partitions between sensitive spaces should normally continue beyond the ceiling up to the structural soffit or roof layer, to prevent noise passing over the top of the partition above the ceiling or through a loft space.
- Openings in walls caused by essential services passing through should be acoustically sealed. Pipework passing between noise sensitive spaces should be appropriately boxed in (see Approved Document E[8]).

Figure 3.14 shows how possible transmission paths through the structure of a building can be mitigated.

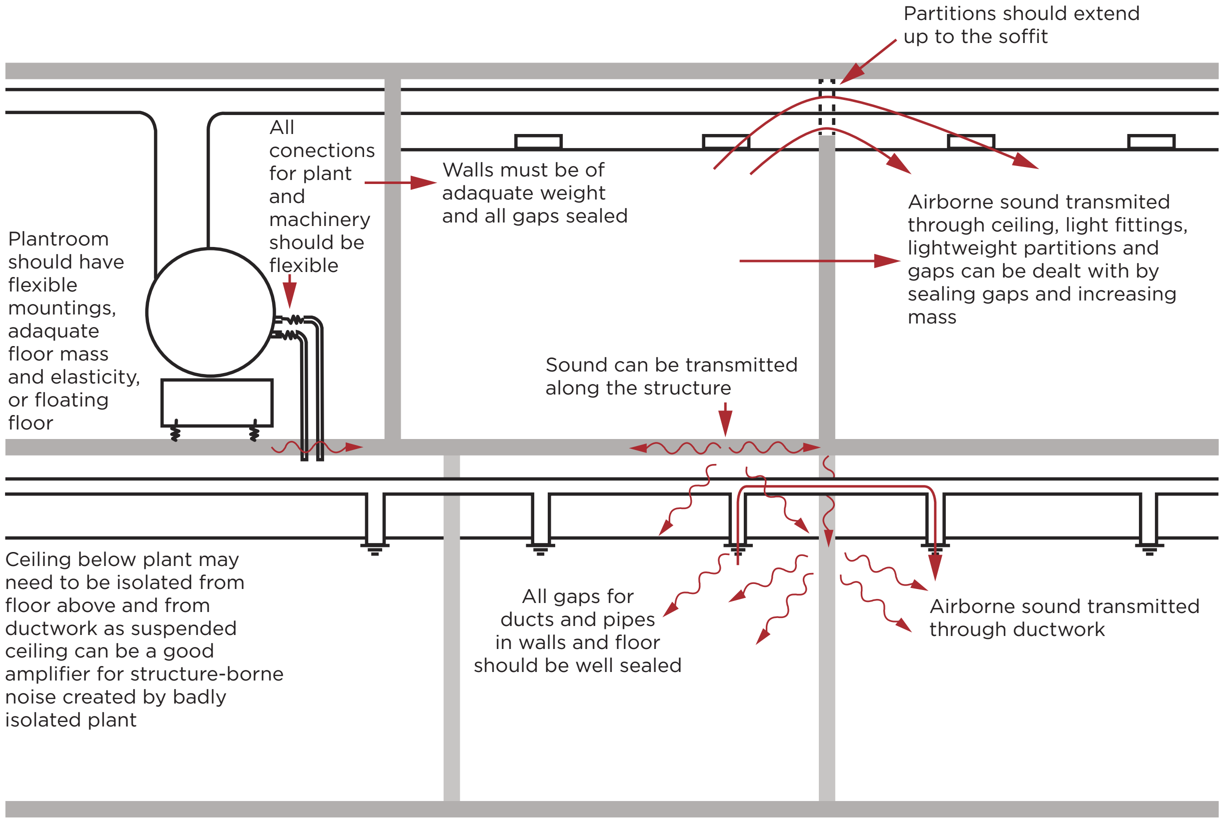



Figure 3.14: Possible sound transmission paths and their mitigation

## 3.8 Sound insulation between teaching rooms and circulation spaces

The requirements for sound insulation in Section 1.3 of Building Bulletin 93 apply between rooms and the circulation area which gives direct access to the room in question. The requirements of Section 1.3 should not be applied to adjacent circulation areas that do not give direct access to the room; in this case, the sound insulation requirements of Section 1.2 should be applied. "Direct access" may be understood as the circulation space that is accessed from the room in question. An adjacent circulation space which is accessed through doors from the first circulation space does not offer direct access to the room in question.

## 3.9 Sound insulation between non-teaching rooms and circulation spaces

Section 1.3 of Building Bulletin 93 describes the performance standards for airborne sound insulation between circulation spaces and other spaces used by students. Some specific room types are listed in Tables 4a and 4b in that section, followed by a reference to "All other rooms used for teaching and learning". Therefore there are no specific performance standards between rooms that are not used for teaching and learning and the circulation space that provides access. However, the walls and doors of these rooms will need to have sufficient sound insulation to control flanking sound transmission between rooms, so that the sound insulation requirements to any adjacent rooms can be achieved in accordance with Section 1.2 of Building Bulletin 93.

## References


1. BS EN ISO 717-1: 2013. Acoustics – Rating of sound insulation in buildings and of building elements. Airborne sound insulation.
2. BS EN ISO 717-2: 2013. Acoustics – Rating of sound insulation in buildings and of building elements. Impact sound insulation.
3. BS EN ISO 10140-2: 2010. Acoustics. Laboratory measurement of sound insulation of building elements. Measurement of airborne sound insulation.
4. BS EN 12354–1: 2000. Building Acoustics. Estimation of acoustic performance in building from the performance of elements. Part 1. Airborne sound insulation between rooms.
5. BS EN ISO 10140-3: 2010. Acoustics. Laboratory measurement of sound insulation of building elements. Measurement of impact sound insulation.
6. BS EN 12354-2: 2000. Building Acoustics. Estimation of acoustic performance in building from the performance of elements. Part 2. Impact sound insulation between rooms.
7. BS EN ISO 10848 series of Standards
8. Approved Document E - Resistance to the passage of sound 2003 edition, incorporating 2004, 2010, 2013 and 2015 amendments. ISBN 978 1 85946 616 2.

# Chapter 4 The design of rooms for speech

The design of rooms for speech is a critical aspect of the acoustic design of a school. Rooms must be designed to facilitate clear communication of speech between teachers and students, and between students. Without good design for speech, teaching and learning spaces may not be suitable for their intended use.

## 4.1 Approach to acoustic design

The majority of rooms in schools are designed for speech, as schools are places to facilitate the imparting and sharing of information. A structured approach to the acoustic design of these rooms needs to consider the following factors:

1. Indoor ambient noise levels (see Table 1 of Building Bulletin 93)
2. Room size and geometry: floor area, room shape and volume and, hence, required reverberation time (see Table 6 of Building Bulletin 93)
3. Amount of acoustic absorption needed to achieve the required reverberation time
4. Type, location, and distribution of that acoustic absorption
5. Special considerations for non-standard rooms (e.g. reflectors and diffusers)
6. Use of electronic sound reinforcement systems.

## 4.2 Internal ambient noise levels and speech clarity

The internal ambient noise level is very important in teaching spaces as the teacher's voice needs to be clearly heard above the background noise. The sound power output of conversational speech is typically 10 microwatts, which results in a sound pressure level of around 60 dBA at 1 m in front of the speaker. This output power can be raised to around 100 microwatts when the speaker talks in a raised voice, which increases the sound pressure level at 1 m to about 70 dBA. By shouting, the output power can be further raised to around 1000 microwatts – with a consequent further increase in sound pressure level to about 80 dBA at 1 m, (see Figure 4.1). In subjective terms, this means that a speaker can approximately double the loudness of the voice by speaking very loudly, and then double it again by shouting.

However, the room should be designed as far as possible to avoid the need for the teacher to speak in a raised voice which can lead to voice strain and possibly permanent vocal damage.

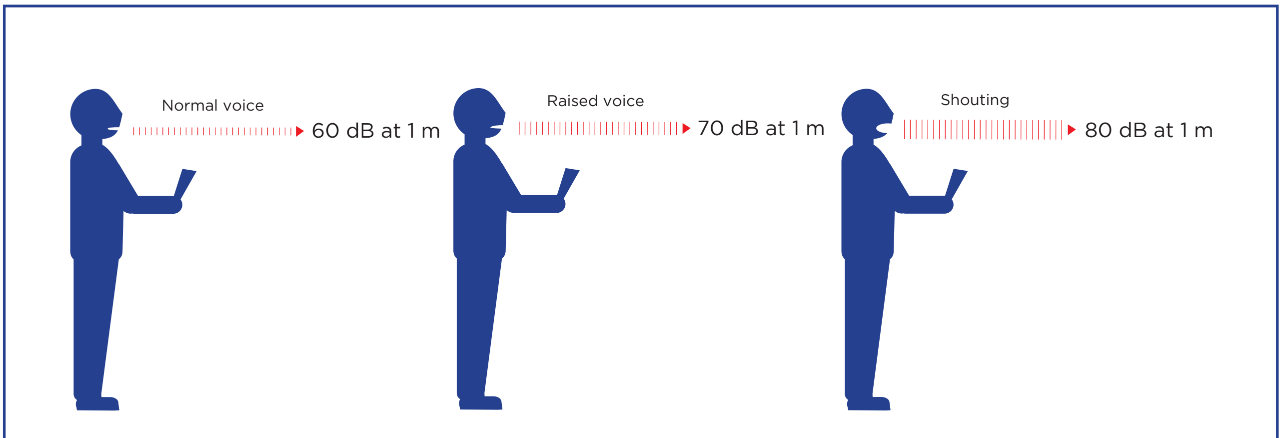



Figure 4.1: Sound pressure levels of speech at 1 m

It is also desirable to preserve the character (nuances and intonations) of speech, as this can convey meaning and emotion. This is particularly relevant to language teaching and to the performance of drama. The frequencies of sound in speech range from bass to treble, i.e. from below 125 Hz to above 8 kHz. Vowels have a sustained, tonal sound that contains characteristics of the speaker's voice. Men's voices have the lowest characteristic pitch (120 Hz), women an intermediate pitch (225 Hz), and children the highest pitch (265 Hz). Vowels contain most of the sound energy in speech but recognition of the consonants, whose energy is generally concentrated towards the higher frequency end of the speech spectrum, is the key factor for intelligibility (i.e. being able to understand, as well as hear, speech).

The intelligibility of speech depends upon its audibility as well as its clarity. Audibility is affected by the loudness of the speech (signal) relative to the background noise level and is often expressed as a 'signal to noise ratio' (SNR). Background noise can be a combination of many factors, including ingress noise from external activities (e.g. road traffic), building services, classroom equipment (e.g. projectors, whiteboards etc.), noise from adjacent spaces and general occupancy noise.

An increase in the background noise will cause greater masking of speech and hence will decrease intelligibility. It is possible to speak more loudly, but this effect is limited and can also lead to voice strain. A higher level of background noise is also undesirable as it can lead to a general increase in activity and speech noise within the space, with each speaker trying to be heard. The indoor ambient noise levels for different rooms specified in Table 1 of Building Bulletin 93 have been chosen such that an adequate signal to noise ratio can be achieved without undue strain on the teacher's voice and to minimise the effects of distraction from other sources.

## 4.3 Reverberation times

A classroom with a long reverberation time of several seconds will cause syllables to be prolonged so that they overlap and hence degrade speech intelligibility. Long reverberation times can occur in large rooms with hard wall and ceiling surfaces. Adding acoustic absorption and reducing the ceiling height will generally reduce the reverberation time and improve speech intelligibility. Table 6 of BB93 specifies the reverberation times required for various teaching spaces ranging from teaching classrooms to assembly halls.

Long reverberation times also increase reverberant noise levels within a room, which further decrease speech intelligibility. To compensate for this, people in reverberant rooms tend to increase their voice levels to make themselves heard over the reverberant noise, which further exacerbates the situation. This is a common feature of many school dining rooms and sports halls, and is known as the Lombard effect.

For rooms with a non-uniform sound field, e.g. rooms having one dimension significantly greater than any other (typically by six times or more) or uneven distribution of absorption, the reverberation time may not be an accurate descriptor as it will vary significantly across the space, being dependant on the source and receiver locations. In such cases, additional descriptors such as Speech Transmission Index (STI) may be appropriate (see ISO 3382-3[1] for information on alternative descriptors relevant to speech).

## 4.4 Amount of acoustic absorption required

In classrooms and other rooms for speech, large amounts of fixed acoustic absorption are often required, particularly where rooms have high ceilings.

When calculating reverberation times to comply with the values specified in Table

6, the effect of furnishings such as chairs, school desks and benches, can be taken into account. It is unlikely that classroom furnishings will provide significant amounts of absorption, but they can be beneficial in scattering sound and deflecting it onto other absorbent surfaces. Where the amount of furnishing in a room may vary with its use (e.g. a main hall) then the least furnished condition should be considered.

## 4.5 Diffusion of sound

It is important to consider the diffusive properties of room finishes and contents as these properties influence the effectiveness of sound absorption in situ and avoid faults such as standing waves and flutter echoes.

## 4.6 Distribution of absorbent materials

The location of acoustic absorption within a room is important. The traditional calculation of reverberation time assumes that the absorbent surfaces in a room are reasonably evenly distributed. If this is not so, the reverberation time equation may be unreliable and undesirable local variations in the acoustic conditions can occur, particularly in large rooms or halls. Large areas of acoustically reflective material can also lead to localised echoes, focusing and standing waves.

In sports halls, it is important to distribute absorption evenly and not solely concentrate on the soffit. Locating absorption and diffusion within 3 m of the floor level can significantly improve the acoustic quality of the space and negate the need for extensive absorption at higher levels.

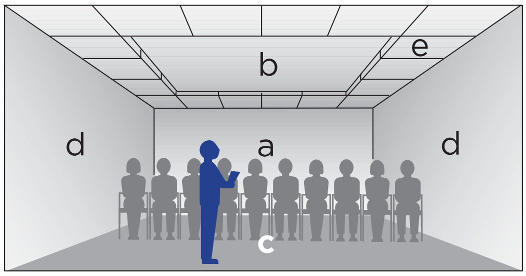
## 4.7 Room geometry

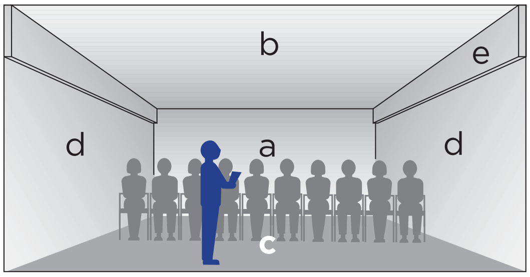
To achieve adequate loudness for all listeners in a room, it is necessary that the direct sound from speaker to listener has a clear, unobstructed path. The loudness of the direct sound can be enhanced by strong, short delay reflections from room surfaces. These short delay reflections should arrive at the listener within one twentieth of a second (50 milliseconds) of the direct sound, which is approximately the time required for the ear to integrate such reflections with the direct sound. Strong reflections after 50 milliseconds become increasingly detrimental to speech intelligibility and, ultimately, if the delay is long enough, they will be perceived as distinct echoes.

## 4.8 Classrooms

For classrooms and other rooms for speech, there are two main approaches to locating the acoustic absorption:

1. To make the soffit predominantly absorbent. In most cases an acoustically absorbent suspended ceiling can provide all of the necessary absorption to meet the reverberation time targets; however, the addition of absorbent panels on the walls may improve the acoustic quality of the space. Alternatively, acoustically absorbent suspended rafts or baffles may be used (particularly useful in the case of rooms with exposed concrete soffits providing thermal mass to optimise thermal comfort), although additional absorption may be required on the walls to meet target criteria. See Figure 4.2(a).
2. To leave the ceiling acoustically reflective (plaster, plasterboard, concrete, etc.) and to add acoustic absorption to the walls. In these cases it is advisable to locate most of the absorption at high level and some on the back wall facing the teacher to prevent a 'slap echo' off the back wall. This is particularly important if the rear wall is concave or the distance from the speaker to the rear wall is greater than 8.5 m. If there is insufficient space to




**(a)** Surface finishes in classroom or lecture theatre:
a. Rear wall - sound absorbing or diffusing
b. Ceiling - sound reflective (eg plasterboard)
c. Floor - sound absorbing (eg carpet)
d. Walls - sound reflective
e. Ceiling - sound absorbing

**(b)** Surface finishes in classroom or lecture theatre:
a. Rear wall - sound absorbing or diffusing
b. Ceiling - sound reflective (eg plasterboard)
c. Floor - sound absorbing (eg carpet)
d. Walls - sound reflective
e. Top of walls - sound absorbing or diffusing

**Figure 4.2: Surface finishes in classroom or lecture theatre**

accommodate the required amount of absorption on the walls or in the form of suspended rafts or baffles, absorptive treatment to lighting rafts, or panels fixed directly to the soffit may be required. See Figure 4.2(b).

Reflections from the rear wall of large rooms can be disturbing for a speaker if they arrive later than 50 milliseconds after the speech has been voiced. This can occur if the speaker to rear wall distance is greater than 8.5 m, and in this case the rear wall should be made acoustically absorbent or acoustically diffusing to avoid the problem.

There are instances where provision of sound field amplification can improve speech intelligibility, although it is considered good practice to design rooms for 'natural' control, wherever possible and all efforts should be made to achieve good acoustic conditions through careful room design before sound field systems are considered.

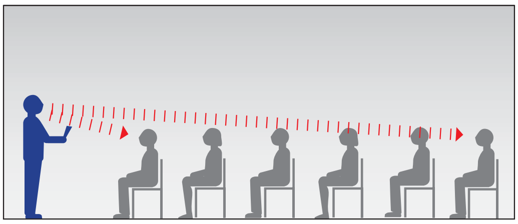
## 4.9 Assembly halls, auditoria and lecture theatres

Most school halls are used primarily for speech functions such as assemblies, meetings and drama, and use for music is less frequent. The most common problem in school halls is excessive reverberation resulting in high noise levels and poor speech intelligibility.

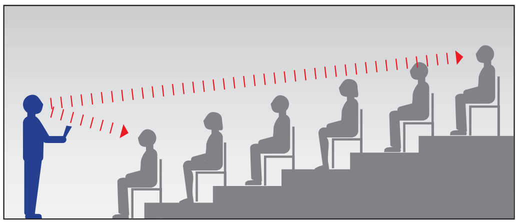
### 4.9.1 Room geometry

The direct sound from speaker to listener must be as strong as possible at all positions. Because direct sound weakens rapidly with distance according to the inverse square law (the intensity is reduced by a factor of four and the sound level falls by 6 dB when the speaker to receiver distance is doubled), the average distance between speaker and listener should be kept as small as possible. Furthermore, there should be no obstructions along the direct sound path. See Figure 4.3 for examples of seating arrangements which ensure this is the case.

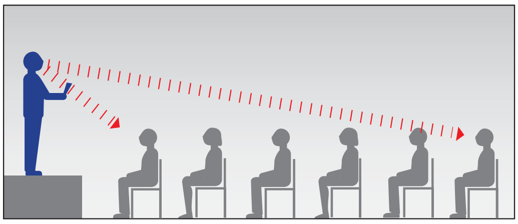
Any reflection that arrives at a listener, or back at the speaker, more than 50 milliseconds after the direct sound is likely to be disturbing. These are most likely in school halls where late reflections can occur from the rear wall, or a control room window at the rear. Rear walls can be made sound absorbing or sound diffusing to avoid this. Control room windows can be tilted to direct reflections away from speakers and listeners. See Figure 4.3 for illustrations of reflected sound paths.



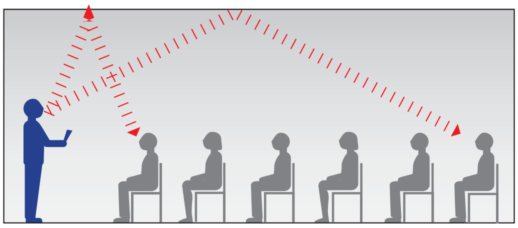
**(a)** Adequate loudness is essential, direct sound must have a clear unobstructed path.



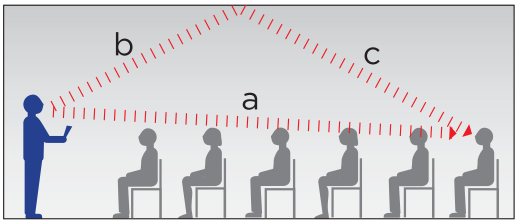
**(b)** Loudness of direct sound towards rear is increased with raked seating.



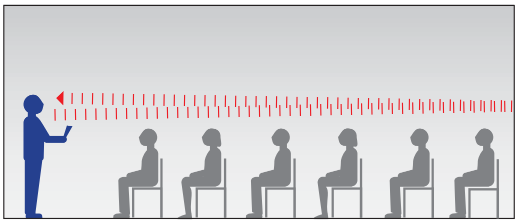
**(c)** Loudness of direct sound can be increased by putting the speaker on a platform.



**(d)** Reflected sound enhances direct sound if time delay is less than 50 milliseconds.



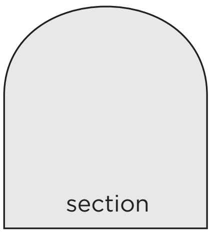

**(e)** For useful sound reflections, additional path travelled by reflected sound must be less than 17 m: b+c – a<17 m.



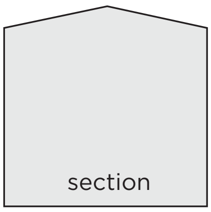
**(f)** Rear wall can cause a disturbing echo for speakers if over 8.5 m away. Rear wall should be absorbing or diffusing.

**Figure 4.3: Effects of room geometry on speech**

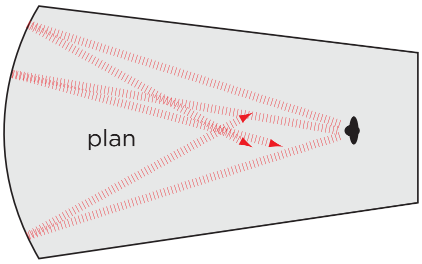
Focusing of sound by domes or barrel vaults can be a serious fault, causing strong late reflections or echoes, as illustrated in Figure 4.4. If the dome or barrel vault is above a flat, hard floor, as in a school hall, flutter echoes can occur which can be disturbing for speaker and listener alike; the focusing of sound can also cause discomfort to listeners along the centre line due to excessive reinforcement of sound. The same effect can also occur on plan where a room has a curved or segmented rear wall opposite a flat front wall, see Figure 4.4.




**(a)** Barrel vault can cause focusing and flutter echoes




**(b)** Shallow hipped roof can cause focusing and flutter echoes




**(c)** Curved rear wall can cause focusing

**Figure 4.4: Room shapes which can cause focusing and echoes**

### 4.9.2 Sound reinforcement

With an acoustically well designed room it is possible for speakers to achieve good speech intelligibility, even with large audiences. Quieter and untrained speakers, however, may not be able to do this and a speech reinforcement system is likely to be required for some functions.

The key aim of such a system is to increase the loudness of the direct sound, particularly for more distant listeners, whilst keeping the sound as natural as possible.

The distribution of loudspeakers and their directional characteristics is a key issue in achieving high speech intelligibility. For large teaching rooms and lecture theatres, loudspeakers can be distributed in the ceiling or on the walls at high level. In school halls, column loudspeakers can be located on side walls, or in a central cluster. Account will need to be taken of the natural time delay in delivery for more distant receivers, requiring electronic compensation to adjust the loudspeaker output to the correct time after the sound is voiced.

The design of sound reinforcement systems is a specialist field and specialist advice should be sought. The incorrect specification of loudspeakers (e.g. domestic hi-fi or over-emphasised bass systems where speech reinforcement is required) can result in poor speech intelligibility in the room and excessive transfer to adjacent spaces.

## 4.10 Spaces for practical subjects

Spaces for teaching practical subjects have particular requirements that need careful design in order to comply with the acoustic requirements for teaching and learning. This section addresses the needs of design and technology spaces and art rooms. Music rooms are considered separately in Chapter 5. Although science involves a significant amount of practical activity, the general approach described for classrooms (Section 4.7) can be applied to spaces for the teaching of science.

Open plan situations may not be appropriate for many practical activities because of the increased risk of disturbance to adjacent spaces resulting from high activity noise levels.

### 4.10.1 Design and technology spaces

Design and technology departments in secondary schools contain timetabled spaces for a variety of practical activities, e.g. graphics, resistant materials (wood, metal and plastics), electronics/control, food and textiles. They also include non-timetabled learning spaces, for example shared design/ICT resource areas.

The equipment and activities in these spaces can vary widely depending on the type and size of department. Activity noise and noise tolerance classifications for different spaces are given in Table 1 of Building Bulletin 93. It is important to establish which activities will take place in any one space and which equipment will be used before calculating required levels of sound insulation to suitably control the background noise in nearby spaces. Activity noise in Table 1 of Building Bulletin 93 is based on commonly expected activities, but where machinery and equipment is unusually noisy, or quiet, the calculations will need to be adjusted accordingly.

Resistant materials areas containing wood or metal working machinery can produce high noise levels, which can, in turn, have a detrimental effect on speech intelligibility. Machines extracting dust particles, CAD/CAM and other noisy equipment will increase the activity noise level of a space. It is important to consider the effects of such equipment on teaching activities both within the space containing the equipment and in adjoining rooms.

Central resource areas are sometimes located in adjoining circulation spaces. A common arrangement uses the central resource area predominantly for individual and small group work, but such areas are not generally suitable for whole class teaching. Usually, there are areas of glazing and doors between the central resource area and adjacent practical spaces. The central area should be suitable for most design/resource activities as long as use of the circulation space is restricted to the department and does not include access to other parts of the school.

The speech intelligibility in open plan spaces will need to be assessed using computer prediction models. This may apply to a shared design/ICT resource area, where group presentation could take place at the same time as other activities. See Chapter 7 for more detailed information on the design of open plan spaces.

### 4.10.2 Art rooms

Art classes in secondary schools involve independent and group activities which are, in general, quieter than those in other practical areas. Noise levels in secondary school art spaces are likely to be similar to those in a general classroom. However, art departments tend to have a more informal environment reflecting the nature of the activity and are often of open plan design. There may be more glazing in partitions in art departments than in other parts of the school, to emphasise the importance of the visual environment.

It is usual for all available wall space to be taken up with displays, leaving very little room for any wall-mounted sound absorption. This, coupled with hard floor finishes and higher ceilings, can make provision of sufficient absorption challenging.

### 4.10.3 Floor finishes in practical spaces

Carpets are not appropriate for most practical areas and so cannot be used as a way of increasing sound absorption, or reducing impact sound transmission through floors, in science, art and design and technology spaces. They may, however, be suitable in some design/resource areas. Impact sound can be controlled by the use of floating floors, resilient underlay or resiliently backed vinyl finishes (see Chapter 3).

## 4.11 Drama rooms

There are three types of drama room in common use:

1. Rooms for small scale drama teaching and practical work
2. Drama studios – for rehearsal, teaching and small-scale performance
3. Theatres and flexible spaces primarily for performance.

Rooms for small scale drama teaching and practical work are usually little more than classrooms, which may be fitted with curtains both for blackout and to reduce reverberation time. They may also be provided with a basic set of performance lights and dimmable main lighting.

Drama studios tend to be larger spaces dedicated to drama, with special equipment such as moveable staging, seating rostra and more advanced lighting and sound systems. They do not normally have fixed stages or platforms and the acoustics will tend to change with the layout, seating and audience. They may be fitted with heavy curtains on some or all walls for blackout, and to allow some flexibility in the room's appearance. These may provide additional sound absorption, but should not be relied on alone to achieve the reverberation time targets in Table 6 of Building Bulletin 93. Studios generally have vinyl-covered wooden floors and acoustically absorbent ceilings, although large amounts of permanent lighting and rigging can also provide useful diffusion.

Theatres and spaces primarily for performance vary considerably in form and size from the conventional assembly hall to adaptable theatres. They can be traditional theatres with fixed proscenium and stage, open stages, thrust stages or in the round, (see Figure 4.5). Adaptable theatres can be converted from one arrangement to another depending on the type of performance.

Each type has different acoustic characteristics. Spaces designed specifically for public performance are specialised rooms and the advice of both an acoustician and a theatre consultant should normally be sought.

For successful drama it is necessary for the audience to see and hear considerably better than in most school halls, because of the close relationship between actors and their audience. In principle, to achieve close communication between actor and the audience it is necessary to restrict the size of the auditorium so that the maximum distance from any member of the audience to the stage does not exceed 20 m. In small theatres this is not generally a problem, but for larger audiences it may require the use of balconies and galleries, giving rise to the traditional fan-shaped theatre. Deep balconies should generally be avoided as the space under these can be acoustically 'dead' and considerable care is required to ensure that reflections from the ceilings and walls compensate for the lack of direct sound in such areas. Alternatively, a suitable infill PA system can be utilised.

It is common for theatres in schools to be used not only for drama, but also for lectures, films, meetings and music, all of which have different acoustic requirements. The acoustics of multi-purpose halls are discussed in the following section.

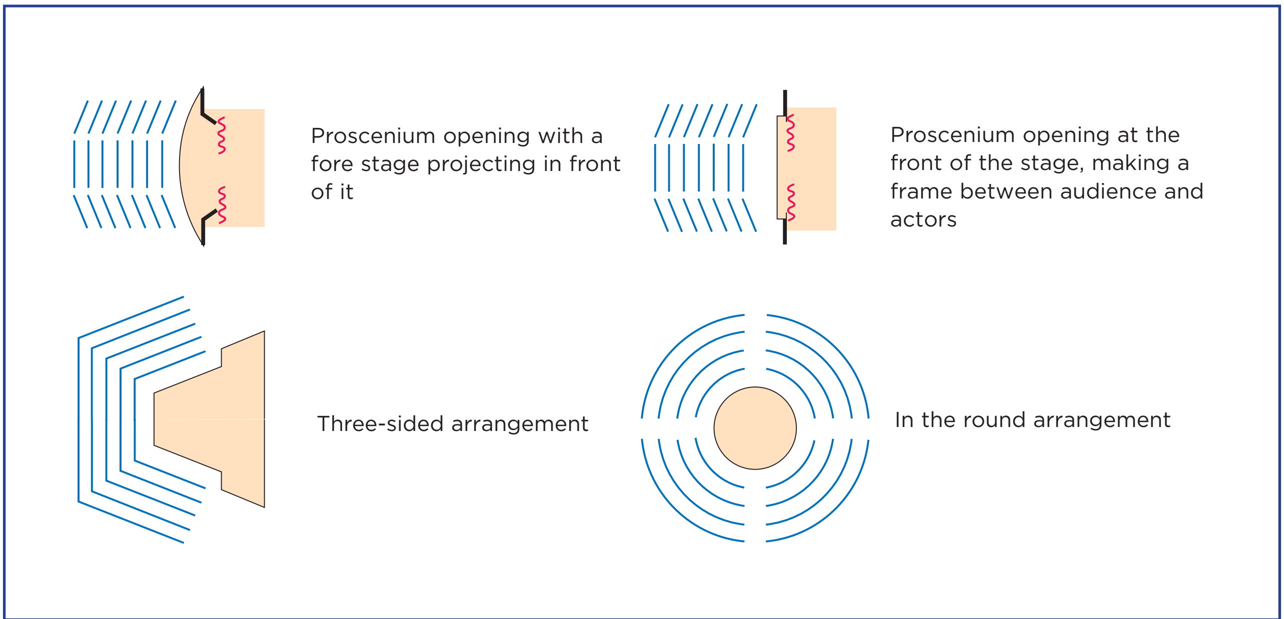



**Figure 4.5: Typical performance spaces for drama**

## 4.12 Multi-purpose halls

In some cases a single flexible hall is required for a variety of uses and this gives rise to specific acoustic problems. The different uses of multi-purpose halls often have conflicting acoustic requirements, making it difficult to provide a space with optimum acoustics for all uses. The main conflict is that between speech and unamplified music, see Table 4.1.

**Table 4.1: General acoustic requirements for speech and music**

| Speech | Music |
|---|---|
| "Dry" acoustic | "Live" or "warm" acoustic |
| Short reverberation time | Long reverberation time |
| Good clarity, loudness and intelligibility of speech | Even decay of sound |
| Sound must appear to come from stage with some contribution from room reflections but no perceptible reverberation | Good "envelopment" - audience should feel surrounded by the sound and musicians should be able to hear themselves and each other easily |
| Small volume | Large volume |

## 4.13 Sports halls, gymnasia and swimming pools

Sports halls, gymnasia and especially swimming pools have long reverberation times through the nature of their construction and surfaces necessary to their function. These can result in high noise levels and poor speech intelligibility.

A variety of relatively rigid, robust and hygienic, acoustically absorbent materials is available and can be used to reduce reverberation times. In general, these materials are installed on ceilings and at high level on walls or as hanging baffles. If there are large areas of acoustically hard parallel surfaces flutter echoes can occur, significantly increasing the reverberation time and reducing speech intelligibility. A reasonable distribution of acoustic absorption or diffusion will help to reduce this effect; fair-faced acoustically absorbent blockwork also performs the same function, with the additional benefit of bringing sound absorption into the listener plane.

Achieving acceptable reverberation times in sports halls requires a good distribution of absorptive finishes around the room surfaces, together with diffusion provided by irregular surfaces. Reverberation times are likely to be long without these finishes and reflections between large, parallel surfaces such as opposing walls can manifest as flutter echoes.

Locating absorptive wall panels at high level, in addition to the roof liner, can be effective, but requires significant coverage. Generally, the closer to the floor the absorbent treatment can be provided, the less the coverage required.

Successful recent designs have included fair faced blockwork (Class D absorbent finish) from ground floor up to 3 m, in addition to a Class C perforated roof liner. This provides adequate distribution of absorption and diffusion within the listener plane, in addition to an impact-resistant finish.

Appendix 4 provides a design guide for sports halls, swimming pools, gymnasia, dance studios and other activity spaces which are usually unfurnished.

## 4.14 Dining areas

Dining areas can suffer from high activity noise, interfering with conversation and leading to increasing noise levels. Sound absorption is, therefore, required in these areas to reduce the reverberant noise level. The most practical place to position sound absorption is on the ceiling and the walls. Shapes in section or on plan that produce focusing, such as barrel vaulted roofs and circular walls, should be avoided unless treated with sound absorbent material.

## References


1. BS EN ISO 3382-3: 2012. Acoustics - Measurement of room acoustic parameters - Part 3: Open plan offices.

# Chapter 5 The design of rooms for music

Music rooms require special attention in the acoustic design of a school. Musical activities range from playing, listening and composing in group rooms to orchestral performances in school halls, and a music room can be anything from a small practice room to a large room for rehearsing and performing music. It is important to establish the user's expectations of the acoustic performance of a space to ensure that it is designed appropriately.

## 5.1 Aspects of acoustic design

The publication Music Accommodation in Secondary Schools: A design guide[1] provides guidance on the design of music facilities in schools. Reference to this publication for details of acoustic design is strongly recommended.

The performance standards of the most common music room types are listed in the tables in Building Bulletin 93. Some non-specialist classrooms may be used for teaching music theory to large groups, with only occasional live or recorded music. Good speech intelligibility, rather than an enhanced acoustic for music, is appropriate for these rooms and classrooms with the same acoustic criteria as normal classrooms may be used.

A brief outlining the client's acoustic requirements should be obtained before starting the design of any specialist music facility. The main problems are noise transfer between spaces, noise ingress from outdoors, excessive loudness whilst playing or singing and unsuitable reverberation times.

## 5.2 Ambient noise

The requirements for indoor ambient noise levels in music rooms are set out in Building Bulletin 93. It is important to select quiet fans or air handling units, connected to appropriately sized attenuators to control noise from mechanical ventilation. Typical primary attenuator lengths will be in the range 2.4 - 3.0 m. Air velocities in the duct system should be kept low and should not generally exceed 5 m/s in main ducts, 4.5 m/s in branch ducts and 2.5 m/s at run outs. Terminal units (grilles etc.) should be selected for low noise output.

Noise from hot water radiator systems should be minimised by good design. Equipment, particularly valves and pumps, should be designed and selected for quiet operation, with vibration isolation where appropriate.

In noise-sensitive spaces, such as music performance spaces and recording spaces, hot water pipes should not come into rigid contact with the building construction. Resilient pipe brackets and flexible penetration details should be adopted to prevent clicking noises resulting from expansion and contraction.

Lighting can cause disturbing buzzing and occasionally sharp cracks from expansion or contraction of metal fittings. 50 Hz fluorescent lights should not be used in music rooms, because they are inherently prone to buzzing and mains hum, which is audible to some people.

These effects do not occur with high frequency (HF) fittings, which should normally be specified on energy efficiency and cost-saving grounds. HF fittings are acceptable for most general music spaces.

Where the quietest conditions are required, lighting should be restricted to lamps with the lowest noise output. In certain spaces, such as a recording/control room, the sound caused by transformers used with low voltage spotlights can be distracting and such transformers should be located outside the rooms.

## 5.3 Sound insulation

Standards for sound insulation between different types of room are set out in Building Bulletin 93, which specifies a minimum of 55 dB $D_{nT,w}$ between most music rooms to avoid excessive noise transfer. These are minimum requirements and will not always prevent disturbance between adjacent rooms. It is beneficial to increase these figures, especially when the indoor ambient noise level is significantly below the level in Table 1 of Building Bulletin 93. This can occur in naturally ventilated rooms on quiet sites, where the indoor ambient noise level is too low to provide useful masking of distracting noise from adjacent rooms.

The level of sound and possible disturbance to adjoining music spaces will vary, depending on the instruments being played. Clearly, as the loudness of the instruments varies from type to type, so the room-to-room sound insulation requirement will also vary. A primary design constraint is the balance between cost and flexibility. Whilst a high level of flexibility is desirable, so that any instrument can be played in any room, it is generally too expensive to provide sound insulation to satisfy the most stringent requirements at all locations throughout the building. Alternatively, designating groups of rooms to types of instruments severely limits flexibility, but concentrates investment in sound insulation where it is most required.

Rooms for percussion and brass will generate high noise levels and great care is needed in choosing their location. Rooms for percussion should, if possible, be located at ground level to minimise the transmission of impact vibration into the building structure. Ideally a box-in-box construction should be used for all percussion and drum rooms, see Figure 5.1.

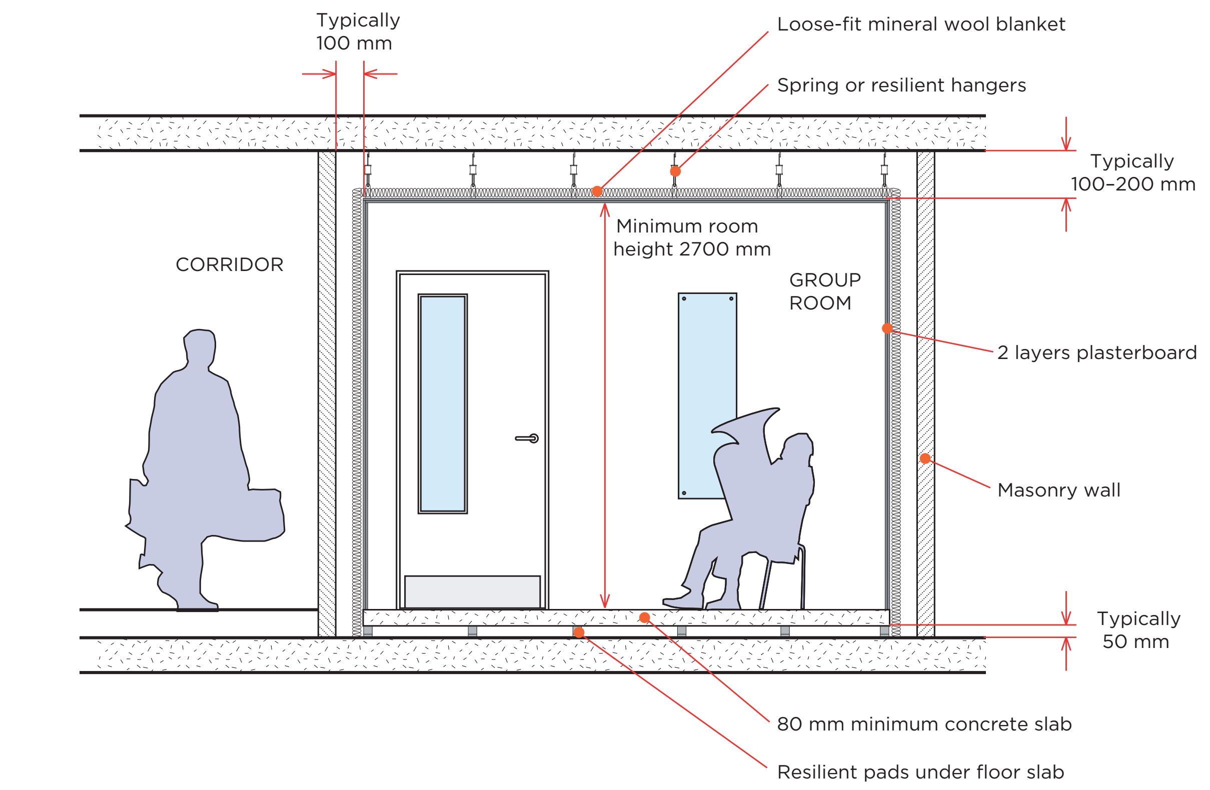



**Figure 5.1: Drum room with box-in-box construction**

Where possible, the principles of good planning should be adopted, for example corridors and storage areas can be used as 'buffer zones' between music rooms. This allows the sound insulation requirements to be met without resorting to very high performance constructions. However, in some cases the provision of special sound insulating constructions is the only option.

Background noise must be controlled in circulation areas. However, limited break-out of musical sounds into circulation routes is acceptable since it allows teachers to monitor, from a distance, unsupervised small group music activities.

### 5.3.1 Sound insulation between music rooms

The sound insulation required between the different types of music room can be determined from the tables in Building Bulletin 93. Other criteria, such as those proposed by Miller[2], which take account of both sound insulation and indoor ambient noise level, are sometimes used in the specification of sound insulation between music rooms; however, the normal way of satisfying Requirement E4 of the Building Regulations is to meet the performance standards in Building Bulletin 93 for airborne sound insulation between rooms.

## 5.4 Room acoustics

### 5.4.1 Reverberation time, loudness and room volume

In general, rooms for the performance of non-amplified music require longer reverberation times than rooms for speech. Figure 5.2 shows optimum mid-frequency reverberation times for speech and music as a function of room volume.

The volume of a room has a direct effect on the reverberation time (RT) and early decay time; in general, the larger the volume, the longer the RT. The reverberation times should be in the ranges given in Building Bulletin 93 and should be constant over the mid to high frequency range. An increase of up to 25% is permissible, and indeed is preferred, at low frequencies, as indicated in Figure 5.3.

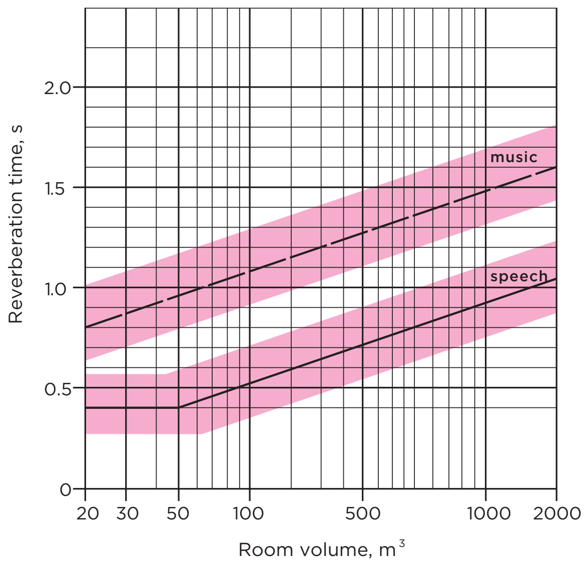



**Figure 5.2: Optimum mid-frequency reverberation times for speech and music, for unoccupied spaces**

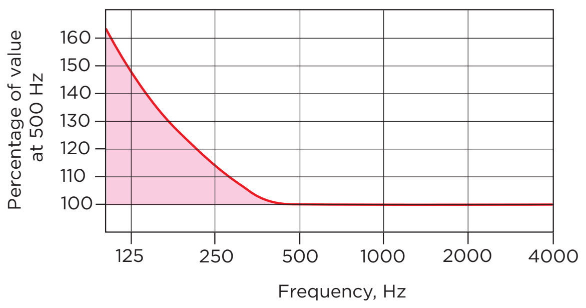



**Figure 5.3: Recommended percentage increase in reverberation times at lower frequencies for rooms specifically for music**

To achieve this, it is generally necessary for the volume of music rooms to be greater than for normal classrooms and this generally requires higher ceilings. These also help with the distribution of room modes as described in Section 5.4.3.

If the volume of a room is too small, the sound will be very loud, even with the correct reverberation time. This is a common problem in small practice rooms with insufficient acoustic absorption, and can give rise to sound levels which could, in the long term, lead to hearing damage.

Many professional orchestral musicians have noise-induced hearing loss due to extended exposure to high noise levels both from their own instruments and, to a lesser extent, from other instruments nearby. There is a general requirement to minimise noise exposure of employees under the Control of Noise at Work Regulations (2005). Employees include full-time, part-time and freelance peripatetic music teachers. It is therefore important to ensure that practice, rehearsal and teaching rooms are neither excessively reverberant nor excessively small for a given occupancy.

Setting the floor area and ceiling height is normally the first step in designing a music room. The floor area is usually determined by the number of occupants and guidelines are given in the publication Music Accommodation in Secondary Schools: A design guide[1], as are methods of curriculum analysis to determine the needs of a secondary school music department. A typical suite of music rooms in a secondary school might consist of:

| | |
|---|---|
| Large performance/teaching room | 85 $m^2$ |
| Second teaching room | 65 $m^2$ |
| Ensemble room | 20 $m^2$ |
| Practice/group rooms | 8 $m^2$ |
| Control room for recording | 10 $m^2$ |

Ceiling heights and, consequently, volumes for halls and recital rooms, are generally equivalent to two storeys, around 6 m. For group rooms and practice rooms, a full storey height (at least 3 m) is normally required.

### 5.4.2 Distribution of acoustic absorption

The acoustically absorbent material required to achieve the correct RT should be distributed reasonably evenly about the room. Where absorption occurs only on the floor and ceiling – for example, in a simple solution employing acoustic ceiling tiles and carpeted floor – users may experience an over-emphasis of sound reflections in a horizontal plane. This often leads to 'flutter echoes' between opposite parallel walls, which result in a distracting colouration of the music being played. A better solution is to distribute some of the absorptive material about the walls.

Although the RT requirements in Table 6 of Building Bulletin 93 are for unoccupied rooms, it is important to remember that the occupants will present a significant amount of absorption which will be in the lower half of the room. Acoustic absorption is, therefore, often located at high level on the walls to give a reasonably even distribution of absorptive material.

There can be large variations in RT in halls, depending on the presence or absence of an audience. Acoustically absorbent seats with upholstered backs can be used to reduce this effect. An acceptable alternative in smaller halls can be the use of retractable curtains to reduce the RT during rehearsals when no audience is present.

In auditoria and music rooms, surfaces around and above the stage or performing area are normally reflective to provide feedback to the performers.

Floors on a stage should also be reflective although carpet in the audience area of an auditorium may be acceptable.

### 5.4.3 Room geometry

It is important to consider both room shape and proportion. In large rooms such as halls and recital rooms, the geometry of the room surfaces will determine the sequence of sound reflections arriving at the listener from a given sound source. Early reflections, that is those arriving within approximately 80 milliseconds of the direct sound, will be integrated by the listener's hearing and will generally enhance the original sound for music (50 milliseconds is the corresponding figure for speech, see Chapter 4).

Prominent reflections with a longer delay (late reflections) may be perceived as disturbing echoes. These are often encountered where the rear wall in a hall has a large flat area of glass, masonry, or a similar acoustically reflective finish. Strong individual reflections can also lead to 'image shifting' where early reflections can be so strong that the ear perceives the sound as coming from the reflecting surface and not the sound source. This problem can be exacerbated if late reflections are particularly strong, which can occur when sound is focused by large concave surfaces such as curved rear walls, barrel vaults, domes, etc. Furthermore, focusing results in an uneven distribution of sound throughout the room. Consequently, large concave surfaces are not generally recommended in music spaces.

In small rooms, such as group rooms and music practice rooms, geometry affects the distribution of standing waves, or room modes, throughout the sound spectrum, but particularly at low frequencies. Where the distance between two parallel surfaces coincides with, or is a multiple of, a particular wavelength of sound, a standing wave can be set up and the balance of sound will be affected. Certain notes will be amplified more than others, leading to an unbalanced tonal sound, sometimes called colouration. As an illustration, bathrooms with tiled walls are a good example of rooms with prominent room modes and, although they can enhance certain notes of a singer's voice, they will not produce a balanced sound and will tend to be 'boomy'. The effect is exaggerated if distances are the same in more than one dimension. Thus rooms which are square, hexagonal, or octagonal in plan should be avoided. The same effect occurs if the room width is the same as the room height, or a simple multiple of it.

Ideally, the distribution and strength of room modes should be reasonably uniform. The best way to control these low frequency modes is to select room dimensions that are not in simple ratios. It should not be possible to express any of the room dimensional ratios as whole numbers, for example, a proposed space 7 m wide, 10.5 m long and 3.5 m high (2:3:1) would not be considered an advisable shape from an acoustic point of view. Mathematically, a good ratio is 1.25:1:1.6; this is sometimes referred to as the 'golden ratio' but many other ratios work equally well. Flutter echoes and room modes can also be controlled by using non-parallel facing walls, but this is often impractical for architectural reasons; the use of absorption, or diffusion in the form of wall-mounted panels is equally effective.

### 5.4.4 Diffusion

In addition to the correct RT, the room should be free from echoes, flutter echoes and standing waves and the sound should be uniformly distributed throughout the room, both in the performance and listening areas. To achieve this, it may be necessary to introduce diffusing hard surfaces to scatter the sound. These are normally angled or convex curved surfaces but bookshelves, balcony fronts or other shapes can also provide diffusion, see Figure 5.4. Acoustic diffusion is a complex subject and if calculation of diffusion is likely to be required, for example in a large hall used for performance, a specialist acoustics consultant should be consulted.

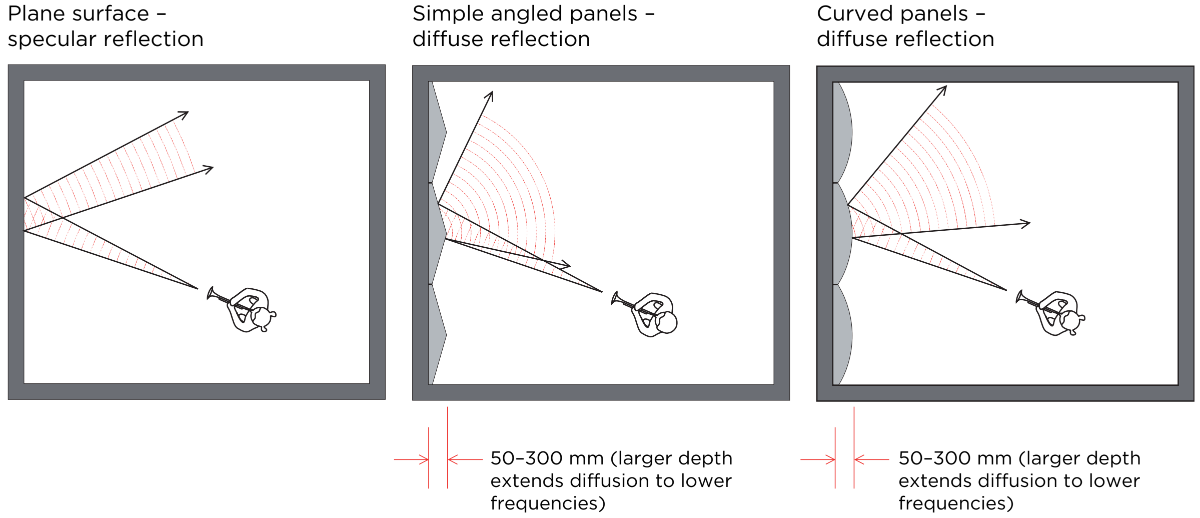



**Figure 5.4: Surfaces that produce specular and diffuse reflections**

## 5.5 Types of room

### 5.5.1 Music classrooms

Figure 5.5 shows a 65 m² music classroom for a range of class-based activities involving a number of different instruments. The room proportion avoids an exact square. The height is assumed to be between 2.7 m and 3.5 m, creating a reasonable volume for the activities (see Section 5.4.3). The main points to note about the acoustic treatment of the space are described below.

1. To minimise the possibility of flutter echoes or standing waves occurring between opposing parallel walls, surfaces are modelled to promote sound diffusion. On the side wall this takes the form of shelving to store percussion instruments, etc. On the back wall, framed pinboards (with a non-absorptive covering) are set at an angle, breaking up an otherwise plane surface.

2. Full length, heavy drapes along the back wall can be drawn across to vary the acoustics of the space. Such drapes should normally have a gather of 50% (i.e. the width of the drape should be 1.5 times the width of the wall) and they should be of a heavy material such as wool serge weighing around 400 g/m².

3. The observation window into the adjacent control room is detailed to ensure a high level of sound insulation between the two spaces (see Figure 5.6 and the discussion of control rooms below).

4. The door into the room is of solid core construction with a small vision panel. The door and frame details, Figures 5.7 and 5.8, are designed to maximise the sound insulation properties of the wall as a whole.

5. The floor is fitted with a thin pile carpet providing an absorbent surface while the ceiling has a hard reflective surface. The type of carpet can have a significant effect on the overall RT in a room. It is worthwhile checking the precise absorption coefficient of any surface finish.

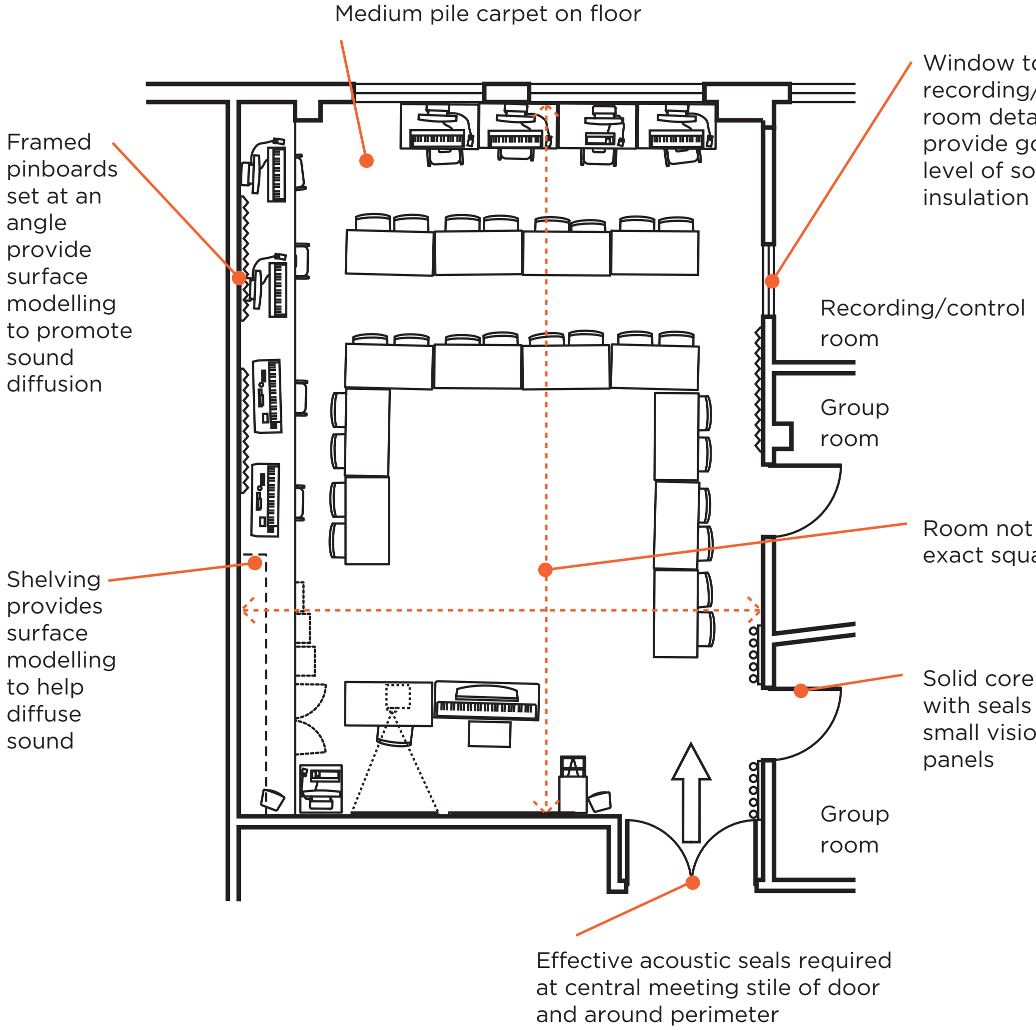



Figure 5.5: Acoustic treatment to music classroom

## 5.5.2 Music classroom/recital room

Figure 5.9 shows a larger, 85 m², classroom. The proportions of the room are in a ratio of fractional numbers (2.6:3.8:1) with the height between 2.7 m and 3.5 m, as for the 65 m² music classroom. The acoustic treatment is similar to that for the 65 m² room but, as this space is larger and bigger groups are likely to rehearse and perform here, drapes are provided on two adjacent walls.

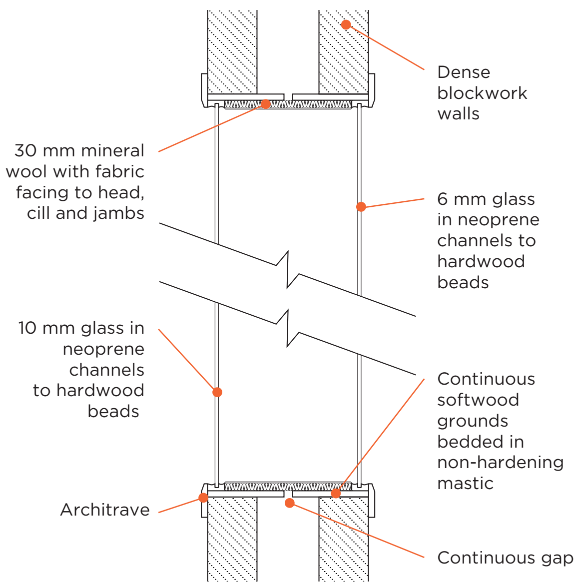



Figure 5.6: Section through control room window

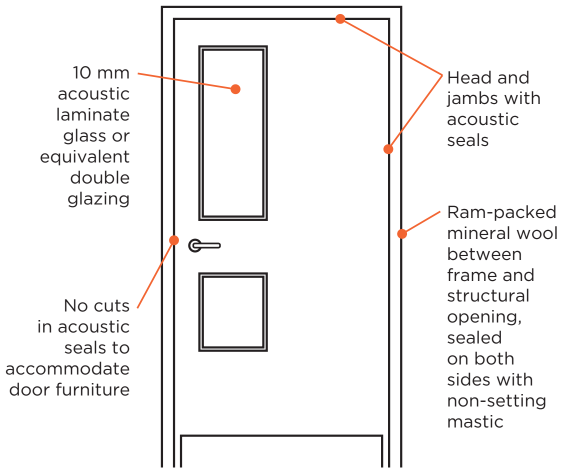



**Figure 5.7: Desirable features of an acoustic door installation**

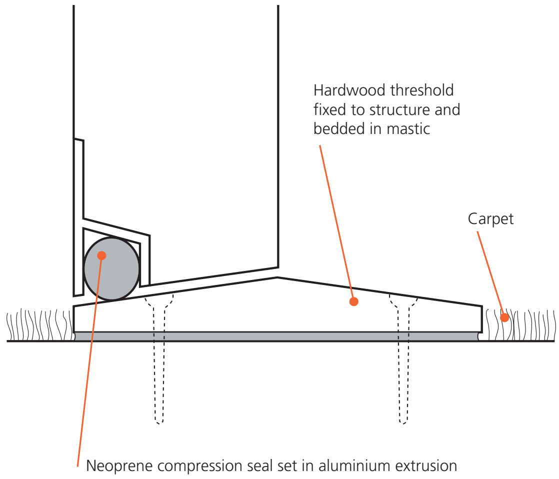



**Figure 5.8: Example of acoustic door threshold seal**

## 5.5.3 Practice rooms/group rooms

Figures 5.10.and 5.11 show typical 8 m$^2$ group rooms, which will accommodate both instrumental lessons and composition groups and which can be used for individual practice. Points to note are as follows.

1. To avoid flutter echoes and prominent standing waves (a particular issue in small rooms with parallel walls), angled timber panels (diffusers) can be fixed to the walls. Window and door reveals provide useful diffusion to other walls (see Figure 5.10). Alternatively, one of the walls can be angled as in Figure 5.11. Diffusing panels are still recommended in this configuration, as angling one wall is usually not sufficient.
2. A full length drape can be pulled across one of the long walls to increase surface absorption and reduce loudness.
3. The window is fairly small and positioned in the centre of the wall to control the amount of external noise reaching the space and avoid sound travelling between adjacent group rooms.
4. Floor and ceiling finishes are as for the larger rooms.

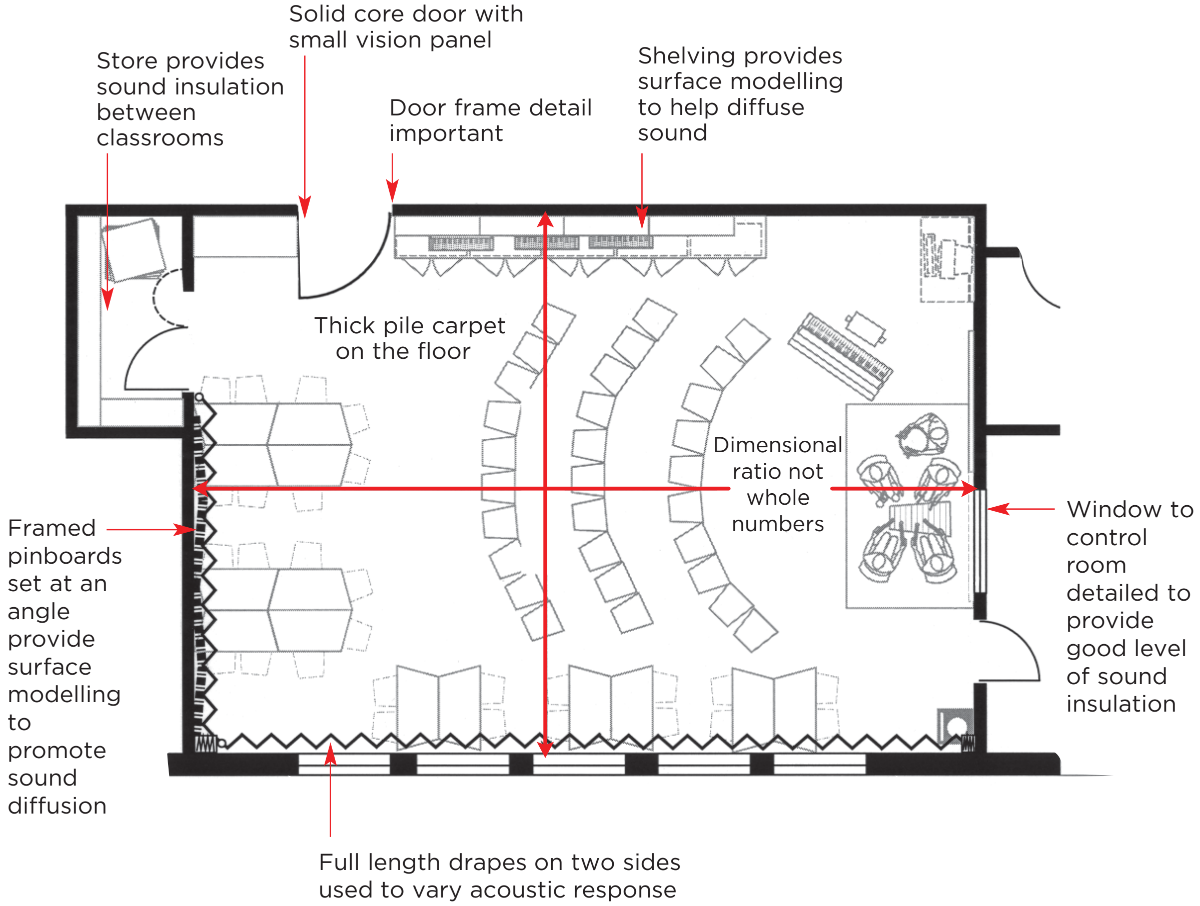



**Figure 5.9: Acoustic treatment to music classroom/recital room**

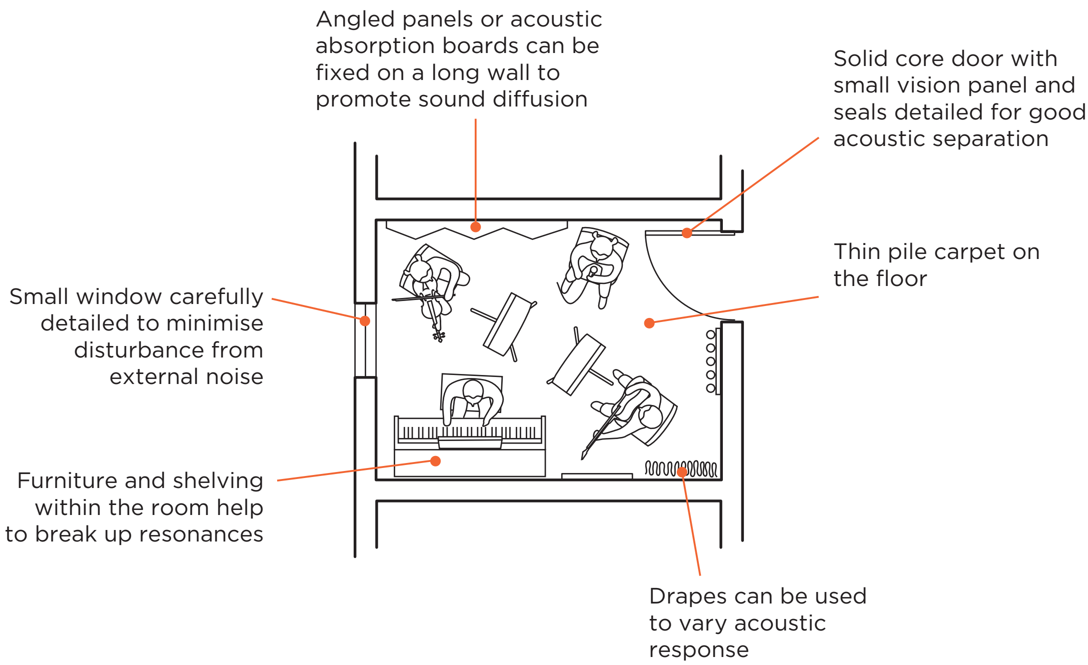



**Figure 5.10: Acoustic treatment to 8 m² group room with parallel walls**

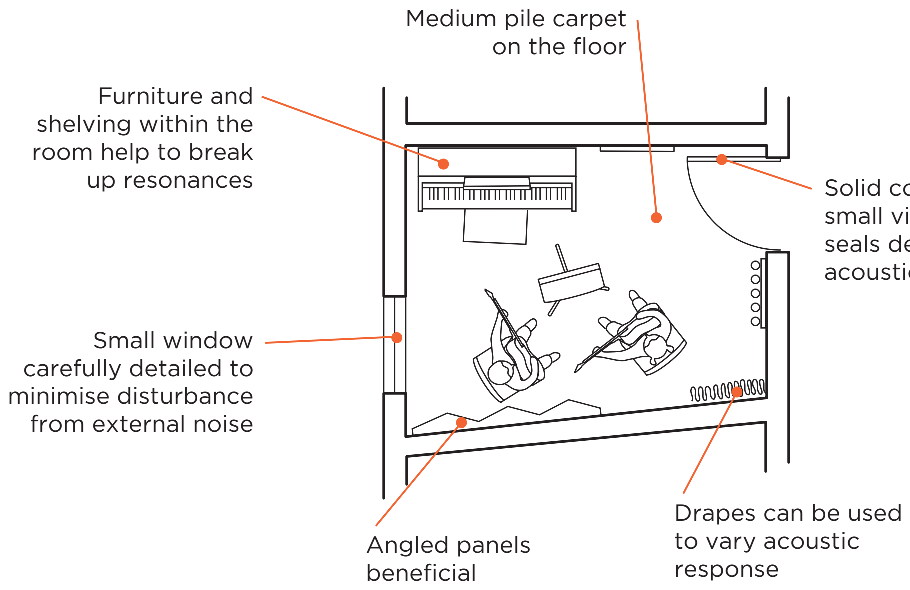



**Figure 5.11: Acoustic treatment to 8 m² group room with angled walls**

## 5.5.4 Ensemble rooms

Figure 5.12 shows a plan of a 25 $m^2$ ensemble room. In terms of shape, the same rules apply as for larger music spaces. Ceilings should be high, of the order of 3 m or more. Surface finishes may comprise carpet on the floor, a suspended plasterboard ceiling to provide the necessary bass absorption, and a mixture of hard and absorptive wall finishes to provide the required RT. An acoustic drape along one wall can provide a degree of acoustic variability.

## 5.5.5 Control rooms for recording

Control rooms for recording have assumed a much greater significance due to the need to prepare recordings of compositions for GCSE assessment. Figure 5.13 shows an 11 $m^2$ control room for recording. A teacher or pupil can record a music performance taking place in an adjacent space, after which the recording may be heard on headphones or loudspeakers. The maximum RT specified in Table 1 of Building Bulletin 93 is 0.5 s.

Notable aspects of the acoustic treatment are as follows.

1. Sound absorbing panels on the walls behind the monitor loudspeakers are used to control strong early sound reflections which could distort loudspeaker sound.
2. Shelving units on the window wall provide surface diffusion.
3. Drapes are fitted on all three observation windows. If a curtain is pulled across one window, problems of flutter echoes and prominent resonances associated with two facing hard parallel surfaces are reduced. Ideally, the effect can be avoided by installing glazing in one of each pair of windows at 5° off parallel. Drapes can also provide additional privacy, if required.
4. The external window is small to minimise disturbance from external noise. A venetian blind can be used to control sunlight, or a blackout blind may be provided if required.
5. The floor is carpeted.
6. Figure 5.6 shows a detail of a typical control room window. Two panes

of heavy plate glass (of different thicknesses to avoid the same resonances) are separated by an air gap of about 100-200 mm. Such a large gap may not always be possible but 50 mm should be considered a minimum. Each pane of glass is mounted into a separate frame to avoid a direct sound path. The glass is mounted in a neoprene gasket to isolate it from the wooden frame. Acoustically absorbent material, such as mineral wool or melamine foam, is incorporated into the reveal to absorb any energy that enters the air gap.

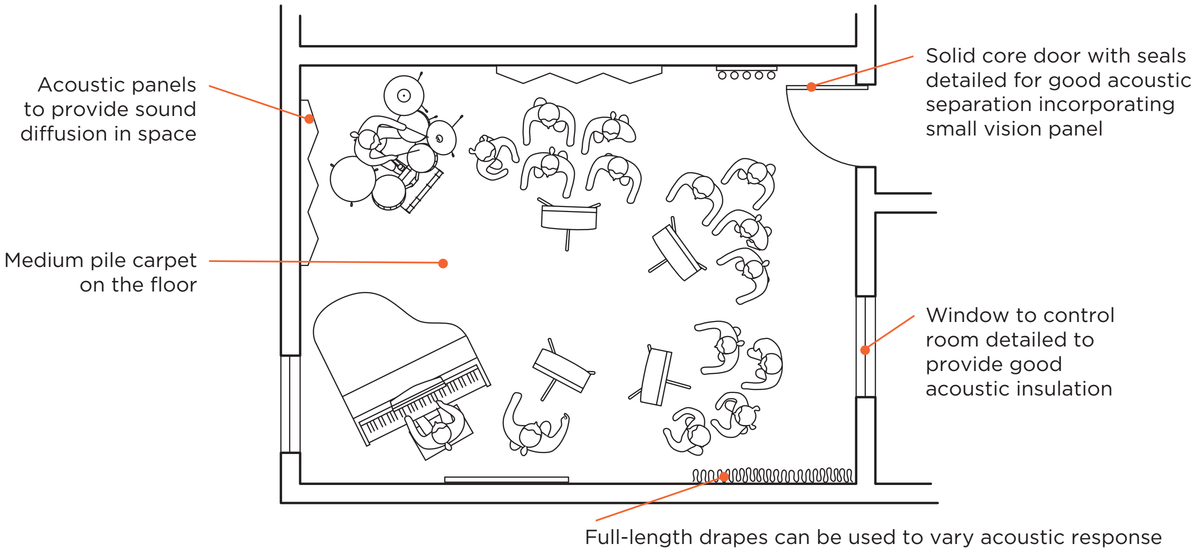



**Figure 5.12: Acoustic treatment to 25 m² ensemble room**

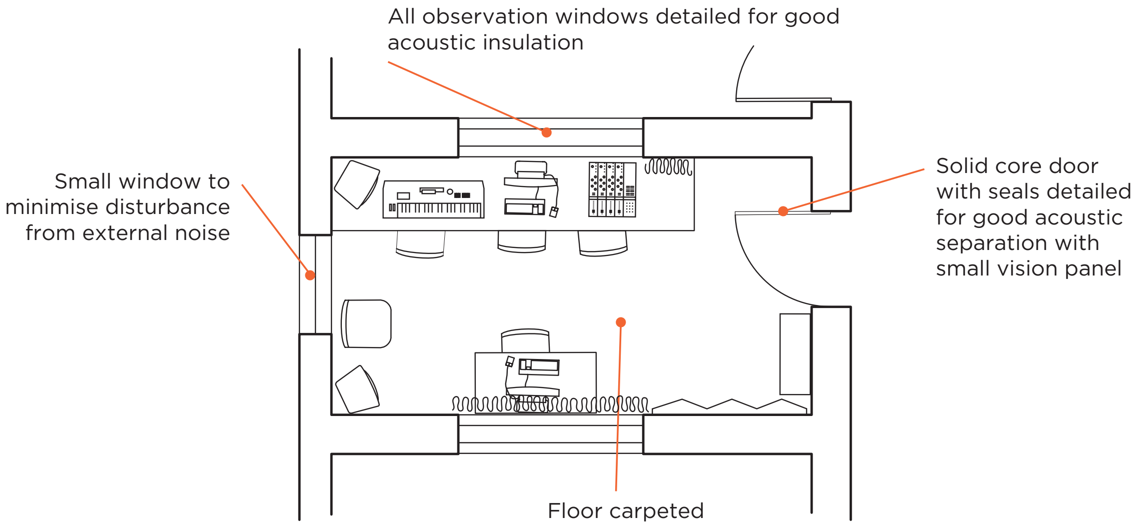



**Figure 5.13: Acoustic treatment to recording/control room**

### 5.5.6 Recording studios

A recording studio as such rarely exists in a school. The control room for recording may have an observation window onto an ordinary ensemble room or professional/recital room. A professional type recording studio would require a lower indoor ambient noise level than that given in Table 1 of Building Bulletin 93, and specialist advice should be sought.

### 5.5.7 Audio equipment

The design and selection of recording equipment and audio systems is a fast evolving subject and guidance on specific technologies would be rapidly out of date. Although members of staff within a school will have their own preferences for specific items of equipment, these may be based on experience of only a few systems and alternatives should at least be considered. Advice from an independent designer or consultant familiar with the full range of available equipment should be sought.

## 5.6 Acoustic design of large halls to include music performance

Large halls designed primarily for music are rare in schools; the main use of any large hall is likely to be multi-purpose, where activities include assemblies, drama performance and dance, as well as music. If a purpose-built concert hall is required, a specialist acoustician should always be consulted early in the project.

### 5.6.1 Multi-purpose with design bias to music

A good approach for a multi-purpose hall where music will be a major activity is to design the hall for music and provide variable acoustics to cater for speech. This section sets out some general principles that can be considered at the concept stage of designing a hall mainly for music use, together with guidelines on the design of fully multi-purpose halls.

The key acoustic requirements are sufficient volume to provide adequate reverberation and a shape that will provide a uniform sound field. These and other considerations are outlined below.

#### Shape

A rectangular plan is the best shape acoustically, because the sequence of sound reflections from stage to listener is close to ideal, and because it is usually the least expensive to build and the most reliable in practice.

In terms of proportions, dimensions approximating to a double cube are good, giving rise to the traditional 'shoebox' shape.

A balcony helps to increase both visual and aural intimacy, but any overhangs must be kept to a minimum. Figure 5.14 indicates the maximum extent of an overhang so that good acoustic conditions are maintained beneath it.

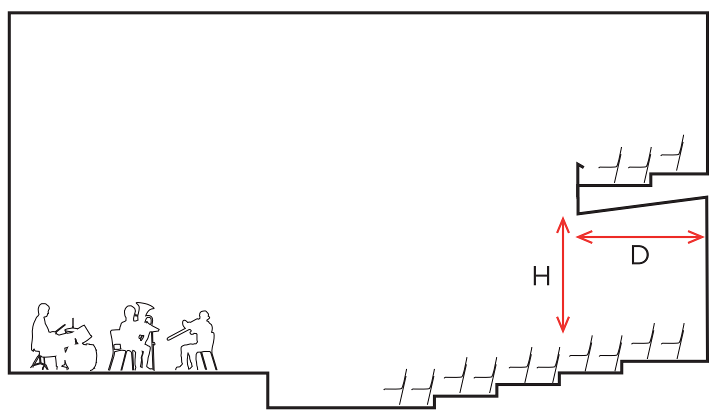



Figure 5.14: Recommended balcony overhang proportions: the depth D should not exceed the height H

An alternative to the rectangular plan shape is the elongated hexagon. This can also provide good visual and acoustic intimacy.

In terms of ceiling shape, a flat ceiling with some surface modelling is appropriate; a steeply pitched ceiling (around 45°) along the main axis is also good. Shallow pitches should be avoided, because they can cause flutter echoes between the flat floor and the ceiling.

Shapes with concave surfaces, such as domes and barrel vaults, are best avoided because they cause focusing of sound, which can result in problematic acoustics. Where concave surfaces are unavoidable and cause a focus near the audience, or performance area, heavily absorbing or diffusing elements will need to be used.

### Volume

A suitable volume to aim for is 8 $m^3$ per audience member. This gives, for example, 2800 $m^2$ for an audience of 350, based on a plan size of 300 $m^2$. This volume will provide an RT of around 1.5 s.

### Surface finishes

Appropriate surface finishes are generally hard and acoustically reflective, for example a wood floor, masonry walls and timber ceiling. Almost all the acoustic absorption is provided by the audience and seating.

Where there is no fixed seating, acoustic drapes should be provided on the rear wall and side walls. These can be extended to control reverberation in rehearsal conditions when the seats are removed. Drapes will also provide suitable conditions for speech-based activities, and when amplified music is being played.

### Seating rake

A seating rake is beneficial, because it provides better sightlines; this also improves the acoustic quality for listeners. A rake of 8° is suitable, although a steeper rake is possible. However, the rake should not be too steep, because musicians and singers find it difficult performing into a highly absorbent block, i.e. the audience, which gives them very little feedback from the hall.

## 5.7 Fully multi-purpose halls

Guidelines for the design of fully multi-purpose halls are similar to those where music performance is extensive, except of course that the halls have to cater equally for drama, dance, assemblies, examinations and so on. A range of configurations for a multi-purpose hall is shown in Figure 5.15.

The two key areas in which the design of a multi-purpose hall varies from that of a music space are volume and the provision of variable absorption.

In terms of volume, it is recommended that a slightly lower figure be aimed for compared with music spaces, namely 6-7 $m^3$ per audience member; this will provide an RT of around 1.2 s, which helps to ensure an effective changeover from music to speech using a variable acoustics system.

Variable acoustics in multi-purpose halls in schools are usually provided by acoustic drapes (see section 5.5.1). These should be deployed on the side walls and rear wall of the hall, and should cover a wall area that is approximately equivalent to the seating area. Theatrical drapes around the stage can form part of the total acoustic drape requirements.

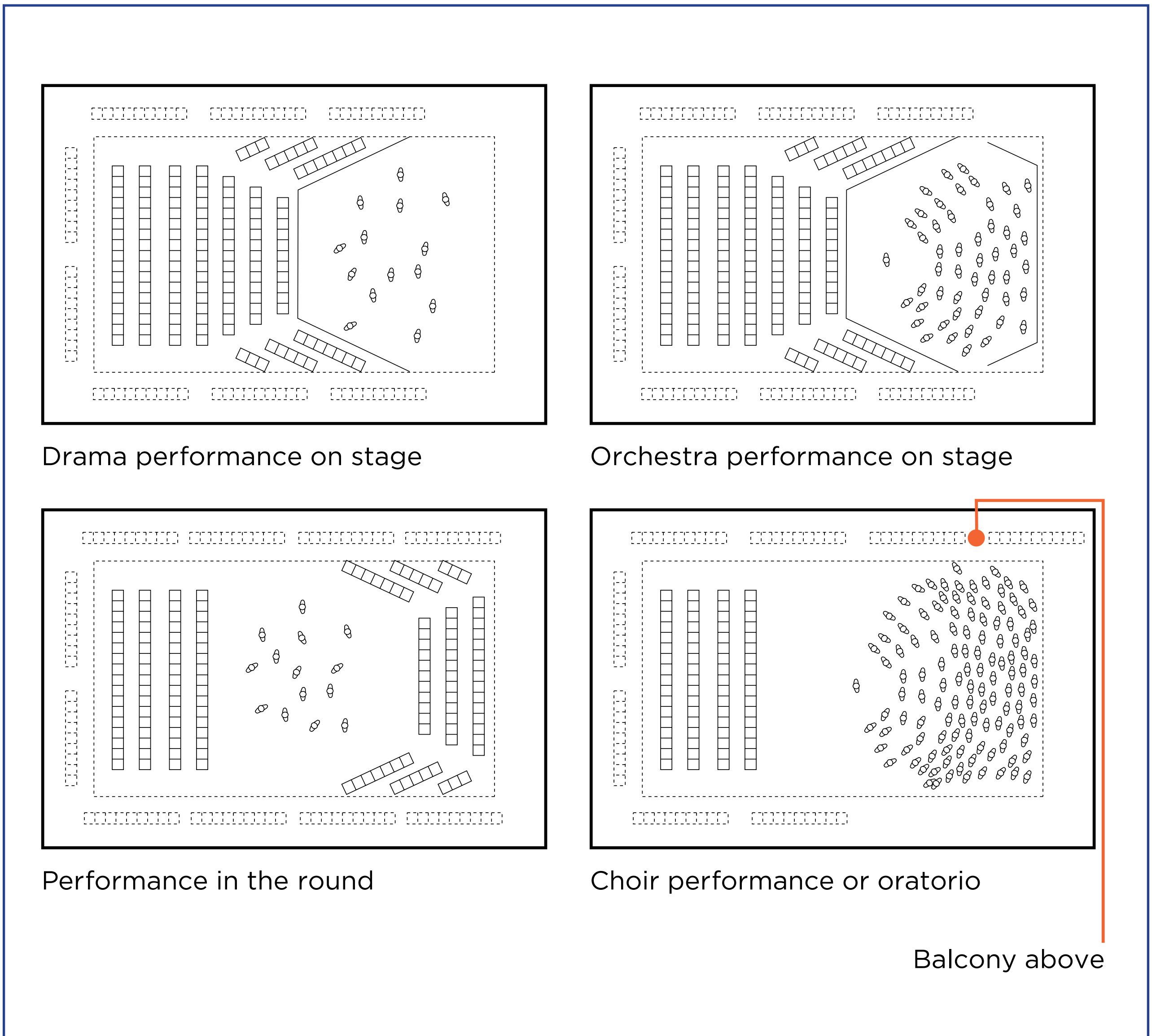



**Figure 5.15: Various configurations of a multi-purpose hall for performing arts**

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# Chapter 6 Acoustic design and equipment for pupils with special hearing requirements

## 6.1 Pupils with special hearing requirements

The drive towards inclusive schooling in recent years has meant that the majority of pupils with special hearing requirements are likely to be educated within a mainstream setting. Recent surveys of the school population show that about 85% of pupils with a permanent hearing impairment are educated in mainstream schools.

Favourable acoustic conditions will benefit large numbers of pupils within mainstream schools who have special hearing requirements. These include pupils:

- with permanent hearing impairment
- with speech, language and communication difficulties
- whose first language is not English
- with visual impairments
- with fluctuating hearing impairments caused by conductive hearing loss
- with attention deficit hyperactivity disorders (ADHD)
- with autistic spectrum disorder (ASD)
- with an auditory processing disorder or difficulty.

Together, the number of pupils falling into one or more of these categories could conceivably be a significant proportion within every mainstream classroom. It is therefore important to consider every teaching and learning space as being one where there are pupils who have special hearing requirements.

## 6.2 The acoustic environment and pupils with permanent hearing impairments

The majority of pupils with permanent hearing impairments use speech and hearing as their main form of communication. A survey by the British Association of Teachers of the Deaf (BATOD)[1] indicated that 67% of pupils with hearing impairments were using an auditory-oral approach and a further 26% used an approach which combined sign with auditory-oral components. For these groups in particular a poor acoustic environment can be a significant barrier to inclusion.

A hearing loss is typically described with reference to the audiogram. This is a graphical representation of an individual's threshold of hearing for a number of pure tones (typically measured at 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz) presented to each ear using headphones. At face value, it suggests that the hearing impairment can be considered as a simple auditory filter and as such should predict a pupil's understanding of speech using traditional acoustic models. Although easy to measure reliably, it says little about an individual's hearing for speech or the key skill of listening to speech in background noise. The audiogram is not a good predictor of educational outcome[2] and only a poor predictor of speech recognition score[3]. Consequently, great care should be taken when considering the audiogram of a pupil as a predictor of the difficulties the pupil might have in a school environment. Pupils with similar audiograms can differ considerably in their ability to hear speech in normal listening environments.

At present there is little empirical data that specifically addresses the acoustic criteria required for the hearing impaired school population (see for example the review of the literature by Picard and Bradley[4]). What is currently available, however, suggests that the individual hearing needs of a hearing impaired pupil are likely to be significantly more demanding than those of pupils with normal hearing.

Ideally therefore, a professional audiologist and acoustician would specify the appropriate classroom acoustic conditions for each pupil with a special hearing requirement. They should have measures of the pupil's hearing available, including acceptable levels of noise, desirable reverberation times and appropriate signal to noise levels. These measures will help to specify an appropriate acoustic environment for each individual pupil.

In practice, however, this is rarely practicable and, for the purposes of school design, Building Bulletin 93 includes acoustic criteria for teaching spaces intended for pupils with special hearing and communication needs. These are designed to accommodate the majority of pupils with such needs in mainstream schools. Rooms meeting these criteria will not necessarily be suitable for all pupils but it can generally be assumed that pupils with special hearing and other communication needs should be taught in rooms which meet these criteria. The criteria are informed by the recommendations of BATOD and the American Speech-Language-Hearing Association (ASHA) which, for information and comparison, are listed in Table 6.1.

**Table 6.1: Comparison of BATOD and ASHA criteria**

| Acoustic Parameter | British Association of Teachers of the Deaf [5] | American Speech- Language-Hearing Association [6] |
|---|---|---|
| Unoccupied sound level | ≤ 35 dBA | ≤ 35 dBA |
| Reverberation Time (unoccupied) | ≤ 0.4 s across frequencies 125 Hz to 4000 Hz | ≤ 0.6 s for smaller rooms (< 10,000 $ft^3$)<br><br>≤ 0.7 s for larger rooms (≥ 10,000 and ≤ 20,000 $ft^3$) |
| Signal to Noise Ratio | > 20 dB across the frequency range 125 Hz to 750 Hz<br>> 15 dB across the frequency range 750 Hz to 4000 Hz | ≥ 15 dB |

## 6.3 Special hearing requirements

Modern hearing aids and cochlear implants (CIs) are designed to make speech audible to the listener without being uncomfortably loud[7]. They deal largely with the issue of audibility, but are less able to address the issues of distortion that typically accompany permanent hearing impairments. One of the major challenges in the design of hearing aids is dealing with unwanted noise.

Recent developments include the use of algorithms that are designed to enhance speech whilst reducing background noise, and better implementation of directional microphones. However, noise will continue to remain a significant obstacle to effective listening. Noise not only masks the speech signal, making it difficult to understand what is being said, but also leaves a pupil tired from the effort required to listen. It is therefore essential that attention be given to creating a quiet classroom.

This requires insulation against noise from outside the school, sound insulation between rooms, control of noise from plant and equipment inside the classroom, and control of reverberant noise within the room. These will help to ensure that a good signal to noise level can be achieved. Typically a signal to noise level of at least +20 dB is considered desirable[5].

Care must also be taken to ensure that the level of low frequency noise is kept to a minimum. For many people with special hearing requirements, low frequency noise can have a substantial impact on speech recognition, masking important speech sounds in a manner that cannot be appreciated by those with normal hearing.

Effective acoustic absorption within the teaching space is required which will lead to short reverberation times, particularly at low frequencies. This is essential to ensure that reverberant sound does not build up when pupils are working in groups, or more than one person is talking at any one time.

## 6.4 The speech signal and hearing aids in educational settings

### 6.4.1 Accessing the teacher's voice

Speech is a critical factor in classroom listening and one important speech source is the teacher. Evidence has shown that teachers' voices are not always sufficiently powerful to deliver the necessary levels of speech required to ensure the best listening opportunities[8].

A growing body of evidence also suggests that teachers are at above-average risk from voice damage[9]. Few teachers have voice training and the vocal demands of teaching are probably underestimated. Hearing instruments such as hearing aids and cochlear implants are usually set up to amplify a 'typical' speech signal based on various measures of the long-term average speech spectrum. If the actual speech signal is weaker than average, perhaps because of distance, or is masked by babble or steady state background noise (such as that from a classroom computer fan or data projector), then the listener with special hearing requirements will have increased difficulty listening. Listening to speech will become particularly challenging[10].

### 6.4.2 Accessing the speech of other children

Pupils are not only required to listen to the teacher but also to each other. Children typically have less powerful speaking voices than adults[8] and listening to their peers is frequently identified by pupils with special hearing requirements as being difficult.

One study suggests that 38% of a pupil's time in the primary classroom might be spent working in groups and 31% of the remaining time spent in mat work[11], both situations where listening to other pupils is important. Establishing low reverberation times and maintaining low noise levels is essential in order to reduce auditory difficulties.

To minimise the challenges to hearing, use is often made of small, acoustically treated rooms attached to the mainstream classroom. These rooms are typically large enough for a group of four to eight pupils to work in. The favourable acoustic conditions and short distances between pupils and teacher, or support staff, ensure that communication is as easy as possible. To allow supervision by the class teacher, they will have a large window to provide a clear view into the classroom. These rooms must have sufficient sound insulation from the classroom to allow the pupils to talk to each other without being disturbed by or disturbing the rest of the class. Where, for operational or safety purposes, it is essential to link a pair of teaching spaces via an interconnecting door, this should be a doorset with a rating of at least 35 dB $R_w$. The surrounding wall containing the doorset should have a sound insulation rating of at least 45 dB $R_w$.

## 6.5 Listening demands within the classroom

Much of the educational activity within classrooms revolves around speech. It is important that, within any room, the acoustic characteristics allow for effective spoken language communication. The UK version of the Listening Inventories for Education[12] identifies the following listening demands within the classroom:

- listening to the teacher when s/he is facing away from the listener
- listening when the class is engaged in activities
- listening to the teacher while s/he is moving around the classroom
- listening when other pupils are answering questions
- listening when other adults are talking within the same room
- listening to peers when working in groups
- listening when there is competing background noise from multimedia equipment.

A teacher should manage teaching in such a way that challenges faced by pupils with special hearing requirements are ameliorated. However, the better the acoustic conditions, the less challenging will be the situations described above.

## 6.6 Strategies developed to assist pupils with hearing and listening difficulties

Effective classroom management by the teacher is critical in ensuring that the pupils can have access to all that is spoken and there are many guidelines available for teachers[13, 14, 15].

Classroom management alone, however, cannot ensure that speech communication is sufficiently audible and intelligible if the classroom acoustics are not adequate, or if a pupil has a particularly demanding special hearing or communication requirement. In order to ensure that pupils are able to hear the teacher and their peers, a number of technological solutions have been developed. Table 6.2 lists the most commonly used of these, together with the advantages and disadvantages of each solution.

**Table 6.2: Advantages and disadvantages of commonly used technological solutions**

| Technology | Advantages | Disadvantages |
|---|---|---|
| Personal radio aids | Reduce the effect of the distance between speaker and listener<br>Portable and convenient<br>Particularly useful in situations where there is a poor signal to noise ratio at the position of the listener | Do not address the needs of group work directly<br>Can require a high level of sophistication to gain maximum benefit<br>Benefits can be lost if the pupil's personal hearing aid microphones are used in noisy environments |
| Classroom soundfield systems | Reduce the effect of the distance between the speaker and listener<br>Inclusive technology<br>Benefit to the teacher and the class<br>Can ensure improved signal to noise levels are maintained throughout the classroom | Do not address the needs of group work directly<br>Poor classroom acoustics (eg high reverberation times or poor sound separation between neighbouring teaching areas) can limit the benefit of this technology<br>Might not provide adequate benefit alone for pupils with more demanding auditory needs |

| | | |
|---|---|---|
| Personal soundfield systems | Portable<br>Address the issue of speaker to listener distance<br>Can ensure favourable signal to noise levels for a particular listener or small group of listeners | Can be cumbersome to transport and manage<br>Do not address the needs of group work directly<br>May not provide adequate signal to noise levels for more demanding auditory needs |
| Auditory trainers and hard wired systems | Provide excellent signal to noise levels<br>Work with hearing instruments and cochlear implants<br>Provide a high level of sound insulation<br>Can be arranged to allow group work<br>Most typically used in schools for the deaf | Users are restricted in movement when using the device<br>Can be heavy and uncomfortable to use when used instead of hearing instruments |
| Induction loop systems | Discreet and cheap<br>Most hearing aids have a telecoil facility<br>Useful for visitors and rooms that are used for community activities | Unpredictable acoustic response for the hearing aid user<br>Spill over of signal into other rooms<br>Do not deal with the needs of group work<br>Susceptible to electromagnetic interference<br>User normally isolated from environmental sounds<br>Not considered appropriate for classrooms. |

Solutions that work in tandem with the pupil's own hearing aids or cochlear implants can be classified as either 'individual technology' or 'whole class technology'. In both of these cases it is important to understand the underlying principles when specifying classroom acoustics.

## 6.7 Individual technology

There are two main types of aid that can be used to assist pupils' hearing on an individual basis: radio aid systems that can be coupled to a pupil's hearing aids, and auditory trainers that are used with headphones or feed directly into the open ear canal.

### 6.7.1 Radio aids

Radio aid systems (also known as personal FM systems) are widely used by pupils with special hearing requirements in schools. They help reduce the causes of listening difficulties in a classroom by

- enhancing the signal to noise ratio
- reducing the impact of unhelpful reverberation
- maintaining a constant signal level irrespective of distance between the speaker and the listener.

All radio aid systems have two main components: a transmitter and a receiver. The person who is speaking (usually the teacher) wears the transmitter. A microphone picks up their voice. A variety of microphones is available and can be worn as a headset or attached to the lapel of the speaker. In classrooms where there is likely to be noise generated by the pupils then the headset microphone is preferable. Speech is then transmitted by a radio signal to the receiver, which is worn by the pupil. The receiver converts the signal to a sound that the pupil can hear. Recent systems allow more than one radio transmitter to be used with a single receiver.

Radio aid systems are usually used in conjunction with the pupil's own hearing instruments. There are also personal radio systems designed to be used by pupils who do not use hearing instruments but require the benefits that a radio aid can provide.

Most radio aid systems can be set up so that the pupil will hear not only the voice of the speaker using the transmitter, but also other sounds such as their own voice and the voices of other pupils near to them. Radio aid systems can do this in a number of different ways and it is often necessary to strike a balance between allowing the pupil to hear the voice he or she needs to listen to and the impact of hearing unwanted background noise. The sounds heard by a pupil using a radio aid system will depend on the quality and correct use of their own hearing instrument. The level of amplification is usually determined by the settings of the hearing instrument, not the FM system. A general principle is that if a pupil uses a hearing instrument, then the pupil is also likely to find a radio aid helpful.

Radio aid systems have often been seen as the solution to poor acoustics in the classroom. However, it must be noted that they only partially address the problem; any solution must lie in addressing the issue from three directions:

- the class teacher and classroom management
- technology that assists listening
- attention to classroom acoustics.

Current information about radio aid systems is available from a number of sources including the National Deaf Children's Society[16, 17, 18].

### 6.7.2 Auditory trainers and hardwired systems

An auditory trainer is a powerful amplifier used with high-quality headphones. As a large, stand-alone piece of equipment, an auditory trainer can be designed without the restrictions of size that exist with typical behind-the-ear hearing aids, and a good quality high level sound output with extended low and high frequency range can be achieved. Within the mainstream educational environment, auditory trainers are most likely to be used for short periods of individual work and speech therapy sessions. However, it is also possible to link several auditory trainers together for group work. In some schools for deaf pupils this equipment is permanently installed within a classroom. The teacher's voice is picked up by a microphone and the output is available at every desk. Each pupil wears headphones that are configured to meet their individual amplification requirements. The pupils may also wear microphones to enable everyone in the class to participate in discussions.

## 6.8 Whole class technology

The use of a personal system is sometimes essential for a pupil with special hearing requirements to be able to succeed in a particular environment. There is also a trend to use the inclusive technology termed 'soundfield amplification' to ensure that the signal level of the speech is delivered to all parts of the classroom at an appropriate level. This technology is of benefit to all pupils in the classroom, not just the hearing aid or cochlear implant user, and has particular benefits for classroom management and the voice of the class teacher.

It is important to note that whole class technology is not a substitute for remedying poor classroom acoustics, and poor room acoustics can limit the effectiveness of such systems. However, it can be particularly valuable in maintaining good signal to noise levels and improving classroom management. Soundfield amplification systems can also be used in conjunction with radio aid systems. In situations where a pupil with special hearing requirements is part of a mainstream class, advice should be sought from members of a relevant professional group (educational audiologist, clinical audiologist or teacher of the deaf) as to the most appropriate technology.

### 6.8.1 Whole classroom soundfield systems

Soundfield systems provide distributed sound throughout a classroom and should always be optimised for their intended use. They use a wireless link between the microphone and amplifier which will operate on VHF, UHF radio or infra red frequencies. Soundfield systems have been shown to be beneficial to hearing impaired pupils and pupils with a mild or temporary hearing loss. They will not usually provide sufficient improvement in signal to noise ratio for a pupil with a significant hearing requirement. In these situations a personal radio aid is also required.

A soundfield system is perhaps more widely known as a sound reinforcement system; the term soundfield system originated from the field of audiology and continues to be associated with classroom sound reinforcement systems. The technology has matured since it was first introduced into classrooms in the late 1970s in the USA, and has evolved to take into account new technologies and teaching management styles. Its benefits have been variously described as:

- academic improvements for all class members
- more on-task behaviour
- greater attentiveness
- improved understanding of instructions
- less repetition required from the teacher
- improved measures of speech recognition
- reduced voice strain and vocal fatigue for the teacher.

However, some authors have questioned the benefits claimed and found little difference in student performance in amplified and non-amplified rooms[19].

### 6.8.2 Induction loop systems

Induction loop systems take advantage of the telecoil facility available with most hearing aids and cochlear implants. A telecoil is a small receiver capable of picking up audio frequency, electromagnetic signals. It is usually activated by setting a switch on the hearing aid to the “T” position. An induction loop system comprises a sound input (usually a microphone), an amplifier and a loop of cable which is run around the area in which the system is to be used. The loop generates an electromagnetic field which is picked up by the telecoil in the hearing aid. The hearing aid user will hear the sound while they are within the looped area.

Induction loop systems have many applications, from large-scale installations in theatres and cinemas to small, domestic products used to listen to the television. In the UK they are rarely used in a classroom setting. Alternatives such as radio aid systems offer improved and more consistent sound quality and are less susceptible to interference. Induction loop systems can also be difficult to use in multiple applications, as the signal from one area can overspill into another.

In schools, induction loop or infra red hearing aid systems should be considered in large assembly rooms or halls. This is primarily for visitors to the school rather than for pupils themselves, who would normally have their own personal assistive listening equipment. They should also be considered in performance spaces, meeting rooms and at reception area desks. In such situations the output from an existing PA system is often connected directly to the loop amplifier. Public telephones in schools should have inductive couplers (a form of induction loop). Induction loop systems should be installed in accordance with British Standard BS 7594[20]. Their advantages and disadvantages are listed in Table 6.2.

### 6.8.3 Audio-visual equipment

Wherever possible, classroom equipment should be integrated with any hearing instruments used by pupils. For example, the audio output from audio visual equipment, televisions, CD players and IT equipment, such as classroom interactive whiteboards, can be connected to radio aid or soundfield transmitters. 'Direct input' leads are available to enable the audio output of computers, or language laboratory equipment to be connected directly to a pupil's hearing aid.

### 6.8.4 Other assistive devices

There is a wide range of devices that can be used by pupils with special hearing requirements in school, besides those that primarily assist listening. These include subtitled and signed video, speech recognition software, palantype and text telecommunication devices. For further details of these devices contact the professional or voluntary organisations listed at the end of this section. Furthermore, it is recommended to seek advice to ensure that all public spaces in a school meet the needs of those with special hearing requirements.

## 6.9 Special teaching accommodation

It is not the intention of this document to address the acoustic design of special schools for hearing impaired pupils and specialist advice should always be sought from an educational audiologist and a specialist acoustician when designing or modifying accommodation for this particular purpose.

Many hearing impaired pupils and other pupils with special hearing or communication requirements attend mainstream schools with resource provisions, sometimes called 'units', or resource bases. These contain specialised rooms which should, as a minimum, be built to the standards for such rooms as set out in Building Bulletin 93. Within these rooms, pupils are able to learn the language skills that might not be possible in a busy mainstream classroom. They are also places where pupils can interact within a favourable acoustic environment. Teachers and support professionals might also use the areas for a range of activities involved in the audiological management of hearing impaired pupils.

It is not uncommon for these rooms to be used for 'reverse integration', where pupils from the mainstream work with hearing impaired pupils. Occasionally this specialised provision may be directly attached to a mainstream class in the form of a 'quiet room' leading from the classroom. Such rooms must have sufficient sound insulation from the classroom to allow the pupils to talk to each other without being disturbed by or disturbing the rest of the class. In other situations the accommodation might be a separate room or even building.

Specialised facilities are not a substitute for addressing the listening needs of pupils taught in regular classrooms. In situations where a pupil with special hearing requirements needs to be in a particular classroom or teaching space, their auditory needs must be met in the environment in which they are taught.

The characteristics of rooms in a Resource Provision for the Deaf (RPD) are:

- excellent sound insulation
- very short reverberation times
- very low ambient noise levels
- flexible space for individual and small group work

- good lighting
- storage facilities for audiological equipment.

## 6.10 Beyond the classroom

Pupils with special hearing requirements should be included in all school activities according to the Equality Act 2010[20]. Improving listening conditions through better acoustics is a very important part of this, but is not the only relevant factor. There are many others including teaching style, class management, staff training in special hearing requirements, and a whole school approach to promoting inclusive practice.

Classrooms are not the only places where hearing impaired pupils interact. It is often overlooked in school design, but critical learning and interaction takes place outside the classroom and, if hearing impaired pupils are to be fully included, attention should be given to all areas of the school where the pupils might be expected to interact with others. These include rooms where aspects of the curriculum are delivered: libraries, assembly areas, sports halls, gymnasia, music rooms and ICT suites. The need for good speech communication is essential in these areas, but can be constrained by the activities taking place. Inclusion in most music activities, for example, requires good acoustic conditions, good planning and structuring of lessons, and the appropriate use of assistive listening devices.

Perhaps the most difficult areas for inclusion are large spaces, such as assembly halls and sports halls. These areas require careful design and forethought. Pupils still need to be able to interact verbally in other areas not designated for delivering the curriculum. These include the corridors, cloakrooms, medical rooms, school offices, dining areas, play areas and toilets. Important social interaction often takes place in these communal spaces and, if inclusion is to be effective, they need to be designed with consideration of the acoustic needs of the hearing impaired pupil and the pupil with special listening difficulties.

## Organisations

| | |
|---|---|
| British Academy of Audiology | www.baaudiology.org |
| British Association of Educational Audiologists | www.educational-audiologists.org.uk |
| British Association of Teachers of the Deaf | www.batod.org.uk |
| British Society of Audiology | www.thebsa.org.uk |
| National Deaf Children's Society | www.ndcs.org.uk |
| Action on Hearing Loss (formerly the Royal National Institute of the Deaf) | www.actiononhearingloss.org.uk |

## Glossary

| Term | Explanation |
|---|---|
| Auditory-oral approach | An umbrella term for approaches to the education of pupils with hearing impairments that seeks to promote the acquisition of spoken language using residual hearing. |
| Residual hearing | A term used to describe the hearing abilities that remain in the case of a hearing impairment. |
| Hearing Instrument | Also known as a hearing aid. It is a battery powered device worn by an individual, either behind the ear or in the ear. A hearing instrument will be selected and programmed to provide the maximum audibility of the speech signal consistent with an individual's residual hearing. If a radio aid is to be used with a hearing instrument then this will need to be set up by an audiologist during the programming of the device. |
| Cochlear implant | A special kind of hearing aid where the inner ear is directly stimulated electrically via an implanted electrode. |
| Central auditory processing difficulty | A broad term used to describe listening difficulties, which are not due to the outer, middle or inner ear. |
| Radio aid | Also know as a personal FM system. It is an assistive listening device, designed to provide an FM radio link between a transmitter (usually on the speaker) and the listener (coupled directly to the hearing aids). |

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# Chapter 7 Design of open plan teaching spaces

## 7.1 Introduction

In order to comply with the School Premises Regulations it is necessary to consider speech intelligibility in open plan spaces.

For enclosed teaching and study spaces it is possible to achieve good speech intelligibility by control of the indoor ambient noise level, sound insulation and reverberation time. Open plan spaces require additional specification as they are significantly more complex acoustic spaces. The main issue is that intrusive noise arising from activities in adjacent learning areas and circulation spaces significantly increases the background noise level, which in turn decreases speech intelligibility and causes distraction. Occupants working and talking within the space tend to raise their vocal effort as the background noise level increases, resulting in a spiralling increase in noise levels, unless sound absorbent finishes are provided.

Open plan spaces are generally designed for high flexibility in terms of the layout of teaching and study areas. However, achieving maximum flexibility usually requires provision of a mixture of both open and enclosed spaces to provide appropriate listening conditions for the diversity of learning activities and learners' needs.

Open plan teaching and learning spaces call for the commitment of end users to co-ordinate and manage activities in adjacent teaching and learning spaces and circulation areas, in order to control intrusive noise levels. Users of the space cannot reasonably expect to use open plan areas in the same way as cellular types of accommodation, whilst maintaining the same degree of privacy.

It should be noted that in practice it is unlikely that well designed open plan schools provide a significantly more cost-effective solution than enclosed classroom designs since the cost of providing sufficient area per student and additional acoustic treatment for open plan designs outweighs any savings achieved from removal of walls.

## 7.2 Criteria

Open plan spaces need to satisfy criteria for speech intelligibility in order to comply with the School Premises Regulations. These criteria are to ensure ease of speech and understanding within open plan teaching areas, and to maintain privacy within individual teaching groups.

Table 7.1 contains the performance standards for speech intelligibility and speech privacy in open plan spaces to comply with the School Premises Regulations.

**Table 7.1: Performance standard for STI in open plan spaces**

| Activity | STI |
|---|---|
| Instruction or critical listening activity, within a group | ≥ 0.6 |
| Critical listening activities, between groups | ≤ 0.3 |

The STI criterion 'within a group' applies to speech transmitted from teacher to student, student to teacher and student to student. The STI criterion 'between groups' applies to the speech signal transmitted from one teaching space to an adjacent teaching space.

In the absence of full partitioning to control sound transmission, it is essential to control reverberation times and reverberant sound levels as far as possible, to cope with the reduced signal-to-noise ratio due to higher intrusive noise. For this reason shorter reverberation times are required in open plan classrooms compared with enclosed classrooms.

In practice the reverberation time should be as short as possible. The maximum mid-frequency reverberation time criterion for open plan teaching and learning areas, as specified in Building Bulletin 93, is 0.5 seconds, and 1.2 seconds in larger volume open plan resource/breakout areas.

A moderate level of ambient noise (from sources other than teaching activity) is recommended in open plan spaces to help mask speech noise transmitted from other areas. The Lombard effect (which causes the speaker to raise their vocal effort as the background noise level increases) does not take effect until the background noise level exceeds 45 dBA. A reasonable ambient noise level target is 40 dBA[1] to provide some masking of speech noise from adjacent spaces, whilst avoiding any detrimental impact on speech intelligibility within the main classbase.

### 7.2.1 Enhanced criteria

Although the standards shown in Table 7.1 are those required for compliance with the School Premises Regulations, more stringent standards may be preferable in certain circumstances.

Enhanced minimum STI criteria (for example 0.75 STI within groups) may be appropriate for pupils with special listening requirements, such as hearing impaired students, very young children and students with English as an additional language (depending on linguistic experience)[2-6].

It should be noted that it is unlikely to be possible to achieve these enhanced STI criteria in all open learning spaces at all seating positions, even with good acoustic design. Therefore it is important to provide enclosed quiet rooms alongside any open space learning areas to maximise flexibility and options for personalised, inclusive learning, particularly for pupils with more demanding listening requirements.

### 7.2.2 Exceptions

In some instances, open plan learning areas may not be intended for multiple and simultaneous independent instruction or critical listening activities. For example, critical listening activity may only occur as a single, plenary session, followed by 'breakout' activity sessions. These breakout sessions may involve personal listening activities (for example one-to-one or small group instruction, paired or small group work) or individual study.

For personal listening activities, speech intelligibility is usually less critical, owing to one or more of the following:

- reduced communication distance
- reduced message urgency
- more opportunity to repeat spoken message
- reduced occurrence of speech communication (e.g. for individual work).

The acoustic objectives for this scenario are a) to ensure sufficient speech intelligibility during the plenary session and b) to control the build-up of speech noise caused by raising vocal effort above the background noise level during breakout sessions.

In this case, the STI should be predicted for the plenary session via computer modelling, and the space may be deemed satisfactory for breakout session mode if it can be shown that STI ≥ 0.6 within the group.

## 7.3 Planning

Open plan spaces are generally designed for flexibility of use in the short term and adaptability in the long term, yet the need for flexibility should be balanced with the need for good acoustics, to ensure effective learning. Research has shown that in many large open plan 'flexible' areas certain activities are severely restricted, or have to be dropped, because of noise interference.

The management team will need to make decisions around curriculum delivery and timetabling at the outset of the educational vision to avoid this pitfall. The design team must also establish the expected open plan layout and activity management plan with the client and furniture/fit-out designers at an early stage.

Achieving maximum flexibility in a learning area usually requires provision of a mixture of both open and enclosed accommodation in a variety of sizes. This ensures appropriate listening conditions for the diversity of learning activities and learners' needs and gives far more opportunities in teaching than accommodation limited to large open spaces with moveable screens.

In order to determine whether or not a proposed open plan space will meet the criteria specified in Table 7.1, layout plans and activity management plans need to be clearly identified so that computer modelling can be carried out to calculate the STI (see Appendix 6 for details and guidance on the acoustic modelling of open plan spaces).

The layout plan should show:

- the positions at which teachers will typically instruct, or carry out other critical listening activities (e.g. presentations, large group discussions, seminars, etc.)
- the seating plan for the students and teachers
- maximum communication distances for instruction or other critical listening activities
- furniture, fittings and equipment plan.

The activity management plan should include:

- the number, size and location of teaching groups where 'critical listening' activities occur (e.g. large group instruction, presentations, large group discussions, seminars, etc.), if applicable
- the number, size and location of teaching groups where instruction or other critical listening activities may occur simultaneously, if applicable
- a description of other simultaneous activities which may occur in adjacent areas during critical listening periods, e.g. quiet individual work, paired work, group work, one-to-one or small group instruction, or social time
- the number of teachers instructing or carrying out other critical listening activity at any one time
- the number of students in each teaching group
- circulation routes to other parts of the building that may be used during teaching and study periods
- any equipment (e.g. engraving machines, CNC machines, dust and fume extract equipment, data projectors, computers, printers, AVA etc.) operating in the open plan space.

### 7.3.1 Achieving the performance standards

STI criteria are intended to ensure that open plan spaces in schools are only built when suited to the planned activities and layout and users are actively committed to adopting an activity management plan that avoids noise conflict.

It will not be possible to achieve these performance standards with some activity plans, room layouts and open plan designs. The decision to introduce an open plan space into the school should be thoroughly re-assessed at this point in the design process, either by altering the design and open plan layout or revisiting the activity management plan, as illustrated in the flow chart in Figure 7.1. If there is still a need for the open plan space after re-assessment, the inclusion of moveable walls between learning bases should be considered. These moveable walls will form classrooms and be subject to the airborne sound insulation requirements in Building

Bulletin 93. It is not appropriate to simply adjust the activity management plan until the performance standards for speech intelligibility are met.

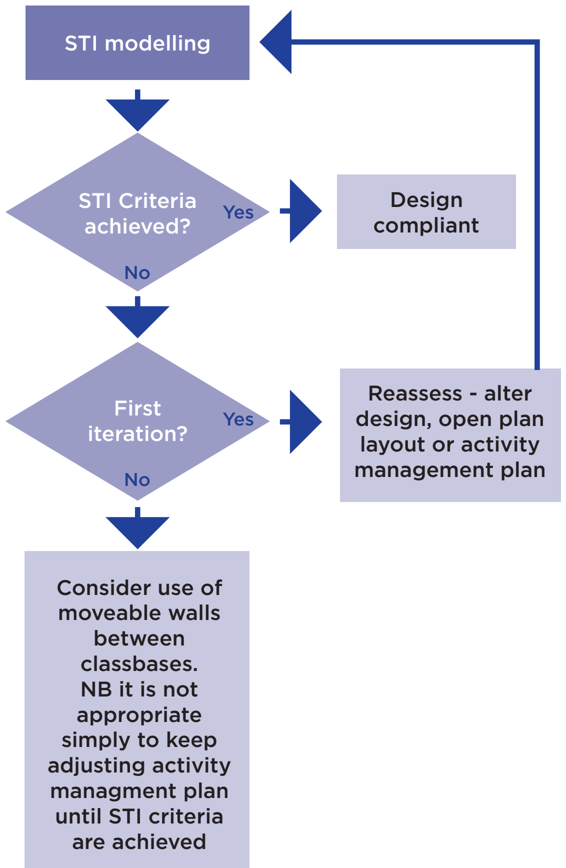


**Figure 7.1: Flowchart to demonstrate open plan assessment procedure**

## 7.4 Types of open plan design

Open plan designs largely fall into three categories[6], each requiring different organisation and management techniques, with some activities being more suitable than others, as summarised in Table 7.2.

### 7.4.1 Fully open plan layouts

Easily accessible and available enclosed rooms are essential in conjunction with any open plan space.

Small group rooms opening off the main open plan space are ideal for this purpose.

Small, pod-like structures, designed to achieve the necessary STI, ideally with a sound insulating ceiling and integrated services, can also be used to effectively contain small groups within a much larger space. Better still, small rooms should be located off the open area to provide a refuge from high activity noise levels and/or contain high noise producing activities such as AV use.

In the absence of partitioning to control sound transmission, the number of students is key to controlling build up of occupancy noise. Currently the minimum space provision for schools in the UK is 2.1 $m^2$ per student, whereas a significantly greater area allowance of at least 4 $m^2$ per student is recommended in fully open plan environments[8].

**Table 7.2: Three types of open plan design**

| Design type | Recommended use and management of space |
|---|---|
| **Fully open plan**<br>Design provides a large degree of openness with divisions provided only by means of loose fixtures | Plenary session recommended for critical listening periods (instruction/discussion/presentation); group and individual work should be co-ordinated and managed by a single team, not organised independently; small enclosed rooms surrounding the open space are essential to withdraw to when needed. |
| **Semi-open plan**<br>Building generally open but teaching spaces are defined by walls with openings in them | Independent teaching involving simultaneous critical listening periods is possible given good acoustic design, seating layout and suitable activity plans. Small group rooms are recommended, particularly if space is used by those with special hearing and communications needs. |
| **Flexible open plan**<br>Areas can be opened out or closed off by means of sliding or folding partitions | Compatible for independent teaching sessions involving general learning activities (provided that the partition is correctly designed and installed in accordance with Building Bulletin 93 sound insulation criteria). Sufficient sound insulation would not be achieved for specialist activity involving high noise levels (such as music, drama and design technology), therefore careful timetabling and management of these activities is required. |

### 7.4.2 Semi-open plan layouts

For open plan arrangements that require multiple groups to be instructed independently (or other simultaneous critical listening activity), semi-open plan designs (where teaching areas are separated by walls, with openings onto a shared area) are generally more effective at controlling intrusive noise and are preferable acoustically.

Semi-open plan classbases opening onto atria or other large volume spaces should be discouraged unless the client is committed to actively managing noise arising from the shared circulation space.

The number of teaching groups contained within an open plan unit should also be carefully considered, to enable teams of teachers to co-ordinate and manage adjacent activities and limit circulation to and from other parts of the building. Research[7] has shown that the number of different classbases or teaching groups sharing the semi-open plan unit should, ideally, not exceed three.

In semi-open designs where teaching groups may be operating independently, it is important to achieve sufficient privacy between classbases in order to avoid distraction from adjacent students and other teachers' voices. A sound attenuation of at least 20 dB is recommended between classbase areas, particularly critical listening zones, in order to achieve sufficient speech privacy. This can be achieved using buffer space (such as quiet rooms, storage or cloakrooms) between classbase openings, or by arranging classbases in a linear layout with staggered openings.

It is more difficult to achieve sufficient attenuation when classbases are clustered together, with partition openings facing onto each other. A popular design in primary schools for critical listening activities is to provide quiet carpeted areas in niched retreat zones, located well away from classbase openings.

### 7.4.3 Flexible open plan layouts

A major improvement in the acoustic privacy between spaces in open plan areas can be realised by installing full height moveable walls which, if fitted with seals, can provide a reasonable degree of sound insulation between the divided spaces (40-45 dB $D_{nT,w}$). In general however it is found that such screens are often under-used because of the time and effort required to open and close them.

Whilst it is possible, in theory, to achieve adequate sound insulation between classrooms using high-performance moveable walls, there are issues of cost, weight, complexity of installation and maintenance to consider. Specialist advice from an acoustics consultant should always be sought if using such partitions to comply with the sound insulation requirements set out in Building Bulletin 93.

### 7.4.4 Large spaces and atria

Large volume, double or triple height atria have been a popular feature of recent school design. Since reverberation time increases with room volume, it is unlikely to be possible to achieve suitably short reverberation times for open plan learning in these types of space, even if sound absorption treatment is maximised. As a result the type of teaching activity occurring in large plaza or central heart type spaces needs to be carefully considered. If critical listening needs to occur, it is preferable for this to take place as a large plenary session, in the absence of any other activity noise. This could be followed by a breakout session with multiple teaching groups involved in more informal learning activities (such as practical tasks in small groups or individual work). These spaces tend to work better when used mainly as a resource or social area.

The recommended minimum absorption area allowance is at least 5 Sabines per person[9] in order to provide sufficient conditions for informal verbal communication in a resource or social area, with normal hearing acuity assumed.

Balconies and mezzanines are popular features in centrally located open learning areas, in order to create a sense of light and airiness, and to allow for passive supervision. However, any opening will allow sound to be transmitted easily between spaces and sound absorbent treatment can only provide limited sound attenuation. Even small openings between floorplates can cause problems. These may occur between spaces which are used by very different subject departments, different age groups, or for conflicting activities in general (e.g. high noise producing versus high noise sensitivity uses), or when a mezzanine or balcony area needs to be used independently of the space below. In practice, it is best to limit the shared open plan area to a common subject base, or for classes in the same year group.

In practice it is more difficult for teaching teams to communicate, plan and co-ordinate activities when they are operating on different floor levels. A solid barrier such as a glazed screen (which will still maintain daylighting and ease of supervision) is recommended where sound transmission needs to be controlled between adjacent spaces. The need for glazed screens should be considered at the design stage because retrofitting such items can be costly and can impact on the ventilation design.

## 7.5 Evaluating suitability

The risk chart shown in Figure 7.2 may be used early in the design process to provide an initial evaluation of whether an open space design is likely to be compatible with the educational vision and the level of detail needed for the acoustic assessment. The chart lists ten features of an activity management plan and possible options for each item. The risk category associated with each option for each item should be determined. The implications of the three risk categories are as follows.

### Low Risk items

Given appropriate acoustic design, the management plan is likely to enable effective learning for the intended activities, with a low risk of speech intelligibility problems. Detailed 3D acoustic modelling to demonstrate that the STI will meet the criterion of 0.6 is not likely to be essential, although an acoustics consultant will still need to be consulted on the following items:

- size/shape of space
- extent of sound absorbent finishes to control reverberation
- furniture layout
- control of circulation noise
- building services noise
- ambient noise
- sound insulation from other parts of the building.

### Moderate Risk Items

The intended management plan could pose a moderate risk of speech intelligibility problems. Detailed 3D acoustic modelling is recommended, particularly for fully open plan designs. Users will need to commit to reasonable management of activities to avoid noise conflicts. If the acoustic modelling assessment reveals poor speech intelligibility, the management plan may need to be reviewed. Small group rooms may be needed to provide alternative options for more vulnerable listeners.

### High Risk Items

The proposed management plan poses a high risk of noise and intelligibility problems. Detailed 3D acoustic modelling will be essential to assist with the design of the space. Even where acoustic treatment can be maximised, fully open plan designs are unlikely to be satisfactory, and even semi-open plan designs will need careful commitment to activity management by the users. Some aspects of the management plan may need to be revised to reduce the risk of poor listening conditions.

**Figure 7.2: Activity management risk chart**

| Management plan | Risk category | | |
|---|---|---|---|
| | High | Moderate | Low |
| 1. Number of teaching groups sharing space | 4+ groups | 2-3 groups | 1 group |
| 2. Point of control | 4+ independently operating teachers/ facilitators | 2-3 facilitators, with some planning and interaction | 1 single team planning cooperatively |
| 3. Area per student | <3 $m^2$ | 3-4 $m^2$ | >4 $m^2$ |
| 4. Time spent in area | Usual or permanent place of learning | Frequent, but not 100% of lessons | Occasional/breakout activities |
| 5. Curriculum grouping | Different age/stage/ subjects | Mixed, but closely linked groupings | Similar age/stage/subjects |
| 6. Activity types | Frequent critical listening (instruction or discussion in large groups) | Critical listening is less frequent: Mainly individual/small group work/1 on 1 instruction | Critical listening occurs as plenary session only. Individual/small group work/1 on 1 instruction is co-ordinated. OR Resource/social area |
| 7. Organisation of activities | Simultaneous use, independently planned | Simultaneous use, but activities planned co-operatively | Sequential use |
| 8. Communication distance | >4 m | 3-4 m | <3 m |
| 9. Extraneous circulation | Access to other areas of the building required through open plan unit during teaching time | Restricted or minimised during teaching time | None within open plan unit |
| 10. Vulnerable listeners | Need to use open plan space frequently | Very occasional use | Mix of enclosed and open to provide extra support/alternative accommodation |

## 7.6 Building design

### 7.6.1 Ceilings

In practice, fully open plan spaces (e.g. without fixed divisions or walls between different classbases) will necessitate a highly sound absorbent ceiling or suspended horizontal acoustically absorbent raft. The recommended absorption area should be equivalent to Class A coverage of 100% of ceiling area, as rated in accordance with BS EN ISO 11654: 1997[10]. Suspended absorbers (such as vertical acoustic baffles or horizontal acoustic rafts) are sometimes preferred, for example to provide thermal cooling via an exposed concrete soffit. Whilst these can be effective at mid to high frequencies, good low frequency absorption is not always achieved. Therefore in addition to suspended absorbers, good low frequency absorbers should also be provided.

Since speech covers a broad frequency range (125 Hz - 8 kHz), it is preferable to provide an absorber which is effective over a wide frequency range, such as a suspended ceiling tile with a void behind.

Where sound attenuation is required between spaces, the height of the sound absorbing ceiling, suspended raft, or panels/baffles should be limited to 3.5 m in order to provide effective attenuation of sound over distance[8]. Due care and attention must be given to the ceiling surface to ensure grazing reflections are minimized. Consideration should also be given to the type of luminaires used; flat lens types should be avoided due to their high sound reflectance.

### 7.6.2 Screens

Sound insulating and absorbing screens should be interposed between class groups and competing activities. Screens should be at least 1.7 m high, that is high enough to block the line of sight, and ideally should reach to within 0.5 m of the ceiling, see Figure 7.3. Screens higher than 2 m, whilst being more effective acoustically, can be difficult to move. Horizontal reflections from walls can also limit the sound reduction of a screen, as shown in Figure 7.4, so, where practicable, the screen should extend to the wall.

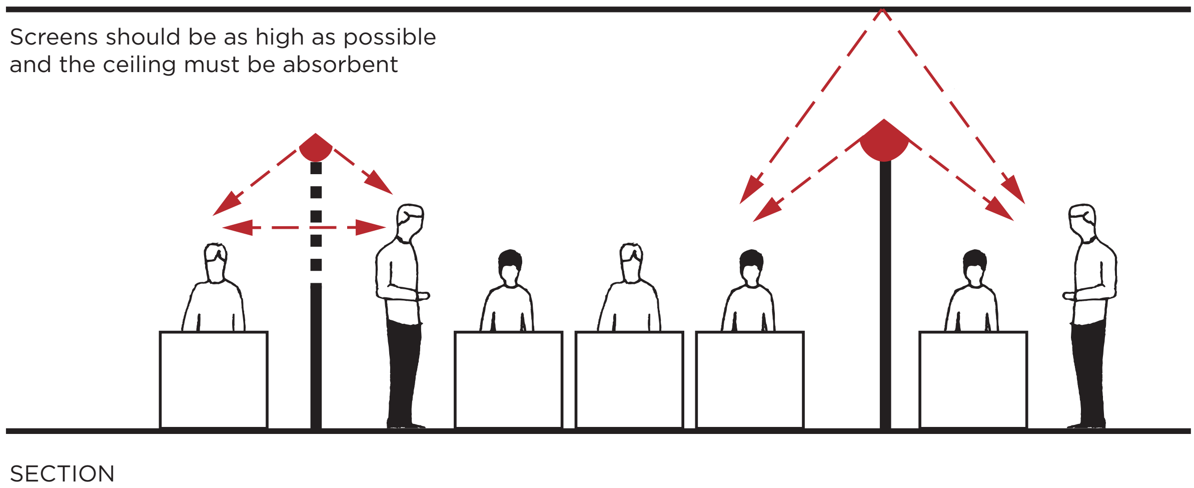


**Figure 7.3: Effect of screen height**

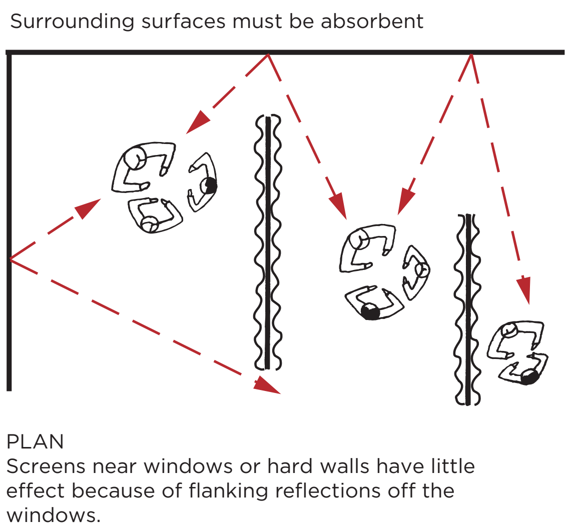


**Figure 7.4: Effect of screen positioning**

A horizontal ceiling or suspended absorbent acoustic raft positioned within 600 mm of the top of the acoustic screens can provide useful local sound attenuation between competing activities. If a screen is not high enough, direct sound paths or paths with only small angular changes are possible. If the angle is small, more low and mid frequency sound will diffract over the top of the screen. If the ceiling is not absorbent, sound can be reflected over the screen.

The design of screens and partitions, the horizontal acoustic absorbent plane and the physical separation of activities should aim to achieve at least 20 dB sound attenuation between adjacent activity areas.

## 7.7 Acoustic modelling

In new buildings and where extensive refurbishment is occurring, detailed speech intelligibility modelling should be carried out in accordance with the guidance in Appendix 6 to comply with the Schools Premises Regulations, except where it is determined from the activity management risk chart register that most issues are low risk.

The expected open plan layout and activity management plan should be agreed as the basis on which compliance with the STI criteria can be demonstrated to the client.

The activity management plan should be used to establish the overall noise level due to the combination of the indoor ambient noise level, all activities in the open plan space (including teaching and study) and transmitted noise from adjacent spaces.

A computer prediction model should be used to calculate the STI in the open plan space. The background noise level to be used in the model is established from the overall predicted noise level due to all intrusive noise activities (including teaching and study from adjacent classbases, but excluding the relevant speech signal) in the open plan space. The STI should be calculated for teacher to student, student to teacher and student to student communication.

See Appendix 6 for further details on the acoustic modelling of open plan spaces.

## 7.8 Demonstrating compliance

The following information should be submitted with the results of the STI calculations.

1. Name of software and version
2. Acoustics consultant and operator
3. Number of rays and length of impulse
4. Absorption and scattering coefficients used in model
5. Diagram of the wire frame model with source and receiver positions
6. Background noise levels in octave bands used for each scenario
7. Assumptions made in calculating overall noise levels
8. Assumptions made in choosing source and receiver positions for calculation.

In addition to the modelling results, the open plan layout, activity management plan and activity management risk chart should also be submitted to demonstrate compliance.

It is also recommended that the design is adaptable so that in the event that the educational vision of the school changes, as often occurs in practice, the spaces can be divided up into more traditional teaching spaces without the need for major structural alterations, and without compromising other areas such as health and safety, daylighting and ventilation. At an early stage in the design an adaptability study should be submitted to demonstrate that potential future adaptations to a cellular design would be achievable without significantly compromising health and safety, access and fire egress routes, daylighting, or ventilation strategy. Any significant design impacts resulting from potential necessary adaptations should be identified as part of the feasibility study. This study should be signed off by the School Client Body.

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# Chapter 8 Refurbishment and integrated design

## 8.1 Introduction

This chapter discusses issues relating to the performance standards in Building Bulletin 93 for refurbishment of existing school buildings and for schools formed by material change of use of existing buildings. It also addresses the need for integrated design solutions in both new and refurbished buildings, and the importance of all the specialists involved in the design of a building to have an awareness of the needs of other disciplines. Thus the acoustics consultant needs to be aware of other environmental considerations such as daylighting, thermal comfort and air quality, and to ensure that acoustic solutions do not compromise the requirements of other areas.

## 8.2 Schools formed by refurbishment or material change of use

### 8.2.1 The need for appropriate strategies

For new-build schools there are clear performance targets given in Building Bulletin 93 and the designer has control over how these targets can be met using new building elements. Design values are also given for refurbishment work in existing schools and for schools formed by a material change of use.

Building Bulletin 93 gives clear guidance on when the acoustic performance specifications are to be achieved as part of Building Regulations compliance. The following information applies to such cases, and also where there is a desire to achieve good acoustic conditions for teaching and learning even though there is no obligation to meet Requirement E4 of the Building Regulations.

The acoustic design is not straightforward when working with existing buildings, as various key factors need to be taken into account, including:

- performance targets that need to be achieved
- the existing performance of the building and its elements
- existing flanking paths
- the prevailing ambient noise climate
- any planning restrictions (including historic building listings) limiting the works that can be carried out.

Each of these will have a determining factor on the acoustic design and performance of the teaching space, as discussed below.

### 8.2.2 Required performance targets

Section 0.3 of Building Bulletin 93 gives a summary of what type of works require compliance with Part E of Building Regulations. There may also be an element of discretion on behalf of the client. For example, the client may ask for performance to be at least as good as other similar situations within the same building, or to be as good as possible within project constraints, even if a new building element is not subject to Building Regulations.

Where an acoustic strategy is proposed, it must include an explanation in practical terms of what any targets will mean in practice (e.g. how much speech will be understood through a partition, whether the amount of reverberation will make speech difficult to understand etc.).

### 8.2.3 Performance of the existing building

Where an existing building element or space is to be converted or upgraded, it is useful to know its prevailing performance. This can assist the client in putting acoustic performance targets into context to gain an understanding of the existing sound insulation, indoor ambient noise level and reverberation time.

The following procedure could be carried out as a minimum to obtain a representative set of data, although individual site conditions may require a different approach:

- at least two airborne sound insulation tests across each type of partition
- at least two airborne sound insulation tests across each type of floor
- at least two impact sound transmission tests across each type of floor
- at least one reverberation time test in each type of room
- indoor ambient noise levels in at least two rooms on each façade.

Notes:

For the purposes of sound insulation testing, a type of partition or floor means a pair of rooms divided by a particular construction of partition or floor and/or having a particular form of flanking element.

A type of room for reverberation time testing is a room of a particular size (i.e. dimensions and proportions), having similar room finishes to others of that size.

Testing should be carried out in accordance with the procedures specified in the ANC Good Practice Guide: Acoustic Testing of Schools[1].

During testing, notes should be made by a competent person of their subjective impressions, i.e. whether transmitted sound seemed 'boomy', whether any fixtures rattled or whether there were any significant flanking paths present, as these will help inform the design.

In some circumstances, testing may be unnecessary, or of limited value. For example, a poorly sealed service penetration through a partition could preclude measurement of the potential sound insulation of the partition, unless the penetration can be adequately sealed.

If new suspended ceilings are proposed, it may not be necessary to measure reverberation times, unless these are needed to inform the specification of the new ceiling.

If the ventilation strategy is to continue to rely on opening windows, measurements may be used to inform the client of the baseline noise levels and hence the suitability of opening windows for the proposed room use.

In these, and other, situations, it may be more appropriate to undertake a design appraisal of the potential performance of the elements, rather than testing, so that appropriate design solutions can be determined.

It is possible that a partition due to undergo refurbishment already meets sound insulation targets or that existing surface treatments meet reverberation time targets, in which case there may be no need to make any changes acoustically.

### 8.2.4 Flanking transmission

All partitions and floors on site are subject to flanking transmission, to a greater or lesser degree. The degree of flanking will be a significant factor in determining the difference between the laboratory performance of the element and the level of sound insulation achieved on site.

Flanking can generally be adequately controlled in new build schools by design and specification, enabling the target criteria to be met. However, where one or more of the flanking elements is pre-existing then its exact composition and detailing may not be evident without significant intrusive investigation. This emphasises the importance of performance testing, wherever possible, to establish the significance of flanking.

The sound insulation will invariably be poor where new partitions are connected to the back of existing mullions, or floors have junctions with transoms. In such cases, it may not be possible to meet even the reduced standards of sound insulation applicable to refurbishment, and the client should be made aware at the earliest opportunity of the practical implications and constraints of such constructions on room use.

Where there are no planning restrictions such as listed interiors, exposed elements including internal skins of external walls and exposed structural steelwork can be clad using plasterboard or a similar material to limit flanking. Any services penetrations through sound insulating elements should be well sealed and boxed in locally where possible.

Exposed services and structure can not only lead to degradation of sound insulation, but can also give rise to 'rattling' or 'ringing'. This can result in an anomalous increase in the measured reverberation time in a space, but can also be detected subjectively during the reverberation time testing.

### 8.2.5 Planning or listing restrictions

Where a building is of historic or local significance, there may be restrictions on what works can be carried out, due to listings, or other restrictions imposed by conservation or planning officers. This could include the requirement to retain single glazed windows, which may need to be able to be opened to provide ventilation, even though external noise levels may be high. Architectural features, such as brickwork or cast iron columns and other structural members may need to be left exposed. In these instances the potential for improvements in the acoustic conditions of the building or space can be limited and the client should be made aware of the practical implications during operation at the earliest opportunity. Internal noise levels with windows opened for ventilation should be documented and the end users made aware of any constraints on conditions for teaching and learning due to noise levels.

## 8.3 The need for integrated design

In order for a school design to be sustainable and efficient, it is critical that all stakeholders in the design process work together towards a common goal. In addition to acoustic requirements, a school needs to meet other environmental performance criteria, including daylighting, thermal comfort and air quality. CIBSE Guide TM57: Integrated School Design[2] illustrates the different environmental design requirements and processes.

Acousticians need to have an appreciation of the requirements of other design disciplines, in order to provide acoustic solutions that are compatible with other design requirements. For example, where a classroom is designed to optimise daylight using full height windows, an exposed soffit with suspended individual absorbers (which will also have significant benefits for thermal mass) may be more appropriate than a suspended ceiling that would obstruct the window head.

### 8.3.1 Thermal comfort

The mass of a building has the potential to provide 'free' cooling. This is cooling through radiant exchange, so anything that obstructs the line of sight from the building mass to the occupant will reduce the cooling.

Generally, massive elements will have the most potential for free cooling. Concrete soffits and walls are effective, although walls are often covered by room finishes, so may not perform as well in use as in calculations.

There are a number of 'phase changing' materials available on the market, which can behave like more massive, thermally activated elements. These have the advantage of being more lightweight, but their effectiveness in practice is not as widely documented as concrete.

Where soffits are to be exposed to promote free cooling, reverberation control strategies must be carefully chosen. Full coverage of a suspended ceiling will eliminate the benefit of the exposed soffit, whereas partial coverage, or the use of suspended absorbers, can be effective. Whilst confining absorption to walls would provide maximum efficiency of the exposed soffit, significant areas of absorption will be required, which may not be practicable in most teaching spaces.

The amount of soffit coverage that is possible will need to be determined on a project by project basis but, as a rule of thumb, no more than 40% of the soffit should be obscured for effective cooling. Liaison is required between the acoustician and mechanical design engineer.

### 8.3.2 Ventilation

Concentrations of carbon dioxide need to be controlled to ensure that children do not lose concentration or fall asleep[3]. The way to control $CO_2$ build-up is to provide a steady stream of air, either directly from outside or via a mechanical system. Liaison is required between the acoustician and mechanical design engineer.

### Natural ventilation

Natural ventilation is often considered to be the most sustainable solution in teaching and learning spaces, requiring little or no energy to operate.

Where external noise levels are too high, the ingress of noise can lead to indoor ambient noise levels exceeding design limits; the amount of noise ingress will depend on the type of openings (e.g. windows, louvres etc.), the open area and orientation to the noise source.

It is possible to ventilate a space naturally, even when external noise levels are high (e.g. 60 dBA and over), although this will be costly and it is likely that pressure drops will be high, making ventilation less efficient. The use of barriers can be very effective but may have other implications with planning authorities and introduce security issues. Double facades are sometimes used in urban locations, which also have the benefit of providing an efficient stack effect which can lead to increased airflow in rooms; care should be taken, however, to ensure that flanking noise does not occur due to reflections from the secondary façade.

Using wind pressure from cross flow ventilation tends to require less of an open area in the external façade (and therefore less noise ingress). In these cases, air passes through the teaching space then through another ventilator on the other side of the space, at a higher level. Where high level ventilators are located in corridor walls, care will need to be taken to control noise transfer to the corridor, whilst also providing a suitably low pressure drop. Cross flow ventilators should not be installed in walls dividing adjacent teaching spaces. To avoid flanking through cross flow units, stack ventilators can be used, where each teaching space has a dedicated chimney or flue. Measures will be required at the termination points to avoid flanking, however, in addition to consideration of the transfer of fire and smoke.

There are disadvantages to natural ventilation that need to be considered, including heat escape and cold draughts when external temperatures are low, which may require the supplementary use of mechanical ventilation with heat recovery. Noise egress from noisy activities such as music can cause problems with flanking to adjacent spaces and potential nuisance to other sensitive locations (e.g. residential dwellings).

### Mechanical ventilation

The most straightforward method of controlling the ambient noise level and regulating thermal comfort within a classroom is to ventilate mechanically. This is often not the preferred ventilation method, however, due to high installation, running and maintenance costs, in addition to the challenge of controlling noise levels in sensitive rooms due to plant operation.

Locating plant remotely from teaching spaces makes control of noise straightforward by the use of extensive lengths of ductwork and attenuators. Care needs to be taken to ensure flanking noise is suitably controlled by cross talk attenuators and/or bends where multiple rooms are fed from a common duct run. Central plant is often not a preferred solution due to all plant needing to operate even when the school is only partially occupied, unless it is designed for variable volume flow.

Serving rooms locally with individual items of plant can provide the greatest levels of control. However, locating plant within, or adjacent to, sensitive rooms can cause noise levels to increase adjacent to the plant unless significant attenuation measures are carried out.

Very quiet forms of ventilation (e.g. chilled beams, chilled ceilings, displacement, etc.) can lead to noise from adjacent areas being distinctly audible, even when levels of sound insulation meet performance targets.

Care should be taken to avoid resonance from ventilation systems in noisy areas such as music classrooms. For example, chilled beams have multiple thin metal fins that are easily set in resonance by music and even speech.

### 8.3.5 Structural considerations

There can be conflicting requirements between acoustics and structural considerations. Generally, structural connections need to be rigid for maximum strength, which may be at odds with acoustic requirements; conversely, movement joints may be required in walls and slabs where acoustic control is critical. Co-ordination is required to avoid conflicts and, where unavoidable, implement details to see that acoustic performance is not compromised.

Exposed steelwork is notoriously problematic for transferring noise from one part of a building to another. No structural steelwork should be left exposed in noisy or noise-sensitive areas; where steelwork needs to be exposed for aesthetic purposes then it should be provided with isolation joints between exposed sections and the rest of the frame.

Where structural bracing occurs within partitions, care should be taken to see that there is no hard contact with studwork, to avoid airborne and impact noise transmission through the frame, or bridging of otherwise independent stud frames.

Where curtain walling flies outboard of the edge of structural slabs or columns, appropriate measures should be put in place to prevent flanking transmission in the gap. Such measures (e.g. boxing) could be required for fire control purposes also. It is likely in these instances that the façade needs to be able to move with wind pressure; flexible mullion and transom closers will be required in order to maintain sound insulation across partitions and floors respectively.

Liaison is required between the acoustician and structural engineer.

### 8.3.6 Aesthetic considerations

Acousticians sometimes criticise architects for designing purely visually, designing only with their eyes. However, acousticians should not design only with their ears. The most elegant solutions have both acoustic and aesthetic merits, in addition to all the functional requirements discussed above.

It is essential that all members of the design team work together to achieve the most appropriate, functional and elegant solutions available. A common understanding within the design team is more likely to result in design solutions which meet the requirements of all necessary disciplines.

## References


1. ANC Good Practice Guide – Acoustic Testing of Schools, ver 2. Association of Noise Consultants, November 2015. Free download available from http://www.association-of-noise-consultants.co.uk.
2. J Palmer and D Mumovic. TM 57 Integrated School Design. CIBSE, 2015.
3. Zs. Bakó-Biró, D.J. Clements-Croome, N. Kochhar, H.B. Awbi, M.J. Williams. Ventilation rates in schools and pupils' performance. Building and Environment 48, 215-223, 2012.

# Appendix 1: Basic concepts and units

## Nature of sound

Sound is usually generated by the vibrations of a surface, which give rise to pressure fluctuations in air or some other elastic medium. Sound is transmitted through the medium as sound waves, and may be described in terms of sound pressure or sound power. Noise is generally defined as unwanted sound.

## Decibels

Sound levels are usually measured in decibels (dB) and relate absolute values to a reference value. The decibel scale is logarithmic and it ascribes equal values to proportional changes in sound pressure, which reflects the response of the human ear to sound. For example, an increase in sound pressure from 10 to 20 Pa would sound the same to the human ear as an increase from 1 to 2 Pa. Use of a logarithmic scale has the added advantage that it compresses the very wide range of sound pressures to which the ear may typically be exposed to a more manageable range of numbers.

## Sound pressure level

The sound pressure level, $L_p$, is a measure of the total instantaneous sound pressure at a point in space. The threshold of hearing occurs at approximately 0 dB sound pressure level (which corresponds to a reference sound pressure of $2 \times 10^{-5}$ Pa) and the threshold of pain is around 140 dB. Some typical sound pressure levels are shown in Figure A1.1.

## Sound power level

The sound energy radiated by a source can also be expressed in decibels. The sound power is a measure of the total sound energy radiated by a source per second, in Watts. The sound power level, $L_w$, is expressed in decibels, referenced to $1 \times 10^{-12}$ W.

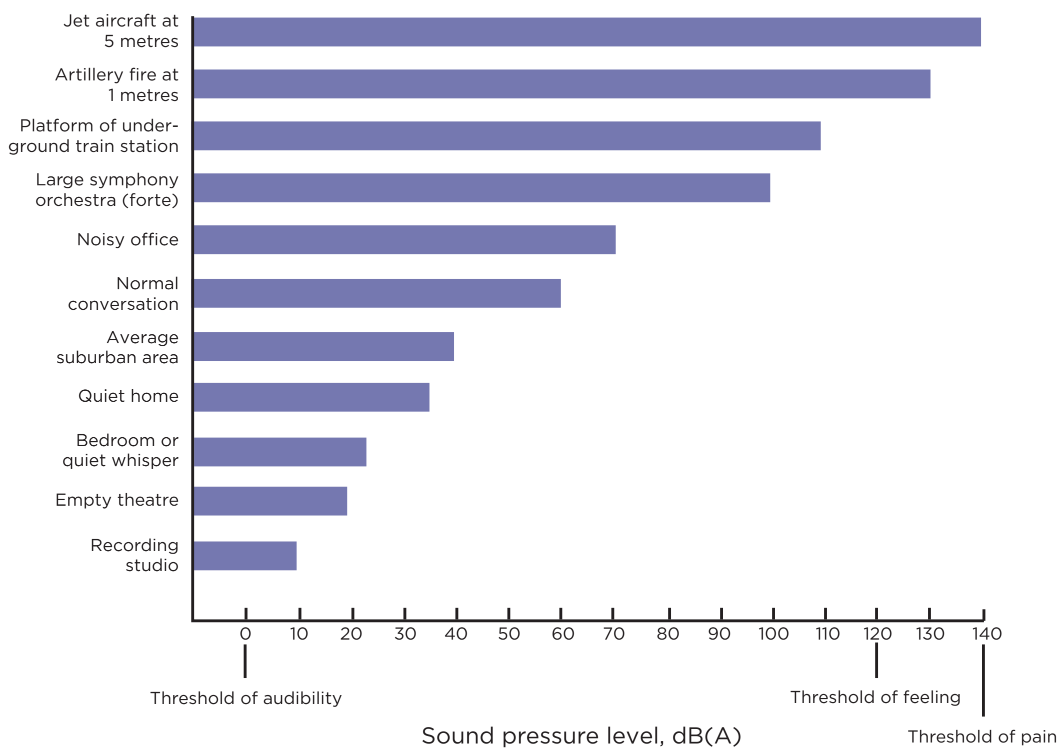


**Figure A1.1: Typical sound pressure levels**

## Addition of sound levels

Because the decibel scale is logarithmic, levels in decibels can not be simply added together. To combine two sound levels, A dB and B dB, to give the total sound level, C dB, the following equation is used:

$$C = 10 \lg (10^{A/10} + 10^{B/10}) \text{ dB} \qquad \text{A1.1}$$

When two identical sounds occur simultaneously, the resulting level is only 3 dB higher than for a single source. By contrast, an increase of 10 dB normally represents a doubling of perceived loudness of the sound. Hence doubling the amount of sound energy results in very much less than a doubling in subjective loudness.

To combine more than two levels, the following equation is used:

$$L = 10 \lg (10^{A/10} + 10^{B/10} + 10^{C/10} + 10^{D/10} + \ldots) \text{ dB} \qquad \text{A1.2}$$

## Frequency of sound

Frequency is analogous to musical pitch. It depends upon the rate of vibration of the air molecules which transmit the sound and is measured as the number of cycles per second or Hertz (Hz). The human ear is sensitive to sound in the range 20 Hz to 20 kHz. Examples of the frequency ranges of musical instruments and the human voice are shown in Figure A1.2. For acoustic engineering purposes, the frequency range is normally divided up into discrete bands. The most commonly used are octave and one-third octave bands.

## Octave bands

For an octave band the upper limiting frequency of each band is twice the lower limiting frequency. Octave bands are described by their centre frequency values and bands typically used for building acoustics purposes range from 63 Hz to 4 kHz.

## One-third octave bands

Each octave band can be divided into three one-third octave bands. The one-third octave bands are described by their centre frequency values and bands typically used for building acoustics purposes range from 50 Hz to 5 kHz.

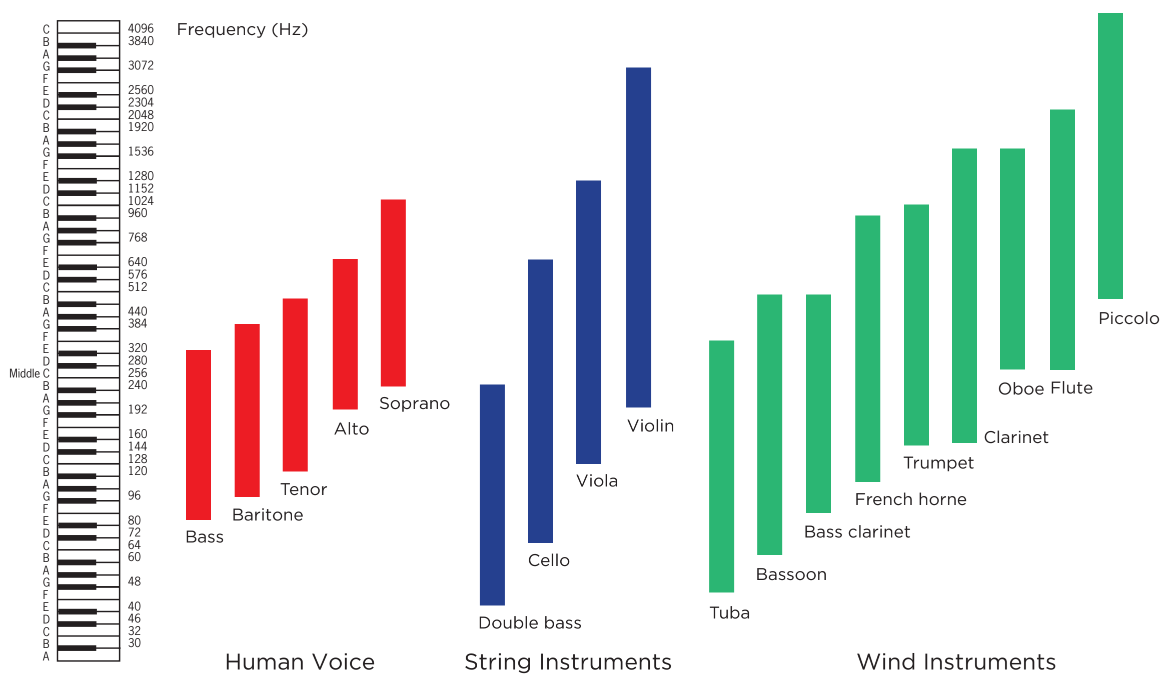


**Figure A1.2: Frequency range of musical instruments and vocals**

| Table A.1.1: A-weighting factors | | | | | | | |
|---|---|---|---|---|---|---|---|
| Octave band centre frequency (Hz) | 63 | 125 | 250 | 500 | 1 k | 2 k | 4 k |
| A-weighting correction (dB) | −26.2 | −16.1 | -8.6 | -3.2 | 0 | 1.2 | 1.0 |

## A-weighted levels

The sensitivity of the ear is frequency dependent. Sound level meters are fitted with a weighting network which approximates to this response and allows sound levels to be expressed as an overall single figure value, in dBA. For clarity and convenience, the 'A' is often included in the acoustic descriptor, eg $L_{Aeq}$, rather than after the units. For example, A-weighted levels can be quoted as 55 dB $L_{Aeq}$.

The A-weighted level can also be calculated manually from octave band or one-third octave band data. For octave band data, see Table A1.1, values are added to the respective sound levels and the resulting values for all octave bands are combined logarithmically (using Equation A1.2)

## Measurement of time-varying sounds

Most sounds are not steady and the sound pressure level fluctuates with time. Therefore, it is necessary to express the results of a measurement over a period of time in statistical terms. Some commonly used descriptors are discussed below.

## Equivalent continuous sound level

The most widely used unit is the equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$). It is an energy average and is defined as the level of a notional sound which (over a defined period of time, T) would deliver the same A-weighted sound energy as the actual fluctuating sound.

## Percentile level

A percentile level is the level exceeded for a certain percentage of a measurement period. The most commonly used percentile levels are:

$L_{A1,T}$ - This is the A-weighted level exceeded for 1% of the measurement period. It is often used to represent typical maximum levels that occur during the measurement period.

$L_{A10,T}$ - This is the A-weighted level exceeded for 10% of the measurement period. It is often used to represent the sound level from road traffic.

$L_{A90,T}$ - This is the A-weighted level exceeded for 90% of the measurement period. It is often used to represent the background level.

## Maximum and minimum sound levels

$L_{Amax,T}$ is the maximum sound pressure level measured during the measurement period T. $L_{Amin,T}$ is the minimum sound pressure level measured during the measurement period T.

## Sound level meter time constants

To give meaningful results, sound level meters use sound pressure levels averaged over short intervals (within the overall measurement period, T). Time constants for this averaging, defined in international standards, include 'fast' (125 ms) and 'slow' (1 s).

The percentile levels described above are affected by the choice of time constant. By definition, all percentile levels must be measured with the fast time constant.

$L_{Aeq,T}$ is not affected by the sound level meter time constant.

$L_{Amax,T}$ and $L_{Amin,T}$ can be measured with either fast or slow time constants so it is important that the results state which time constant has been used.

# Appendix 2: Basic principles of room acoustics

## Reflection and absorption of sound

Once emitted from a source, sound waves in a room travel through the air until they reach a boundary surface or other obstacle. When a sound wave reaches a surface it will be partly reflected off the surface back into the room and continue travelling in a new direction, and it will be partly absorbed by the surface with the absorbed energy being dissipated as heat.

## Absorption coefficient, α

The amount of sound energy that can be absorbed by a surface is given by its absorption coefficient, α. The absorption coefficient can take values in the range 0 to 1. A surface that absorbs no sound (i.e. a totally reflective surface) has an absorption coefficient of 0 and a surface that absorbs all sound incident upon it has an absorption coefficient of 1. Thus the higher the value of α, the more sound will be absorbed. In practice, most surfaces have values between 0 and 1.

## Absorption classes

The absorption of surfaces varies with frequency. Therefore, absorption coefficients are generally given for each octave band. A surface is categorised as being in a particular absorption class, A to E (according to BS EN ISO 11654) depending on its absorption coefficients across the frequency range. Note that a very reflective surface may be unclassified.

## Scattering coefficient, s

When sound is reflected from a surface it is partly reflected in a specular direction (i.e. the angle of incidence equals the angle of reflection) and partly scattered into other directions. The amount of reflected sound energy that will be scattered is given by the surface's scattering coefficient, s. This is in the range of 0 to 1 where a perfectly smooth surface giving pure specular reflection has a scattering coefficient of 0 and a very irregular surface scattering all sound away from the specular direction has a scattering coefficient of 1. Scattering coefficients are a relatively new measure in room acoustics so there is little data currently available but they are important in room acoustics computer modelling.

## Reverberation time, T

After being emitted from a source, sound waves are repeatedly reflected from room surfaces and, as a result of absorption, gradually reduce in strength. The reverberation time, T, of a space is a measure of the rate at which the sound decays. It is defined as the time taken for the reverberant sound energy to decay to one millionth of its original intensity (corresponding to a 60 dB reduction in the sound level).

The reverberation time is proportional to the volume of the room and inversely proportional to the quantity of absorption present:

$$T = \frac{0.161\ V}{\sum S_i \alpha_i} \text{ seconds} \qquad \text{A2.1}$$

where $S_i$ and $\alpha_i$ are respectively the surface area and absorption coefficient of each surface in the room. This relation between absorption and reverberation time is only representative of spaces in which the sound field is diffuse and the reverberation time is not short. Many classrooms do not have diffuse sound fields, as the absorption is not evenly distributed. This relation should be used with caution owing to its limitations.

## Mid-frequency reverberation time, $T_{mf}$

The sound absorption of surfaces usually varies with frequency and therefore the reverberation time in a space also varies with frequency. Hence, values of T are normally given in frequency bands. In Building Bulletin 93 the reverberation time criteria are set in terms of the average value of the three octave bands, 500 Hz, 1 kHz, and 2 kHz, or alternatively the nine one-third octave bands between 400 Hz and 2.5 kHz, denoted as $T_{mf}$. Although these are not mathematically equivalent, in practice the difference will be small and in the interests of simplicity and ease of measurement, either is acceptable.

$$T_{mf} = (T_{500} + T_{1k} + T_{2k}) / 3 \text{ seconds} \qquad \text{A2.2}$$

or:

$$T_{mf} = (T_{400} + T_{500} + T_{630} + T_{800} + T_{1k} + T_{1.25k} + T_{1.6k} + T_{2k} + T_{2.5k}) / 9 \text{ seconds} \qquad \text{A2.3}$$

## Other acoustic measures

Sound heard in a room generally comprises an extremely complicated combination of many reflected and scattered sound waves. This situation is made manageable by considering only the overall statistics of the sound field such as the reverberation time. Unfortunately, this does not convey all the intricate details of the sound field that determine peoples' subjective responses. There are many other measures used to represent various aspects of subjective response to room acoustics. For school acoustics there is a need to have criteria for subjective speech intelligibility for which the objective measure selected for Building Bulletin 93 is the Speech Transmission Index.

## Speech Transmission Index, STI

The intelligibility of speech in a room is a complex function of the location of the speaker, the location of the listener, ambient noise levels, the acoustic characteristics of the space, and the loudness and quality of the speech itself. In addition, if a sound reinforcement system is used, it depends on the design and adjustment of this system. The Speech Transmission Index, STI, is an objective measure defined in BS EN 60268-16[1], which accounts for all these factors.

To measure the STI, a special sound source is located at the position of the speaker (with the normal microphone in place for any sound reinforcement system). The resulting signal is detected at the listening position. Signal processing using the modulation transfer function between transmitted and received signals is carried out to determine the STI.

STI is a value between 0 and 1, the higher the value, the better the speech intelligibility. Speech intelligibility ratings corresponding to STI values are shown in Table A2.1, for native listeners with good hearing.

**Table A2.1: STI values and speech intelligibility rating**

| STI | Speech Intelligibility |
|---|---|
| 0.1 to 0.3 | Bad |
| 0.3 to 0.45 | Poor |
| 0.45 to 0.6 | Fair |
| 0.6 to 0.75 | Good |
| 0.75 to 1 | Excellent |

## References


1. BS EN 60268-16: 2011. Sound system equipment. Objective rating of speech intelligibility by speech transmission index.

# Appendix 3: Basic principles of sound insulation

## Airborne sound insulation

Speech, AV systems and musical instruments are all sources of airborne sound in buildings. Sound in a room (the source room) causes the surrounding surfaces, such as walls, ceilings and floors to vibrate. This vibration is transmitted through the building structure and radiated into other rooms (receiving rooms) in the building. Depending upon the building construction, varying amounts of energy are lost during the sound transmission process, resulting in airborne sound insulation between rooms.

The greater the airborne sound insulation between two rooms, the lower the resulting sound level in the receiving room.

## Measurement of airborne sound insulation

The site measurement procedures for airborne sound insulation are given in BS EN ISO 16283-1[1]. Normally, pink noise or white noise is played through an amplifier and loudspeaker in the source room, to provide a high sound level across the frequency range of interest.

The sound level in the source room must be high enough to ensure that the levels in the receiving room are above the background noise level.

The resulting sound levels in the source and receiving rooms are measured in one-third octave bands. As the sound levels vary with location, they are averaged either across a number of fixed microphone positions or by using a continuously moving microphone. The resulting time and space averaged sound levels are denoted $L_1$ in the source room and $L_2$ in the receiving room.

## Level difference, D

D is the difference in sound levels in dB between the source room and the receiving room in one-third octave bands:

$$D = L_1 - L_2 \text{ dB} \qquad \text{A3.1}$$

This level difference depends on:

- direct sound transmission through the separating element (i.e. separating wall or floor)
- flanking sound transmission (see Chapter 3) through flanking elements (e.g. flanking walls, suspended ceilings, access floors etc)
- wall and floor dimensions
- reverberation time of the receiving room.

## Standardized level difference, $D_{nT}$

The reverberation time, T, measured in a room may be significantly different from the value predicted at the design stage due to a lack of detailed knowledge of finishes, furniture and fittings and their absorption characteristics. This means that the predicted sound level difference, D, which depends on T, is also subject to change. To avoid problems, a reference reverberation time, $T_o$, can be used in predictions of D. When the building is constructed and D is measured, the measured reverberation time, T, is referenced to $T_o$. This gives the standardized level difference, $D_{nT}$.

$$D_{nT} = D + 10 \lg \left(\frac{T}{T_o}\right) \text{ dB} \qquad \text{A3.2}$$

## Building Bulletin 93 standardized level difference, $D_{nT}$

$D_{nT}$ is widely used to set sound insulation criteria for dwellings, where $T_o$ is taken as 0.5 seconds. Although Building Bulletin 93 uses $D_{nT}$ in the sound insulation criteria for schools, a value of $T_o$ = 0.5 seconds would not be appropriate for many school rooms.

For the purposes of the design, $T_o$ is specified as the maximum value of $T_{mf}$ given in Table 6 of Building Bulletin 93. This descriptor for airborne sound insulation in schools was formerly written as $D_{nT\,(Tmf,max)}$, but is now more simply written as $D_{nT}$.

## Sound reduction index, R

The sound reduction index, R, of an element such as a wall, floor, door or window describes the sound transmitted through that element. It is measured in a laboratory with suppressed flanking transmission. R varies with frequency and is expressed as a value for each one-third octave band or octave band.

## Apparent sound reduction index, R´

Using field measurements of the level difference, D, it is possible to estimate the value of the sound reduction index, R, for a partition. However, because field measurements include flanking transmission, the resulting quantity is called the apparent sound reduction index, R´.

The apparent sound reduction index, R´, of wall or floor constructions in schools (and all other buildings), is usually lower than the laboratory measured value of R. The difference between the results is usually due to flanking transmission and a lower standard of workmanship on site.

Guidance on flanking transmission is given in Chapter 3. Problems due to workmanship can be reduced by close supervision during the construction process.

## Weighted sound reduction indices and level differences $R_w$, $R'_w$, $D_w$, $D_{nT,w}$,

Most constructions provide higher airborne sound insulation against mid and high frequency sounds (such as speech) than low frequency sounds (such as the bass in music). This typical characteristic is defined in BS EN ISO 717-1[2] as a rating curve that can be applied to one third octave band values of R, R´, D, $D_{nT}$ from 100 Hz to 3.15 kHz. The rating curve is used to calculate the following single-number quantities: weighted sound reduction index, $R_w$; weighted apparent sound reduction index, $R'_w$; weighted level difference, $D_w$; weighted standardized level difference, $D_{nT,w}$.

## Impact sound insulation

In the case of impact sound, the building construction is caused to vibrate as a result of a physical impact, such as footsteps on floors or stairs. The resulting vibration is radiated into other rooms in the building.

## Measurement of impact sound insulation

The site measurement procedures for impact sound insulation are given in BS EN ISO 140-7[3]. Impact sound insulation is measured using an ISO standard tapping machine, which consists of a series of hammers driven by an electric motor so as to produce a continuous series of impacts on the floor under consideration. The resulting sound level in the receiving room is measured in one-third octave bands. The receiving room is usually the space directly below the floor excited by the tapping machine, although the impact sound insulation can also be measured in other neighbouring rooms. As the sound levels will vary with location in the receiving room, they are averaged either across a number of fixed microphone positions or by using a continuously moving microphone.

## Impact sound pressure level, $L_i$

The impact sound pressure level, $L_i$, is the time and space averaged sound pressure level in the receiving room, while the ISO standard tapping machine excites the floor or stairs above the receiving room.

## Standardized impact sound pressure level $L'_{nT}$

The impact sound pressure level, $L_i$, depends on the reverberation time, T, of the receiving room. In the same way that D is standardized to give $D_{nT}$ for airborne sound insulation to avoid changes caused by variations of T, an equivalent descriptor is defined for impact sound as the standardized impact sound pressure level, $L'_{nT}$:

$$L'_{nT} = L_i - 10 \lg \left(\frac{T}{T_o}\right) \text{ dB} \qquad \text{A3.3}$$

## Building Bulletin 93 standardized impact sound pressure level $L'_{nT}$

$L'_{nT}$ is widely used for dwellings, where $T_o$ is taken as 0.5 seconds. In a similar manner to airborne sound insulation for schools, a value of $T_o$ = 0.5 seconds is not appropriate for many school rooms so $T_o$ is specified as the maximum value of $T_{mf}$ given in Table 6 of Building Bulletin 93. This new descriptor for impact sound insulation in schools is written in the same way as the descriptor referenced to a 0.5 second reverberation time, $L'_{nT}$.

## Weighted standardized impact sound pressure level $L'_{nT,w}$

To reduce the impact sound pressure level data from values in frequency bands to a single-number quantity, BS EN ISO 717-2[4] contains a rating curve that can be applied to one-third octave band values of $L'_{nT}$ from 100 Hz to 3.15 kHz. The rating curve is used to calculate the following single number quantity: the weighted standardized impact sound pressure level, $L'_{nT,w}$.

It is important to note that impact sound insulation is measured in terms of an absolute sound level, so that a lower number indicates a better standard of impact sound insulation. This is the opposite of airborne sound insulation, which is based on differences in levels so that a higher number indicates a better standard of airborne sound insulation.

## References


1. BS EN ISO 16283-1: 2014. Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.
2. BS EN ISO 717-1: 2013. Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.
3. BS EN ISO 140-7: 1998. Acoustics - Measurement of sound insulation in buildings and of building elements - Part 7: Field measurements of impact sound insulation of floors.
4. BS EN ISO 717-2: 2013. Acoustics - Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation.

# Appendix 4 Design Guide for sports halls, swimming pools, gymnasia, dance studios and other normally unfurnished activity spaces

Sports halls, swimming pools, gymnasia, dance studios and other normally unfurnished activity spaces shall be designed to achieve a mid-frequency reverberation time ($T_{mf}$) given in Building Bulletin 93. Compliance with this $T_{mf}$ criterion may be demonstrated by one of the following methods:

1. Measurement of the $T_{mf}$ in accordance with ANC Good Practice Guide[1].
2. Use of established industry standard, commercially available software used for room acoustic prediction to form an acoustic model to predict the average $T_{mf}$ calculated using a minimum of two source positions and six receiver positions at a height within the model of 1.5 m above finished floor level and at least 1 m from the model walls. The receiver positions should be distributed equally over the available space for making real measurements over the whole floor area, excluding the area within the minimum distance, $d_{min}$, from the source according to ISO 3382-2[2].
3. Use of the Sabine formula to calculate both $T_{mf}$ and the reverberation time in the 1 kHz octave band, $T_{1kHz}$. Neither $T_{mf}$ nor $T_{1kHz}$ should exceed the performance standard for $T_{mf}$ for the particular activity space, with the following constraints upon distribution of absorption in the room:
   - Requirement A: a minimum of 25% of the absorption (Sabines) in the 1 kHz octave band provided by at least Class D sound absorption distributed reasonably evenly over at least two non-opposite walls with the absorption located no higher than 75% of the room height above the finished floor level (see figure A4.1).

     and
   - Requirement B: a minimum of 30% of the absorption (Sabines) in the 1 kHz octave band provided by at least Class D sound absorption distributed evenly on the soffit

     and
   - the remaining 45% of the required absorption in the 1 kHz octave band to be provided by finishes on any of the room surfaces.

Evidence of compliance can be provided by submission of the acoustic model results or design calculation together with acoustic laboratory test data for all sound absorbing finishes used in the sports hall construction showing that the installed finishes can achieve the design objective. Assumptions for values used in calculations should be explained and justified where laboratory test data are not available. If either design method is used and the installation of the materials is in accordance with the design calculations, commissioning measurements of the reverberation time would not be required.

Below is a summary of the Sabine calculation method to determine sound absorption requirements:

1. Determine the amount of absorption (in Sabines) required in the 1 kHz octave band, based on the Sabine formula and maximum allowable reverberation time:
   $A_{min\ 1kHz} = 0.161 \times V/T_{1kHz}$
   where $T_{1kHz}$ is taken to be equal to $T_{mf,max}$
2. Requirement A: Minimum area of absorber provided on walls = $0.25 \times A_{min\ 1kHz} / \alpha_{wall,\ 1\ kHz}$
   where
   $\alpha_{wall,\ 1\ kHz}$ is the average absorption coefficient of the wall.
3. Requirement B: Minimum area of absorber provided on soffit = $0.3 \times A_{min\ 1kHz} / \alpha_{soffit,\ 1\ kHz}$
   where
   $\alpha_{soffit\ 1\ kHz}$ is the average absorption coefficient of the soffit.
4. Remaining absorption in 1 kHz octave band can be located on any room surfaces.
5. Check calculated $T_{mf}$ meets performance standard.

It is common practice to provide absorption in a sports hall by use of a perforated metal deck or liner tray with insulation behind. Test data submitted for a perforated metal deck or liner tray must be for the actual deck profile, perforation pattern and sound absorbing profile filler or backing that is installed.

Class A, B C and D absorbers are as defined in BS EN ISO 11654[3].

## Worked examples of the design calculation for absorption in a sports hall

The example calculations are based on the use of acoustic absorption coefficients as defined in Table A4.1.

**Table A4.1 Sound absorption of sample materials**

| Sound absorbing material | Absorption coefficient, α | | |
|---|---|---|---|
| | **500 Hz** | **1 kHz** | **2 kHz** |
| Sports hall floor | 0.04 | 0.05 | 0.05 |
| Painted concrete block | 0.06 | 0.07 | 0.09 |
| Timber doors | 0.08 | 0.08 | 0.08 |
| Sample 1 absorber (sound absorbing wall panel) | 0.90 | 0.90 | 0.90 |
| Sample 2 absorber (perforated liner tray) | 0.65 | 0.60 | 0.55 |
| Sample 3 absorber (sound absorbing blockwork) | 0.25 | 0.30 | 0.30 |
| Sample 4 absorber (sound absorbing ceiling tile) | 0.90 | 0.90 | 0.90 |

In a 30 m x 20 m sports hall of 9 m height, the room volume is 5400 $m^3$. The Sabine calculation ($A = 0.161 \times V / RT$) shows that a minimum 435 Sabines are required to achieve a reverberation time of < 2.0 s in the 1 kHz octave band.

Requirement A: a minimum of 25% of the required absorption in the 1 kHz octave band (109 Sabines) must be provided by class D or better absorption located on the walls

Requirement B: a minimum of 30% of the required absorption (131 Sabines) must be provided by class D or better absorption located on the soffit.

Example 1 illustrates the required calculation when sound absorbing wall panels are used, while Example 2 shows the calculation when using sound absorbing block walls.

### Example 1

Table A4.2 shows the calculation required when using sound absorbing wall panels with a perforated liner tray.

**Table A4.2 Example calculation: perforated liner tray and sound absorbing wall panel**

| | | Absorption area, Sabines | | |
|---|---|---|---|---|
| **Surface** | **Area ($m^2$)** | **500 Hz** | **1 kHz** | **2 kHz** |
| Sports hall Floor | 600 | 24 | 30 | 30 |
| Painted block walls | 768 | 46.1 | 53.8 | 69.1 |
| Timber doors | 10 | 0.8 | 0.8 | 0.8 |
| Sound absorbing wall panel | 122 | 109.8 | 109.8 [Req A] | 109.8 |
| Perforated liner tray | 600 | 390 | 360 [Req B] | 330 |
| Total absorption area | | 570.7 | 554.4 | 539.7 |
| | | **Reverberation time (s)** | | |
| T= 0.161V/A seconds | | 1.5 | 1.6 | 1.5 |

Requirement A: > 109 Sabines to walls, $\alpha_{wall, 1 kHz}$ = 0.9
Minimum area wall panel = 108 / 0.9 = 122 m$^2$

Requirement B: > 131 Sabines to soffit, $\alpha_{soffit, 1 kHz}$ = 0.6
Minimum area perforated liner tray = 131 / 0.6 = 219 m$^2$

Check calculated $T_{mf}$ (1.5 s) is within maximum RT requirement (≤ 2.0 s)

## Example 2

Table A4.3 shows the calculation required when using sound absorbing block walls with a perforated liner tray.

**Table A4.3 Example calculation: perforated liner tray and sound absorbing block walls,**

| | | Absorption area, Sabines | | |
|---|---|---|---|---|
| **Surface** | **Area (m²)** | **500 Hz** | **1 kHz** | **2 kHz** |
| Sports hall Floor | 600 | 24 | 30 | 30 |
| Painted block walls | 526 | 31.6 | 36.8 | 47.3 |
| Timber doors | 10 | 0.8 | 0.8 | 0.8 |
| Sound absorbing block walls | 364 | 91 | 109.2[Req A] | 109.2 |
| Perforated liner tray | 600 | 390 | 360[Req B] | 330 |
| Total absorption area | | 537.4 | 536.8 | 517.3 |
| | | **Reverberation time (s)** | | |
| T= 0.161V/A seconds | | 1.6 | 1.6 | 1.6 |

Requirement A: > 108 Sabines to walls, $\alpha_{wall, 1 kHz}$ = 0.3
Minimum area sound absorbing blocks = 108 / 0.3 = 364 m$^2$

Requirement B: > 131 Sabines to soffit, $\alpha_{soffit, 1 kHz}$ = 0.6
Minimum area perforated liner tray = 131 / 0.6 = 219 m$^2$

Check calculated $T_{mf}$ (1.6 s) is within maximum RT requirement (≤ 2.0s)

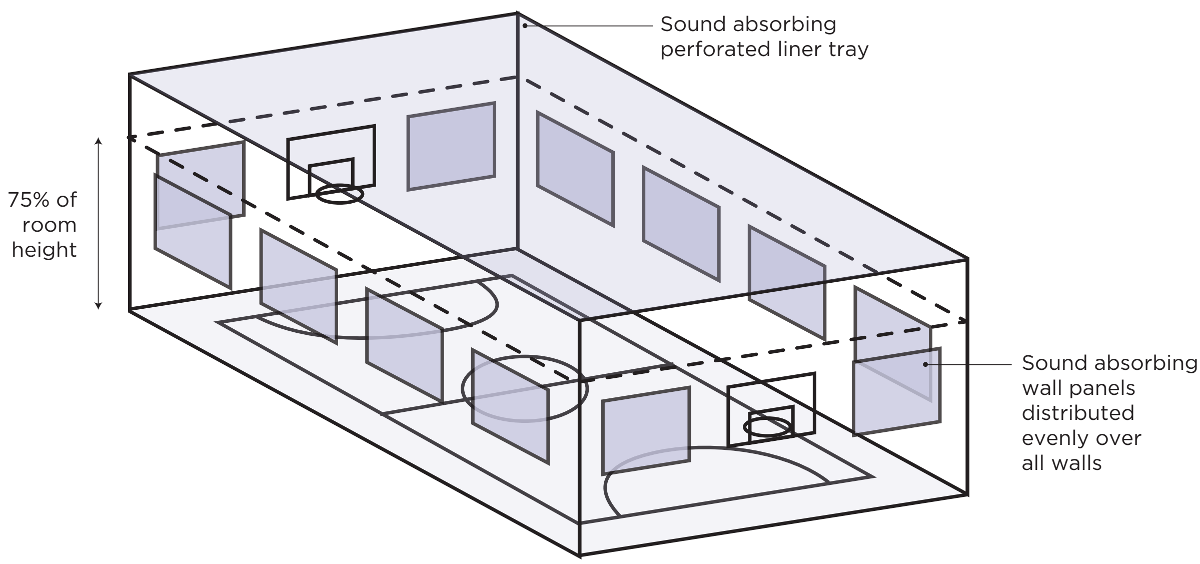


**Figure A4.1 Example of sound absorbing finishes and even distribution of sound absorbing wall panels below 75 % of room height**

## References

1. ANC Good Practice Guide – Acoustic Testing of Schools, ver 2. Association of Noise Consultants, November 2015.
   Free download available from http://www.association-of-noise-consultants.co.uk.

2. BS EN ISO 3382-2: 2008. Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms.

3. BS EN ISO 11654: 1997. Acoustics - Sound absorbers for use in buildings – Rating of sound absorption.

# Appendix 5: Calculating noise from equipment

## A5.1 Assessment of new equipment

In order to determine the potential noise from proposed teaching equipment, manufacturers' data may be used. Sound power levels may have been measured and declared in accordance with recognised standards. Table A5.1 indicates which standards may be utilised to declare noise emissions for different types of equipment.

**Table A5.1: Standards for the assessment and declaration of source sound levels**

| Noise source | Assessment method |
|---|---|
| Projectors including those integral to electronic whiteboards | Noise emissions may be declared in accordance with ISO 9296 (BS 7135-3[1]). This requires sound power levels to be determined in accordance with ISO 7779[2], which is based on the use of ISO 3741[3], 3744[4], 3745[5] and ISO 11201[6] along with definition of operating cycles and points |
| Computer equipment including but not limited to desktop, laptop, server equipment etc. | |
| Workshop machinery and equipment related to resistant materials | Sound power levels determined in accordance with ISO 3741, 3744 or 3745 as appropriate. |

ISO 3741, 3744 & 3745 describe measurements of sound pressure level around equipment over reflecting planes, in reverberant rooms and anechoic chambers such that the measurements may be used to determine sound power level. Other standards, such as ISO 11201 and ISO 11202[7] are concerned with the noise level at an operator position, and as such may give limited information on the overall sound power level of the equipment. It may be difficult to determine the sound power level of the equipment from this type of measurement, which is likely to be influenced by direct sound in a particular direction, as well as reverberant sound in the room. However, this limited information may be useful in assessing the equipment in the absence of more appropriate data.

It should be noted that in most cases, it is not mandatory for manufacturers to measure the sound power levels to these or any other standards, so that new equipment may not necessarily have appropriate data to enable an assessment. If sound power levels are not declared, then a sample item of equipment may be measured in the same way as for legacy equipment described below. There is useful information on noise from computer equipment at the silentpc website[8].

The effect of the potential equipment in the room may be calculated according to the methods described in BS EN 12354-5[9]. Mounting arrangements may have a significant effect if equipment is mounted on lightweight walls, but there may be insufficient information to assess this in detail; the potential effect should nonetheless be noted.

## A5.2 Assessment of legacy equipment

For items of equipment or machinery that will be retained and moved into new classrooms, it may be possible to estimate the sound power level by measuring the sound pressure level and calculating the sound power using the methods of the ISO 3740 series of standards. ISO 3747[10] may be the most appropriate for in-situ measurements; although this can yield engineering grade accuracy, it has significant restrictions on the type and condition of rooms that are acceptable for measurements to achieve this. If a reference sound source is not available for measurements, it may be possible to estimate the sound power based on the measured reverberation time and room volume, although the uncertainty associated with this type of method compared with the methods described in standards is not known.

It should also be noted that the mounting condition and arrangement of the equipment may have a significant effect on the noise levels measured. For example, where a projector is mounted below a suspended ceiling, the measured room noise levels may depend on the absorptive properties of the particular ceiling. The directivity of noise emissions and the effect of room surfaces mean that there is considerable uncertainty associated with in-situ measurements unless the proposed arrangement and room are similar to those measured.

The 3740 series of standards provide details for measuring and accounting for background noise in the measurements. If the source in question is not the dominant source in all relevant octave bands, it may not be possible to reliably determine the sound power of the source. The ISO 9614 Standards provide guidance on the determination of sound power using sound intensity measurements.

A survey carried out by London South Bank University[11] has demonstrated that the sound pressure level from data projectors in secondary school classrooms, measured at 1 m, varied between 34 and 46 dBA. The necessity of undertaking an appropriate assessment is therefore evident.

## A5.3 Simple assessment of sound power

The relationship between sound pressure level (at positions much greater than the critical distance) and sound power may be approximated, assuming a diffuse sound field, using the following equation:

$$L_p = L_w - 10 \lg (A) + 6 \text{ dB}$$

Where

$L_p$ is the sound pressure level in the room, dB

$L_w$ is the source sound power level, dB

A is the total absorption in the room, $m^2$

This equation is a gross simplification of the relationship between the sound power level of a source, its directivity, location in a room and the room response. It neglects direct sound entirely, and the decay with distance in rooms such as classrooms. Measurements of the room sound pressure level may be carried out in accordance with ISO 16032[12], which is indicated in EN 12354-5 as the measurement standard.

The total absorption may be determined with measurements of reverberation time and room volume, and using either the Sabine or Eyring relation. The reverberation time should be measured in octave bands according to, as a minimum, the engineering method of ISO 3382-2[13]. The assessment should be carried out in octave bands, typically between 63 Hz and 8 kHz, and the octave band levels summed to determine the A-weighted level.

The potential noise level in a room may be calculated by measuring the reverberation time in that room (or by calculating according to BS EN 12354-6[14]), and similarly using the above expression to determine a noise level in the room.

Use of this simple method may not yield reliable or accurate results at close proximity to an item of equipment. If the noise level is required at a relatively short distance, i.e. less than two metres, this simple method may not be suitable.  There is little guidance available for calculating the effect of a non-diffuse room acoustic response to a source of sound in relative proximity to the source.  In this case, measurements made at 1 metre from a source in another room may be a reasonable indication of potential noise levels at the same distance in rooms of similar acoustic response.

## A5.4 Calculation of combined effects of equipment in new rooms

When there is more than one item of equipment in a room, the combined effect of all items should be considered. Where some but not all of the equipment may be used at any one time, the cumulative effective of all equipment that may be used simultaneously should be considered. This may require an understanding from the users as to their potential pattern of use.

The equation below may be used to calculate the overall sound pressure level, L, due to all pieces of equipment in the room under consideration, assuming a diffuse sound field:

$$L = 10 \lg \left(10^{L_{p1}/10} + 10^{L_{p2}/10} + \ldots 10^{L_{pn}/10}\right) \text{ dB}$$

where $L_{pi}$ are the noise levels in a diffuse reverberant sound field from each piece of equipment.

This calculation may be undertaken in octave bands for all equipment, or for the A-weighted levels determined in the proposed room for each item. The overall A-weighted broadband level can then be compared against the noise level limit.

## A5.5 Standards for measuring in-situ

The noise from equipment in rooms can be measured following the guidance of the ANC Guidelines, Noise Measurement in Buildings, Part 1: Noise from Building Services[15], and BS EN ISO 16032[12]. The methods of BS EN ISO 16032 also contain useful information on accounting for background noise.

## References


1. BS 7135-3: 1989. Noise emitted by computer and business equipment, Part 3: Method for determining and verifying declared noise emission values (ISO 9296: 1988, Declared noise emission values of computer and business equipment).
2. BS EN ISO 7779: 2010. Acoustics – Measurement of airborne noise emitted by information technology and telecommunications equipment.
3. BS EN ISO 3741: 2010. Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for reverberation test rooms.
4. BS EN ISO 3744: 2010. Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane.
5. BS EN ISO 3745: 2009. Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision methods for anechoic and semi-anechoic rooms.
6. BS EN ISO 11201:2010. Acoustics -- Noise emitted by machinery and equipment. Determination of emission sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental corrections.
7. ISO 11202:2010. Acoustics -- Noise emitted by machinery and equipment -- Determination of emission sound pressure levels at a work station and at other specified positions applying approximate environmental corrections.
8. http://silent.se/pc/
9. BS EN 12354-5:2009. Building acoustics. Estimation of acoustic performance of building from the performance of elements. Sounds levels due to the service equipment.
10. BS EN ISO 3747: 2010. Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering / survey methods for use in situ in a reverberant environment.
11. R Conettaand B Shield. Noise levels of data projectors in secondary school classrooms in the UK. London South Bank University, December 2011.
12. BS EN ISO 16032: 2004. Acoustics. Measurement of sound pressure level from service equipment in buildings. Engineering method.
13. BS EN ISO 3382-2: 2008. Acoustics. Measurement of room acoustic parameters. Reverberation time in ordinary rooms.
14. BS EN 12354-6: 2003. Building acoustics. Estimation of acoustic performance of buildings from the performance of elements. Sound absorption in enclosed spaces.
15. ANC Guidelines - Noise Measurement in Buildings, Part 1: Noise from Building Services., The Association of Noise Consultants, September 2011.

# Appendix 6 Acoustic modelling of open plan spaces

## A6.1 General

Where computer modelling for speech intelligibility is required, the expected open plan layout and activity management plan should be agreed as the basis on which compliance with the Speech Transmission Index (STI) criteria in Table 7.1 can be demonstrated to the Client.

The activity management plan should be used to establish the overall noise level due to the combination of the indoor ambient noise level, all activities in the open plan space (including teaching and study) and transmitted noise from adjacent spaces.

A computer prediction model should be used to calculate the STI in the open plan space. The background noise level to be used in the model is established from the overall predicted noise level due to all intrusive noise activities (including teaching and study from adjacent classbases, but excluding the relevant speech signal) in the open plan space.

The model, which should be capable of simulating an impulse response, should be used to create a three-dimensional geometric model of the space, comprising surfaces with scattering coefficients and individually assigned absorption coefficients for each frequency band. It should allow for the location and orientation of single and multiple sources with user-defined sound power levels and directivity.

The computer model should use octave bands from 125 Hz to 8 kHz and incorporate separate absorption and scattering coefficients, and background noise levels at these frequencies. The model should calculate the STI in general accordance with BS EN 60268-16[4], but with the modifications described in this appendix.

The STI method can discriminate between male and female speech signals. Gender related factors are expressed in different test signal spectra and different weighting factors. Although female speech is generally considered to be more intelligible than male speech, the spectra used for the assessment are the average of male and female speech.

Once the basic geometry of an open plan space has been modelled, single point locations and characteristics of sound sources (teachers or students) and receivers (teachers and students) need to be defined. Locations of teachers and students should be taken from the agreed open plan layout.

The results should be expressed as the minimum and maximum STI values predicted for all student locations. If a receiver grid is used instead of discrete receiver positions, it is acceptable to report the range of predicted STI values given by the 10th and 90th percentile values, provided that a maximum 1.0 m receiver grid is used. STI predictions should be rounded to the nearest 0.05.

STI should be calculated for the following three situations:

### 1. Teacher to student

This is to ensure that oral presentations by the teacher, with a raised voice, are intelligible to the whole class (or, depending on the activity plan, a group). In this situation, the teacher is the source and every student is a receiver.

### 2. Student to teacher

This is to ensure that responses made by students to the teacher, in a raised voice, are intelligible to the teacher. At least three separate calculations are required, one for each of three different student source locations. The student source location should be chosen to represent the furthest student from the teacher.

### 3. Student to student

This is to ensure that conversation within groups of students, at normal voice levels, is intelligible for the students in that group. Communication at very short distances (e.g. 1 m) would normally be intelligible and should not need checking by calculation. The calculations for this situation are to assess speech intelligibility over slightly greater distances, typical of the furthest distance between students in a group. Three calculations are required for each group: one for each of three pairs of students selected to represent the furthest distances across groups. The source and receiver in each pair should be a minimum of 3 m apart. If the open plan layout does not show groups or only has very small groups, then arbitrary locations in the student area should be used that are 3 m apart. The results should be expressed as the minimum and maximum STI values for the three (or more) pairs of students.

Assumptions for source-receiver height, orientation and vocal effort to be made in the assessment of speech intelligibility for each situation are summarised in Table A6.1.

| Table A6.1: Assumptions for source-receiver height, orientation and vocal effort for the assessment of speech intelligibility (n: nursery, p: primary, s: secondary) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Minimum number of source positions | Source(s) | | | | Receiver(s) (omnidirectional) | |
| | | Height (m) | Location | Orientation | Vocal effort | Height (m) | Location |
| Teacher to student | 1 | 1.65 | As defined in the agreed open plan layout | Facing centre of student group | Raised voice | 0.8 (n) 1.0 (p) 1.2 (s) | One at every student location in the group as defined in the agreed open plan layout |
| Student to teacher | 1 | 0.8 (n) 1.0 (p) 1.2 (s) | The furthest student location from the teacher | Facing teacher | Raised voice | 1.65 | As defined in the agreed open plan layout |
| Student to student | 3 | 0.8 (n) 1.0 (p) 1.2 (s) | At typical student locations | Facing other student | Normal voice | 0.8 (n) 1.0 (p) 1.2 (s) | At least 3 m from the student speaking |

## A6.2 Speech levels

Vocal effort is typically expressed as the equivalent continuous sound pressure level at a distance of 1 m in front of the speaker's lips in the free field. For the purpose of STI modelling, suitable values should be used for the seven octave bands from 125 Hz to 8 kHz. The octave bands from 250 Hz to 8 kHz are defined in ANSI 3.5:1997 – Methods for calculation of the speech intelligibility index. Values for the 125 Hz octave band are taken from Rindel et al (2012)[1].

Table A 6.2 contains the sound pressure levels at 1 m in free field that should be used for normal and raised voice effort. These values have been averaged from data for male and female speakers, and hence should be used in the model to represent both male or female speakers.

| Table A6.2: Speech spectra SPL at 1m in front of the speaker's lips in the free-field SPL (dB) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Octave band centre frequency (Hz) | | | | | | | dBA |
| Vocal effort | 125 | 250 | 500 | 1k | 2k | 4k | 8k | |
| Normal voice effort | 46.9 | 57.2 | 59.8 | 53.5 | 48.8 | 43.8 | 38.6 | 59.5 |
| Raised voice effort | 51.0 | 61.5 | 65.6 | 62.3 | 56.8 | 51.3 | 42.6 | 66.5 |

The associated octave band weighting factors to calculate the STI with these source levels are shown in Table A6.3. These are taken from Steeneken and Houtgast (1980)[2].

| Table A6.3: Octave band weighting factors for the calculation of STI | | | | | | | |
|---|---|---|---|---|---|---|---|
| Octave band centre frequency (Hz) | 125 | 250 | 500 | 1k | 2k | 4k | 8k |
| Weighting factor, wk | 0.13 | 0.14 | 0.11 | 0.12 | 0.19 | 0.17 | 0.14 |

## A6.3 Directivity of speech

The source directivity should be modelled by means of a representative three-dimensional directivity pattern for each octave band. Data may be taken from Chu and Warnock (2002)[3].

## A6.4 Calculation of overall noise level (background noise)

The prediction of STI relies on accurate and realistic prediction of the overall noise level (referred to as the background noise) in the open plan space.

The activity plan should be used to establish the overall noise level due to the combination of the indoor ambient noise level, all activities in the open plan space, and transmitted noise from adjacent spaces.

Noise from "all activities in the open plan space" includes teaching and studying but excludes the speech signal from the "source" teacher and student(s) for which the STI is being calculated.

Noise sources that must be included are:

- teachers' speech from surrounding areas (raised voice)
- students talking in surrounding class areas
- noise produced by equipment used in the space (e.g. machine tools, CNC machines, dust and fume extract equipment, compressors, computers, overhead projectors, fume cupboards)
- students working quietly in surrounding areas
- students listening to the speaking teacher or student.

The background noise must be predicted in octave bands from 125 Hz to 8 kHz using the computer prediction model.

Sound power levels that may used to calculate the background noise are contained in Table A6.4.

**Table A6.4: SWL to be used to calculate overall noise level in the open plan space**

| | Octave band centre frequency (Hz) | | | | | | |
|---|---|---|---|---|---|---|---|
| Sound power levels (dB) | 125 | 250 | 500 | 1k | 2k | 4k | 8k |
| Open plan space – general working (per 15 students) | 62 | 62 | 62 | 62 | 57 | 52 | 47 |
| Dining space (per 60 students) | 61 | 65 | 69 | 69 | 61 | 51 | 40 |
| Speech at normal level (per person) | 55 | 65 | 69 | 63 | 56 | 50 | 45 |
| Speech at raised level (per person) | 59 | 70 | 75 | 72 | 64 | 57 | 48 |
| Quiet student being addressed by the teacher (per student)* | 30 | 32 | 32 | 30 | 28 | 26 | 20 |

* This sound power level should be used to account for noise from 'quiet' working, including breathing.

In order to determine the number and vocal effort of people talking – described as operational speech sources in the model for a given number of students and for a specific learning mode - it is convenient to introduce the group size, g, defined as the average number of people per speaking person.

**Table A6.5: Learning modes, associated group size and vocal effort assumed**

| Learning mode | g, average number of people per speaking person | Vocal effort |
|---|---|---|
| Individual study | n/a | n/a |
| Individual instruction | 2 | Normal |
| Paired work | 2 | Normal |
| Small group work | 3 | Normal |
| Large group work | 4 | Raised |

It is also important to consider the dynamic sound source level which occurs as a result of a large number of people talking in a large volume with longer reverberation times. This is due to the Lombard effect where people unconsciously raise their voice as the ambient noise level increases, leading to a spiralling increase in noise levels. A suitable method for modelling the dynamic sound source for simulating the Lombard effect in room acoustic modelling software is described in Rindel et al (2012)[1]. This alternative method may be considered for open plan layouts with a large number of students.

Where there is spatial variation of the background noise level predicted across the receiver locations, but the STI calculation in the computer model only allows for constant background noise levels, then

- the highest background noise level should be used at all receiver positions; or
- the model can be run repeatedly so that each receiver position has its corresponding noise level.

When predicting background noise it is important to consider each activity zone or classroom separately, as each area in an open plan design can be exposed to a different level of noise.

## A6.5 Calculation of barrier diffraction

Screens or barriers are often used in open plan spaces to interrupt the direct sound transmission path and to provide absorption in the space. Although a barrier may block the line of sight, some sound will diffract around the edges of the barrier. Diffraction occurs when a sound wave travels within close proximity of an edge and, in general, is more significant at lower frequencies than at higher frequencies.

When modelling barriers, it is essential that the position and orientation be detailed precisely; the length and height of the barrier is of critical importance and should be included in the model to an accuracy of at least 5 cm.

The absorption and scattering coefficients of the barrier should be included for the octave bands from 125 Hz to 8 kHz. For lightweight barriers it may be important to include transmission loss in these octave bands

The computer prediction model should include a diffraction option. The diffraction option should account for the wavelength of the sound being modelled. Diffraction should be possible to predict from at least the edges prescribed by the model as diffracting, whether the edges are formed by screens, acoustic barriers or room surfaces.

The computer prediction model should be capable of predicting at least one diffraction effect per sound path. Note that some computer models use the term “diffraction” where, in practice, an approximation that simply introduces scattering is being made. This approximation is not appropriate for calculating sound transmission around barriers.

## A6.6 Absorption and scattering of seated students

In general it is not practical, or necessary, to model each person and item of furniture separately. This can result in models with a large number of surfaces, which may take a long time to calculate and can be less accurate than simpler models.

An area of floor occupied by people, for example groups of students and their desks/tables, should be modelled as an acoustically absorbent plane, typically about 1 m above the floor, with appropriate absorption and scattering coefficients. This plane must be “boxed in” with vertical planes forming, effectively, the sides, front and back of the ‘audience’ area. These vertical planes should have the same absorption and scattering coefficients as the audience plane.  Other ‘small’ objects (<2 $m^2$ surface area) such as the teacher and their desk do not need to be included as surfaces in the model.

There is a great deal of published data for absorption coefficients of the audience in auditoria and elsewhere. These are generally quoted as the amount of acoustic absorption (Sabines) per square metre of floor space occupied by the people, although some older data are quoted in Sabines per person. The coefficients are a function of the seating density, furniture and configuration. For example, an adult audience sitting in rows of upholstered chairs with a density of two people per square metre will be more absorbent than students sitting on wooden chairs at desks in a classroom (typically with a density of about one student per square metre).

Acoustic software manuals should be referred to for further guidance on scattering coefficients for areas of people. In the absence of data it is appropriate to model scattering coefficients for people using a value of at least 0.7 in all frequency bands.

Historically, most computer modelling has been limited to the octave bands from 125 Hz to 4 kHz. This is because measurements of acoustic absorption have, for technical reasons, been limited to this range and there is little published data for acoustic absorption coefficients above 4 kHz. For calculation of STI, the range has to be extended to 8 kHz and in the absence of any other data, it is reasonable to use the same coefficients at 8 kHz as at 4 kHz.

At these high frequencies, the acoustic absorption of the air becomes significant, especially in larger rooms, and this can have a real effect on speech intelligibility over large distances. The air absorption is a function of ambient temperature, humidity and air density (barometric pressure) and the model should take this into account. Except in special circumstances, it is appropriate to assume air at 20° C, 50% relative humidity and a density of 1.2 kg/m$^3$.

Different modelling systems use different methods for calculating the effect of scattering. Further information can be found in specific software guidance.

## References


1. J H Rindel, C L Christensen, A C Gade, "Dynamic sound source for simulating the Lombard effect in room acoustic modeling software", Internoise 2012.
2. H Steeneken and T Houtgast. A physical method for measuring speech transmission quality. J. Acoust. Soc. Am. 67 (1), 318 – 325, 1980.
3. W T Chu and A C CWarnock. Detailed Directivity of Sound Fields around Human Talkers. IRC-RR 104, National Research Council, Canada (2002).
4. BS EN 60268-16:2011. Sound system equipment. Objective rating of speech intelligibility by speech transmission index.

# Appendix 7 Assessment of noise from window actuators

Section 1.1.4 of Building Bulletin 93 states that the noise from window actuators, when installed and operating, should be no more than 5 dB above the indoor ambient noise level specified in Table 1 of Building Bulletin 93. It refers to ISO 16032[1] for the measurement of noise from these installations and indicates that assessment of a reference installation may be used to demonstrate suitability.

## A7.1 Use of ISO 16032 to measure noise from window actuators

ISO 16032 concerns measuring and assessing the noise level over the period of operation. The notes below should be used to assist in the application of this standard to measuring noise from window actuators.

The standard notes that windows and doors should be closed for the assessment but clearly this is not possible when measuring the noise from opening windows. It may be necessary to undertake in-situ measurements during a quiet period of the day/evening/night to ensure that external noise ingress does not corrupt the test data. For a reference installation, it may be necessary to measure in an acoustic test chamber. For in-situ measurements in schools, as the required limit from actuators is higher than that for the space, external noise ingress should not prevent a demonstration of compliance with the criteria, although it may not be possible to get accurate measurements of the source under test.

As window actuators may typically operate for only a short period of time and intermittently, the whole operating cycle – from fully closed to fully open to fully closed - should be used to assess the noise.

Any noise associated with the window frame seals brushing open or closed, or the frame opening light impacting on the surrounding frame, may be excluded from the assessment.

The sound level meter should be used on the Fast setting. The following should be reported:

- The number of measurements at each position, determined by paragraph 6.4.1 of ISO 16032
- The actuator operating speed
- For an in-situ measurement, the room conditions, which should preferably be finished and furnished for normal use.

For an in-situ measurement, the in-situ continuous equivalent A-weighted sound pressure level, $L_{Aeq,\,T}$ should be reported.

## A7.2 Use of reference installation

Section 1.1.4 of Building Bulletin 93 identifies that an assessment of a reference Installation measurement may be used as evidence of suitable noise emission performance. The measurement level reported for a reference installation should be the normalised level $L_{Aeq,n}$, in accordance with ISO 16032. It is preferable for the reference installation to be in an acoustic test chamber, such as mounted in a wall in the aperture of a sound transmission suite, to enable results not to be contaminated by background noise. This also enables only the noise that is radiated into the room to be accounted for, as opposed to a mock-up installation within a room where both sides of the opening light are within the room.

It is noted that the reference installation should be based on a window frame that is within a certain size tolerance to be representative of the actual design and the actuator should be the same model as that proposed for the intended installation.

The allowable variables for a reference installation are:

- The window frame opening light should have a width between 0.9 and 1.4 metres, and a height between 0.4 and 1.1 metres.
- The window should be top hung, bottom opening.
- The frame materials, frame fixing and actuator operating speed should be declared.

A project specific assessment, normally based on a reference installation measurement, should be made by a suitably qualified acoustician. The applicability and limitations of the assessment should be made clear and should take account of the following factors that may affect the noise emission of the proposed installation compared with the reference installation:

- frame material
- actuator fixing to the frame
- operating speed of the actuator
- size of the opening light
- type of glazing
- number of actuators.

In addition, when evaluating the potential impact of noise from window actuators, consideration should be given to the control system mode of operation.

Small, but frequent actuator adjustments have the capability to be far more distracting even if the noise levels are low. When evaluating noise from actuators, the compatibility with the proposed control system should be checked by the system designer and actuator manufacturer to ensure that the frequency of operation is not excessive.

Supplier/manufacturer case studies or product guidance may also assist the assessment. For a reference installation, the normalised continuous equivalent A-weighted sound pressure level, $L_{Aeq,\,n}$ should be reported.

## A7.3 Performance Standards

It is intended that the assessment of a reference installation measurement will provide sufficient confidence that the in-situ level will be suitable for the intended use of the space.

For a given normalised level of X dB $L_{Aeq,n}$, the in-situ noise level $L_{Aeq,T}$ should be calculated not to exceed the value of X dBA in a room of at least 50 m$^3$ with a reverberation time of up to 0.8 seconds. Similarly, in a room of at least 150 m$^3$ with three such units installed, the in-situ noise level should not exceed the same value of X dBA as installed. In smaller rooms or in rooms with higher reverberation times then the in-situ levels may be higher.

The assessment of the reference installation should use the normalised level reported to determine the standardised level for the proposed installation, based on the reference reverberation time in the proposed room. The reference reverberation time may be the maximum mid-frequency reverberation time, $T_{mf,max}$, or it may be the calculated reverberation time for that room type. The potential for variation due to the factors indicated above and any others that may be relevant in a particular situation should be reported.

The measured results of installed equipment will be essential in developing an understanding of acceptable levels (from post-occupation evaluation) and of what is achievable.

## References

1. ISO 16032:2004. Acoustics - Measurement of sound pressure level from service equipment in buildings - Engineering method.

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