Scottish Health Technical Memorandum 2045

(Part 2 of 4)

Design considerations

Acoustics

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The production of this document was jointly funded by the Scottish Executive Health Department and the NHSScotland Property and Environment Forum.

NHSScotland, P&EFEx, June 2001

Executive summary

A basic knowledge of the fundamental theory of sound is vital to the appreciation of problems associated with noise generation and control.

Sound is heard as the result of vibration in the air. These vibrations yield pressure fluctuations which can be measured on a sound level meter or heard due to vibration of the human eardrums. A sound wave transmits energy and so energy is required to produce a wave. The sound power of a source will govern the intensity of waves produced.

A given sound source will radiate energy more or less irrespective of its surroundings. The power can be measured in watts. The human ear does not judge sound power in absolute terms, but judges how many times greater one power is than another. This behaviour, combined with the very large range of powers involved, makes it convenient to use a logarithmic scale when dealing with sound power. The decibel (dB) scale of sound power level is based on the logarithm to the base 10.

Sound pressure produced in given surroundings will depend on the acoustic properties of those surroundings. Thus sound pressure does not depend entirely on the source but also on the surroundings. The range of sound pressures experienced in everyday life is very wide and is also conveniently expressed in a logarithmic form.

The basic instrument for measuring sound is the sound level meter, which consists of a microphone, input and output amplifiers, and an indicating device. The microphone transforms sound pressure waves into voltage fluctuations which are displayed on the indicating device.

A system of weighting networks is incorporated which biases the meter readings so that the meter behaves like the human ear. There are three principal weighting networks in use: “A”, “B” and “C”. The “A” weighting gives a good overall agreement between subjective reaction and the weighted sound level.

Most noise standards are based on the “A” weighted scale. Its simplicity is a disadvantage as far as detailed design and calculations are concerned. By breaking sounds down into octave bands, the relative importance of the different frequency bands can be determined. This is often done by comparing octave bands with sets of standard rating curves.

There are a number of rating curve systems in use, for example noise criteria (NC) curves, noise rating (NR) curves and preferred noise criterion (PNC) curves. NR curves have been adopted as the most suitable rating system for use in healthcare premises.

It is important to set appropriate acoustic design criteria in relation to healthcare premises. The parameters to be considered include equivalent continuous sound pressure level, noise rating curves, vibration dosage value, weighted apparent sound reduction index, weighted standardised impact sound pressure level, reverberation time, and speech transmission index.

Mechanical services noise criteria should be specified in terms of NR value for each area under consideration. Appropriate values are quoted for various locations.

Airborne sound insulation of external facades and internal partitions is examined. The degree of airborne sound insulation provided by a facade dictates how much noise from external sources breaks into the building.

Airborne sound insulation performance requirements of internal partitions are closely linked to noise criteria. Internal partition performance requirements should be established through the use of the "privacy factor" concept. This is explained, and recommended levels indicated.

Sources of noise and noise control are discussed and guidance is given on the choice and installation of mechanical services and plant. Noise control aspects covered include planning considerations, construction techniques, plant and machinery and vibration.

The appendices provide a glossary of terms, sample acoustic specification, noise sources, effects of openings in walls and partitions, sound insulation values of glazing, and sound insulation values of walls and partitions.

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1. Introduction

1.1 Acoustics in healthcare premises requires careful consideration for many reasons. Management have statutory obligations, for example to control noise exposure to workers, along with other responsibilities to provide an environment suitable for the various activities undertaken in hospitals.

1.2 Scottish Health Technical Memorandum (SHTM) 2045; *Acoustics*, is published in four separate parts. It is mainly applicable to new sites, but measures have sometimes been given which could also be applied retrospectively to existing premises. It gives comprehensive advice and guidance to healthcare management, design engineers, estates managers and operations managers on the legal requirements, design implications, maintenance and routine measures which should be adopted.

1.3 Noise becomes a health hazard when people are exposed to it in large quantities and when it becomes intrusive to an extent that patients and staff are put under stress. Staff work more efficiently and patients may recover more quickly, if their noise environment is appropriate.

1.4 Noise must be controlled in a number of ways. For example, the interior noise environment must be sufficiently insulated against local exterior noise sources. Conversely, the site must not significantly affect the exterior noise environment.

1.5 Noise from any activity within the premises should not appreciably intrude on other activities. This requires careful positioning of rooms in relation to one another or provision of sufficient sound insulation for the purpose.

1.6 In rooms where communication is important or low noise levels are essential, additional factors need to be taken into account. For example, proprietary acoustic materials on walls may be required to ensure that speech is intelligible and that noise levels created in the room itself do not build up.

1.7 In general, the term “noise” also encompasses “vibration”.

1.8 This SHTM replaces any acoustic guidance given previously.

1.9 Parts of the document may appear repetitive if read from start to finish. However, important points are reiterated as and when necessary to enable a busy design team to find information quickly and in one place.

2. Principles of acoustics

2.1 A basic knowledge of the fundamental theory of sound is vital to the appreciation of problems associated with noise generation and control. The purpose of this chapter is to provide a background to the physics of sound as a basis for the consideration of specific items in the remainder of the part.

Definition of sound

2.2 Sound is heard as a result of vibrations in the air. These vibrations yield pressure fluctuations which can be measured on a sound level meter or heard due to vibration of the human eardrums. There are two primary mechanisms for the generation of sound:

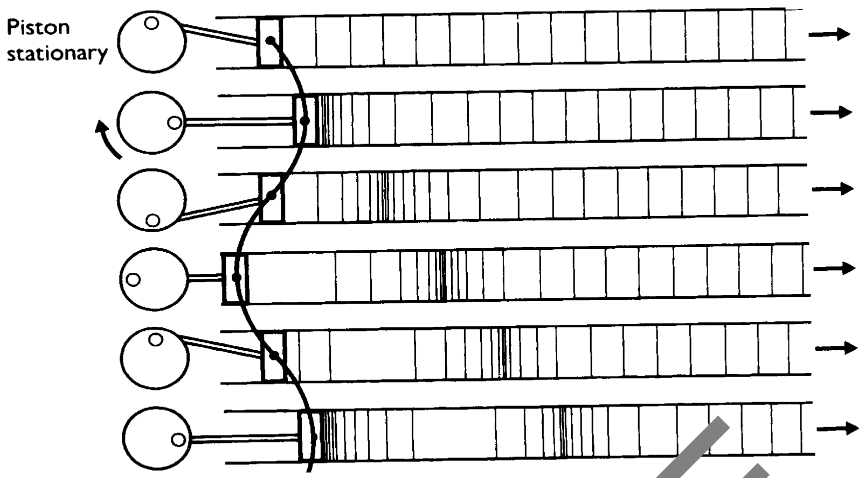
a. any moving surface will cause disturbance of the air around it. Given the right circumstances, the disturbance moves away from the surface as a sound wave;

b. sound may also be generated as the result of a change in the way air or gases are moving. For example, an air-conditioning fan generates noise as the blades change the direction of air flowing through it.

Physical characteristics of sound

2.3 The physical nature of sound can be explained by way of a simple example, such as a piston. If the piston in Figure 1 is suddenly moved forward a short distance, the air immediately adjacent to its face will be compressed. This compressed region will in turn affect the region next to it and the disturbance will pass down the tube, compressing subsequent sections of air in turn. The speed at which the disturbance will pass down the tube will depend upon the density of the air and its bulk modulus. For air at normal temperatures the disturbance will travel at approximately 340 metres per second (m/s).

Figure 1: Mechanism of generating a sound wave



2.4 Unless the action is very extreme, the single pulse of pressure will not produce an audible effect. However, if the piston is driven backwards and forwards by means of a crankshaft running at a suitable speed, it will produce a train of waves which will be audible.

2.5 The rotational speed of the crankshaft and the rate at which waves pass a fixed point will be the same, and is defined as the frequency. It is the frequency of a sound which determines its pitch; high-frequency sounds are heard as high-pitched, and low-frequency sounds as low-pitched. The unit of frequency is the hertz (Hz). The frequency in hertz is equal to the repetition rate in cycles per second. The audible range of frequencies varies widely with circumstances, but for people of good hearing it is normally considered to be between about 20 Hz and 20 kHz. In most practical noise control problems, however, it is possible to consider a rather narrower range of, say, 63 Hz to 4 kHz.

2.6 **Wavelength**. Taking again the example of a piston, the rate at which the piston is operated will determine not only the frequency of the sound waves, but also their spacing. Since the waves travel at a fixed speed, the higher the frequency the closer the spacing. The spacing is related to:

$$\lambda = \frac{c}{f}$$

Where:

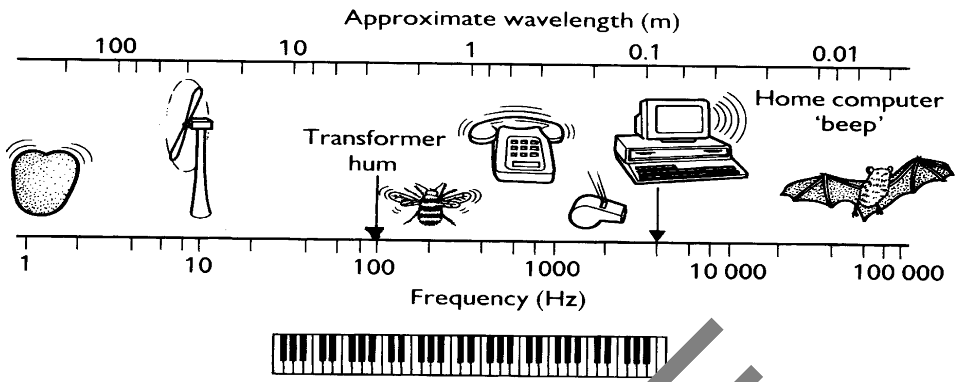
λ is the wavelength (the distance between successive waves) in metres

c is the speed of sound in metres per second

f is the frequency in Hz

For audible sounds, the wavelengths will vary from several metres to a few millimetres. Figure 2 shows a comparison of frequencies and wavelengths against a standard piano keyboard.

Figure 2: Comparison of frequencies and wavelengths



2.7 **Sound intensity**. A sound wave transmits energy, and no energy is required to produce a wave. The sound power of a source will govern the intensity of the waves produced. The greater the intensity of a given wave, the greater will be its loudness.

2.8 **Sound power and sound power level**. Under normal conditions, a given sound source will radiate energy more or less irrespective of its surroundings, in the same way that a 1 kW electric fire will radiate 1 kW of heat. The power in each case can be measured in watts. Actual sound sources can cover a range from about 10-12 watts up to many millions of watts.

2.9 The human ear does not tend to judge sound powers in absolute terms, but judges how many times greater one power is than another. This behaviour, combined with the very large range of powers involved, makes it convenient to use a logarithmic scale when dealing with sound power. This leads to the decibel (dB) scale of sound power level, which is based on the logarithm to the base 10. This enables one source to be related in power to any other source.

2.10 In order to describe the power of a source in absolute terms, however, it is necessary to have a reference level. The normal reference (in the metric system) is the picowatt (10_{-12}watts).

2.11 The sound power level (L_w) is related to the sound power (W) of a source by:

$$L_W = 10 \log_{10}(W/W_0)\text{dB}$$

where

$W_0 = 10^{-12}$ watts and

W = source sound power in watts.

The multiplier 10 is a scaling factor to produce a convenient size unit – the decibel, as opposed to the larger bel – in the same way that we can convert from cm to mm by the relationship 10 mm = 1 cm.

2.12 For example, if the sound power of a given source is 10^{-3} W, the sound power level is given by:

$$L_w = 10 \log_{10}(10^{-3}/10^{-12})$$

$$= 10 \log_{10} 10^9 = 90 \text{ dB re } 10^{-12} \text{ watt}$$

Sound power level is denoted by L_W. Other descriptors still in common use include SWL (sound watt level) and PWL (power watt level). Examples of sound power levels are given in Table 1.

2.13 **Sound pressure level.** The sound power from a source, as indicated previously, can be compared with the power from an electric fire. However, the temperature in the area in which the fire is located will depend upon the thermal properties of its surroundings. Similarly, the sound pressure produced in given surroundings will depend on the acoustic properties of those surroundings (see Figure 3). The sound produced in a confined space will be very different from that produced in the open air. Thus, the sound pressure does not depend entirely on the source but also on the surroundings. The range of sound pressures experienced in everyday life is very wide and is also conveniently expressed in a logarithmic form.

2.14 Sound power and sound pressures are related in a manner analogous to electrical power (W) and voltage (V). The corresponding relationships are as follows:

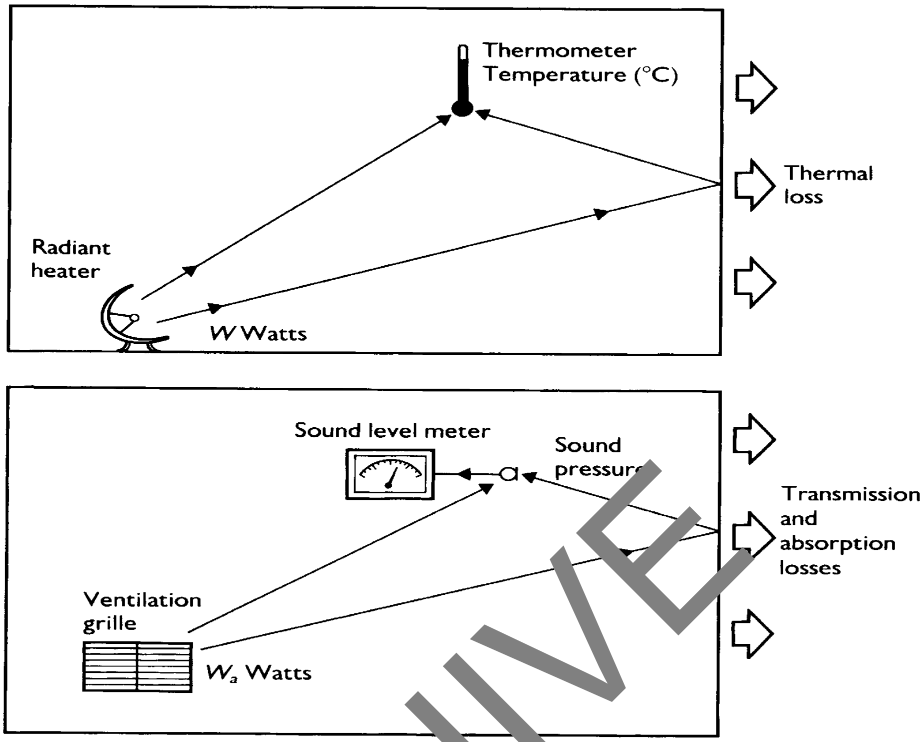
Electrical power	Sound power
power $W = V^2/R$	power $W = p^2/z$

where p is the sound pressure and z is the acoustic impedance of the transmitting medium. In the case of electrical power, R is the resistance or electrical impedance.

Table 1: Sound power levels

Acoustic power (watts)	dB re 10^{-12} W	Typical sources
$1\ 10^{8}$	200	Saturn booster rocket
$1\ 10^{7}$		
$1\ 10^{6}$	180	
$1\ 10^{5}$		
$1\ 10^{4}$	160	Boeing 707 at full power
1000		
100	140	75 – piece orchestra
10		
1	120	Chainsaw
0.1		
0.01	100	
0.001		Average motor car
$1\ 10^{-4}$	80	
$1\ 10^{-5}$		Normal voice
$1\ 10^{-6}$	60	
$1\ 10^{-7}$		
$1\ 10^{-8}$	40	
$1\ 10^{-9}$		Whisper
$1\ 10^{-10}$	20	
$1\ 10^{-11}$		
$1\ 10^{-12}$	0	Threshold of hearing

Figure 3: Thermal and acoustic analogy



2.15 Taking the acoustic case further:

$W = p^2 \times \text{constant}$

Expressing this in logarithmic form relative to reference power and pressure, this becomes:

$\text{Log}_{10} (W/W_0) = 20 \log_{10} (p/p_0) + \text{constant}$

or, in decibel terms:

$10 \log_{10} (W/W_0) = 20 \log_{10} (p/p_0) + \text{constant}$

This is the equation relating the sound pressure level and sound power level in any given circumstances. The constant is defined by the circumstances. This leads to the definition of sound pressure level (L_p):

$L_p = 20 \log_{10} (p/p_0)$ where $p_0 = 2 \times 10^{-5}$ N/m^2 (Pa)

2.16 **Pure tones**. So far, the sounds discussed have been those corresponding to an idealised crank system which produces a pure sine wave consisting of one frequency only. Sounds of this type are relatively rare in nature but are important because, in theory, any sound can be regarded as consisting of a suitable mixture of these simple tone sounds.

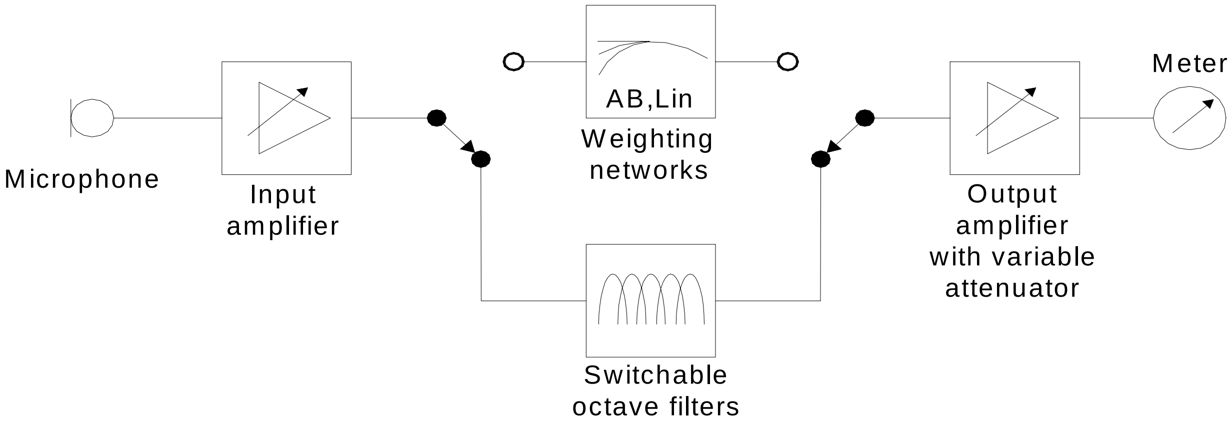
2.17 **Periodic sounds**. Musical notes, the sound of a diesel engine, the hum of a transformer, or the screech of a circular saw consist of simple or complex mixtures of pure tones. The number of pure tones involved is finite and results in a sound whose waveform repeats itself regularly. Such sounds are referred to as periodic. With the use of suitable analysis equipment it is possible to pick out the individual components.

2.18 **Broadband or random sounds**. Many other sounds are composed of an infinite mixture of inseparable components which combine to produce a waveform which never repeats and is unpredictable in the future. This applies to the noise of a fan, the roar of the wind, or the additive effects of a large number of unrelated sounds. With such sounds it is impossible to separate individual components. These sounds can only be divided up into bands of energy.

2.19 Because of the differing behaviour of long and short wavelength sounds, it is necessary to know whether high – or low – frequency sounds are present when dealing with a noise problem. It is therefore necessary to be able to divide sounds into suitable bands of frequency. For most purposes, division into octave bands is adequate. Octave bands are frequency bands which cover a 2-to-1 range of frequencies; for example, the 1 kHz octave band covers the range from approximately 707 to 1414 Hz. The nominal "centre frequency" of each band is equal to the geometric mean of the upper and lower frequencies. The standard octave bands have centre frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, etc. Where more detailed information is required, a finer sub-division may be used. Bands one-third of an octave wide are the most common of the finer subdivisions.

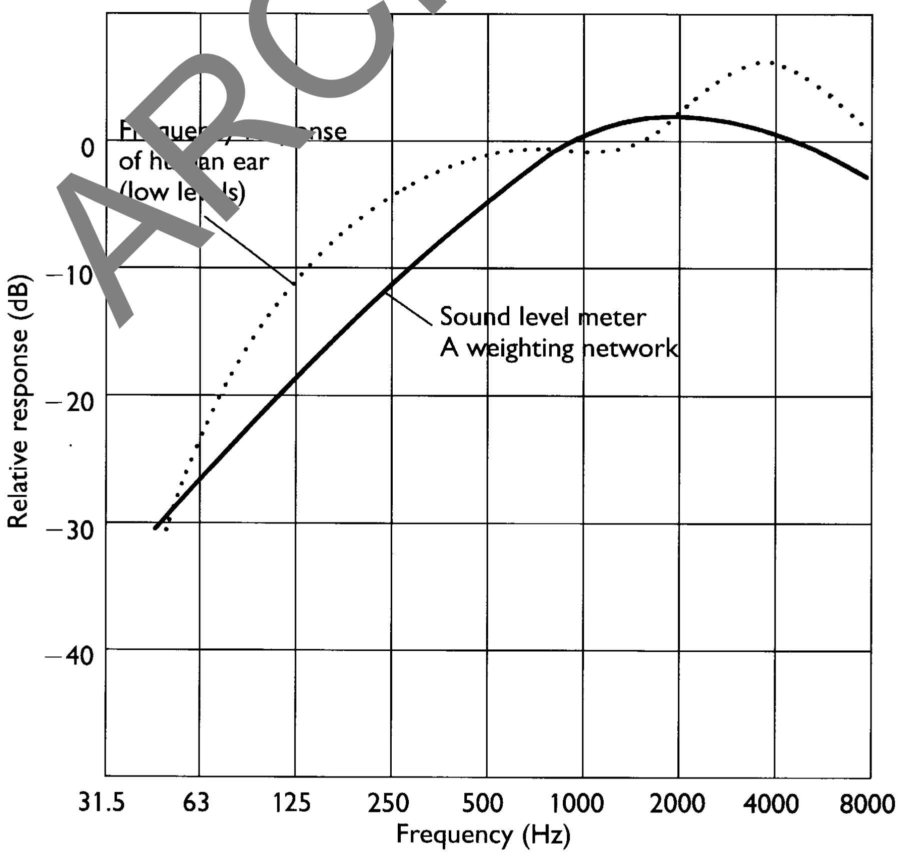
2.20 **Basic measurements**. The basic instrument for measuring sound is the sound level meter, which consists of a microphone, input and output amplifiers and an indicating device. This arrangement is shown diagrammatically in Figure 4. The microphone transforms sound pressure waves into voltage fluctuations, which are gain amplified sufficiently to activate the indicating device. It should be noted here that, just as a thermometer measures temperature and not the heat output of an electric fire, so the sound level meter registers sound pressure; it cannot read sound power directly. Range switching has to be incorporated to enable a wide range of sound pressures to be measured.

Figure 4: Schematic diagram of a sound level meter



2.21 Since the ear is not equally sensitive to all frequencies, a meter which measured overall sound pressure level would not be a very good indication of the loudness of a sound. A reading of 70 dB might represent either a nearly inaudible low-frequency sound or a loud sound at middle frequencies. Figure 5 shows the relative response of the human ear at low noise levels (the response changes at higher levels) for different frequencies.

Figure 5: Relative human ear response and "A" weighting network



2.22 In order to make the sound level meter give readings which are representative of human response, a system of weighting networks is incorporated which biases the meter readings so that the meter behaves in a manner comparable with the human ear. There are three principal weighting networks in existence – “A”, “B” and “C”, but it has been found that the “A” weighting gives a good overall agreement between subjective reaction and the weighted sound level, for any generally similar noise source. Consequently the “A” weighting is normally used for most situations. Figure 5 also shows the “A” weighting curve.

2.23 Most noise standards have been based upon the “A”-weighted decibel. As a method of measuring noise levels, it has the advantage that an assessment of the level can be made with a single reading of the meter. Unfortunately this simplicity is a disadvantage as far as detailed design and calculations are concerned. The information that a given noise source produces a level of x dBA gives no indication of whether the energy is concentrated at low frequencies or high frequencies. If any curative measures or preventative design measures are required, it is necessary to know over what part of the frequency range the noise is concentrated, since the behaviour of high- and low-frequency sounds is very different.

2.24 By breaking the sounds down into octave bands, the relative importance of the different frequency bands can be determined. This can be done either by applying the weighting effect of the network to the individual octave bands, which enables the relative importance of the different bands to be assessed, or alternatively by comparing the octave bands with sets of standard rating curves.

2.25 **Rating curves**. There are a number of rating curve systems in use, the most common being noise criterion (NC) curves, noise rating (NR) curves and preferred noise criterion (PNC) curves. NR curves are widely used throughout Europe, and have been adopted as the most suitable rating system for use in healthcare premises.

2.26 **NR curves**. The NR curves shown in Figure 6 are generated by the formula:

$L = a + bn$

where

L is the octave band sound pressure level for NR level n;

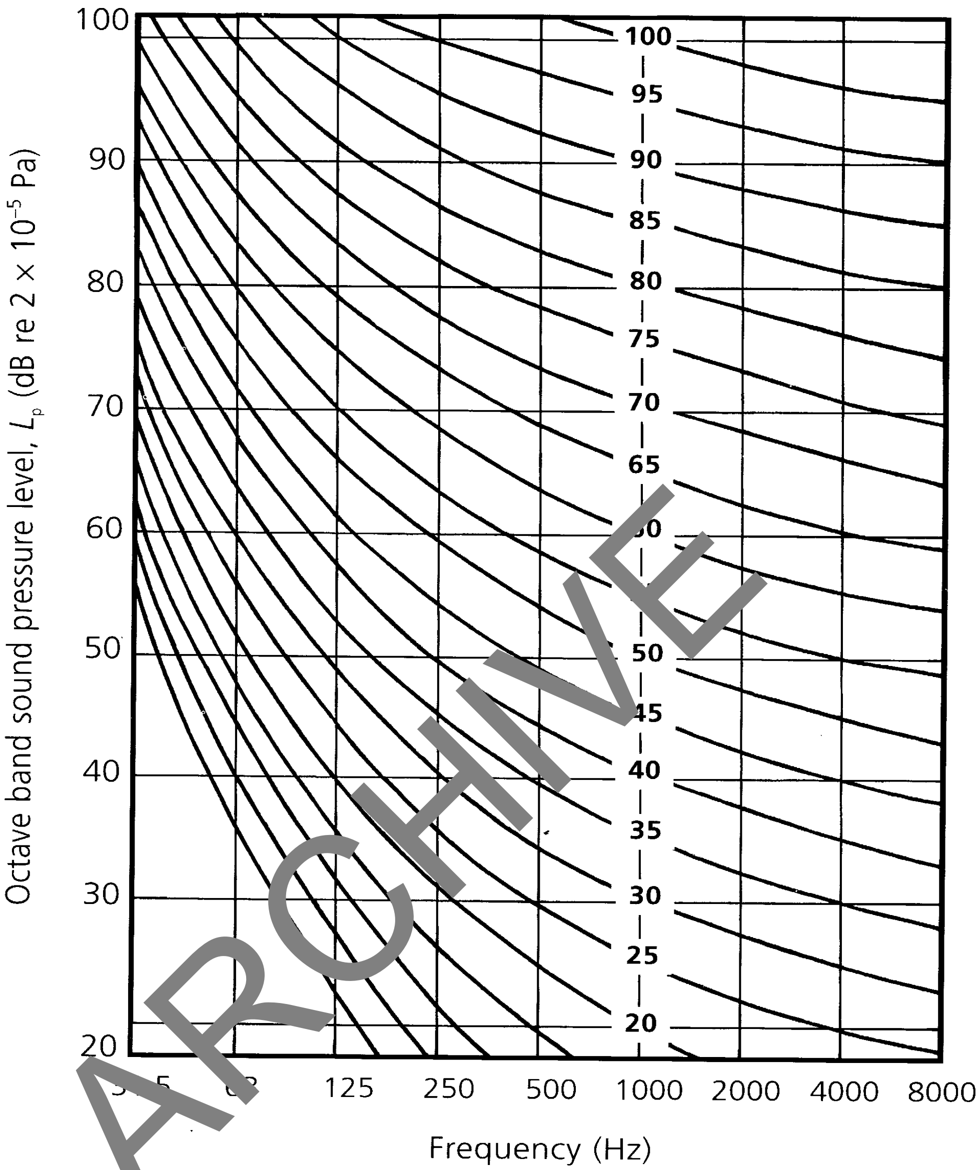
a, b are constants taken from the table below:

Octave band centre frequency (Hz)							
	63	125	250	500	1k	2k	4k
a	35.4	22	12	4.8	0	-3.5	-6.1
b	0.87	0.87	0.93	0.97	1	1.02	1.03

2.27 NR levels can be determined from the above formula and table. However, they may also be determined by plotting the octave-band values under consideration in Figure 6. The NR value is then the lowest value curve which is not exceeded by any part of the octave band spectrum.

2.28 **Equivalent continuous sound pressure level (L_{eq}).** L_{eq} is the continuous sound pressure level which contains the same amount of sound energy as a varying noise over the measurement period. It can be considered as the "average" noise level.

Figure 6: NR curves



Note that NR values should only be stated as integers and are defined at 1 dB intervals.

2.29 L_{eq}'s can be quoted as octave band values for direct comparison against NR curves. Alternatively, octave band values can be A-weighted and summed to give an overall value, designated L_{Aeq}. For further guidance see 'A guide to measurement and prediction of the equivalent continuous sound pressure level L_{eq}' by the Noise Advisory Council, published by HMSO.

2.30 Other statistical parameters (L_n). In general, L_n is the sound pressure level in dB which is exceeded for n% of the measurement period. For example, background noise is normally measured using L_{90} (or L_{A90} if A-weighted), and is the sound pressure level which is exceeded for 90% of the measurement period Similarly, L_{10} is the sound pressure level exceeded for 10% of the measurement period and is used mainly to measure road traffic noise.

Decibel arithmetic

2.31 Addition and subtraction. Since decibel scales are logarithmic, sound power levels and sound pressure levels cannot be added or subtracted in the way that normal numbers can. For example, if two sound sources of 100 dB are to be added, the procedure is as follows:

Source A: $100\, dB\, re\, 10^{-12}\, watt = 10 \log_{10} \frac{w}{w_0} = 10 \log_{10} \frac{w}{10^{-12}}$

w = 0.01 watt

Source B: 100 $dB\ re\ 10^{-12}\ watt$ = 0.01 watt

Total = 0.02 watt

hence 0.02 watt = $10 \log_{10} \frac{0.02}{10^{-12}}$ dB

= 103 dB

that is, 100 dB + 100 dB = 103 dB

From this procedure it can be seen that when two identical levels are added, the result will be an increase in level of 3 dB. When adding or subtracting decibels, Table 2 can be derived.

Table 2: Adding / subtracting decibels

Addition – If the levels differ by	The following should be *added to the higher* level
0 to 1 dB	3dB
2 or 3 dB	2dB
4 to 9 dB	1dB
10dB or over	0dB

Subtraction – If the levels differ by	The following should be *subtracted from the higher* level
more than 10dB	0dB
6 to 9 dB	1dB
5 or 4 dB	2dB
3dB	3dB
2dB	5dB (approx)
1dB	7dB (approx)

For example:
34 dB + 37 dB = 39 dB
41 dB – 36 dB = 39 dB

2.32 This rule can be used to combine individual octave band readings to obtain overall dB(A). For example, if the following octave band readings were predicted in a design calculation, what would the dB(A) level be?

Frequency (Hz)	63	125	250	500	1k	2k	4k
Octave band readings (dB)*	63	50	48	45	40	35	30
"A" weighting (nearest whole number)	-26	-16	-9	-3	0	1	1
"A" weighted octave band levels	37	34	39	42	40	36	31
Combining octave bands	39		44		43		31
		45				43	
					47 dB (A) Total		

* dB re 2 x 10^{-5} Pa (N/m^2)

2.33 **Multiplication**. Where a large number of similar sources are to be combined, logarithmic multiplication's can be used. For example, what is the total sound power level from five individual sources, each with a sound power level of 90 dB?

$L_{W1} = 10\log_{10}W = 90$ dB

$L_{W2} = 10 \log_{10}(W \times 5)$

$= 10(\log_{10}W + \log_{10}5)$ (add logarithms to multiply)

$= 10(\log_{10}W + 0.7)$

$= 10\log_{10}W + 7$

$= 90 + 7 = 97$ dB

Vibration

2.34 When a surface or structure oscillates backwards and forwards fairly rapidly, the motion is referred to as vibration. The rate at which this oscillation takes place is the frequency of the vibration measured in hertz (Hz).

2.35 Vibration may be caused by a continuous oscillating force from, for example, a rotating fan. On the other hand, a momentary force due to an impact such as a door being slammed can set the surrounding structure into free vibration which gradually decays away.

2.36 The amplitude of vibration is commonly described using various measures. To understand this, consider a surface vibrating to and fro either side of its mean position. The amplitude of the movement may be described by the distance the surface deflects either side of the mean position. This is referred to as displacement and is usually measured in either millimetres (mm) or micrometres (µm). To complicate matters, displacement may be measured in terms of the absolute magnitude (peak displacement) or in terms of a time average "root mean square" (RMS) displacement. For steady forced vibration the peak displacement is 1.4 times as great as the RMS displacement. For impacts the difference between peak and RMS is greater and can only be determined by measurement.

2.37 As well as displacement, the amplitude of vibration may be described in terms of the velocity or acceleration of the oscillating surface. The units of measurement are generally mm/s for velocity and m/s^2 for acceleration. As with displacement, both peak and RMS values may be used. In order to distinguish the velocity at which a surface vibrates from the velocity at which such a vibration travels away from its source (to other parts of the building for example), the former is termed particle velocity.

2.38 Vibration displacement, particle velocity and acceleration are usually measured in engineering units, for example mm/s but as with sound pressure they can also be measured on a logarithmic ratio scale, that is, in decibels (dB). For the purposes of these guidelines the use of engineering units is recommended.

2.39 Consideration of vibration of buildings and associated mechanical plant is usually limited to the frequency range 1 Hz to 1 kHz. Higher frequencies, although relevant to designers of machinery, are rarely a consideration in the design of a building. Consideration of lower-frequency movements such as building sway are outside the scope of this document.

2.40 The acceptability of vibration to the occupants of a building depends on the following physical factors:

a. amplitude;

b. frequency;

c. direction (vertical or horizontal);

d. intermittency and duration (if not continuous).

To judge the acceptability of vibration in occupied areas, the factors of amplitude and frequency are combined as the weighted vibration level, analogous to the A-weighted sound level. Different criteria are set for vertical and horizontal vibration.

2.41 If vibration is not at a steady level, for example where it is caused by railway trains passing close to a building, the duration and frequency of train passbys must be taken into account. This is done by using the vibration dose value (VDV), which can be measured directly using special equipment.

3. Specification of acoustic design criteria

3.1 This chapter covers the setting of appropriate acoustic design criteria in relation to healthcare premises. Emphasis has been placed on achievable and practical criteria which are straightforward to use. Consideration has also been given to the extent to which the various criteria lend themselves to commissioning surveys. Each of the following parameters should be considered for each type of room in the development. The sources which may affect the noise environment inside rooms are given in Chapter 4.

Parameters

3.2 **Equivalent continuous sound pressure level (L_{eq})**: a method of expressing sound pressure levels measured over a given time period. Can be quoted as frequency-dependent values or an overall A-weighted value, designated L_{A90}. See paragraphs 2.28-2.29 for more details.

3.3 **Noise rating (NR) curves**: a system for quantifying frequency-dependent noise levels with a single number. Used for the assessment of both mechanical services and intrusive noise. See paragraphs 2.26-2.27 for more details.

3.4 **Vibration dose value**: an index used to reflect the annoyance caused by whole-body vibration, which takes into account varying amplitude of weighted acceleration and the duration and frequency of intermittent vibration events.

3.5 **Weighted apparent sound reduction index (R'_w)**: used to quantify the airborne sound insulation performance of building elements.

3.6 **Weighted standardised impact sound pressure level ($L'_{nT,w}$):** used to quantify the impact sound insulation performance of building elements.

3.7 **Reverberation time (RT)**: a measure of the “echoic” nature used to describe the acoustical character of an internal space.

3.8 **Speech transmission index (STI)**: a value between 0.0 and 1.0 used for the objective quantification of audio systems.

Mechanical services noise

3.9 The levels of mechanical services noise encountered within an occupied building are rarely so high as to be considered "dangerous". Therefore, mechanical services noise should be controlled in order to provide an acceptable and, wherever possible, pleasing and appropriate acoustic environment for the occupants.

3.10 Mechanical services noise criteria should be specified in terms of an NR value for each area under consideration. Appropriate values are given in Table 3.

Table 3 Mechanical services noise criteria

Location	Recommended NR noise level for mechanical services noise
Operating theatre, single bed ward	30
Private office, meeting and consultation room	30
Lecture theatre	30
Multi-bed ward, waiting room	30
Staff room, recreational room, cafeteria	35
General office	35
Corridor, laboratory	40
Washroom, toilet, kitchen	40

3.11 The list given above is not exhaustive. Where an area is not listed, the most similar location should be selected and the appropriate criterion specified.

3.12 The noise criteria given above apply to the sum of noise from all services installations and should include duct-borne fan noise, noise from terminal units, noise break-out from ducts, airflow-generated noise, noise from roof-mounted unitary plant, etc.

Intrusive noise

3.13 Intrusive noise is a blanket term used to describe the sum of noise reaching an area from all sources other than the mechanical services installation. Examples of intrusive noise would be:

a. traffic on nearby roads;

b. aircraft flying overhead;

c. plant on neighbouring buildings.

3.14 Intrusive noise criteria should be specified in terms of an NR value for each area under consideration. Appropriate values are given in Table 4.

Table 4 Intrusive noise criteria

Location	Recommended NR level for mechanical services noise
Lecture theatre	35
Operating theatre, single bed ward	35
Private office, meeting and consultation room	35
Multi – bed ward, waiting room	40
General office	40
Staff room, recreational room, cafeteria	45
Corridor, laboratory	50
Washroom, kitchen, toilet	50

3.15 The NR values given above are in terms of equivalent continuous sound pressure level (L_{eq}) for “worst-case” situations, that is, the periods during which intrusive noise is likely to be at its highest value. For example, traffic will generally be loudest during rush-hour periods. PPG 24 ‘Planning and Noise’ quotes World Health Organisation recommendations of 35 dB(A) at night in a domestic bedroom. The guidelines in this document are consistent with these recommendations.

3.16 The list above is not exhaustive. Where an area is not listed, the most similar location should be selected and the appropriate criterion specified.

Vibration

3.17 Guidance on satisfactory magnitude of building vibration with respect to human response is given in BS 6472.

3.18 Continuous vibration should be assessed in terms of the RMS value of the frequency-weighted acceleration in the floors of occupied areas. Limits may be set in terms of the direction of vibration: either foot-to-head vibration (z axis) or back-to-chest/side-to-side (x or y axis). Generally, the former corresponds to vertical, and the latter, horizontal vibration. However, if occupants are lying down, as in the case of hospital wards, this correspondence is reversed, the z axis corresponding to horizontal and the x or y axis to vertical vibration. Limits are recommended as multiples of a base value:

Base value of frequency-weighted acceleration:

z axis	0.005 m/s^2 RMS
x, y axis	0.0035 m/s^2 RMS

Multiplying factors for different types of accommodation corresponding to a low probability of adverse comment are as follows:

Operating theatre, precision laboratories	1
Wards, residential - day	2 to 4
- night	1.4
General laboratories, offices	4
Workshops	8

3.19 Intermittent vibration should be assessed in terms of the vibration dose value (VDV) measured in units of $m/s^{1.75}$ in the floors of occupied areas. VDV values corresponding to a low probability of adverse comment for different types of accommodation are as follows:

	z axis ($mm/s^{1.75}$)	x, y axis ($mm/s^{1.75}$)
Wards, residential - day	0.2 to 0.4	0.14 to 0.28
- night	0.13	0.09
General laboratories, offices	0.40	0.28
Workshops	0.80	0.56

In the case of operating theatres and precision laboratories, it is not appropriate to make allowance for the intermittency of events, so the maximum frequency-weighted acceleration should be within the limits set in paragraph 3.18 for continuous vibration.

3.20 It is difficult to design a mechanical installation to achieve a particular vibration level elsewhere in the building. Therefore, it is a more practical approach to also specify vibration limits for plantroom structures; this should be in terms of frequency-weighted acceleration level. Appropriate limits are:

Plantrooms on occupied floors	0.015 m/s^2
Plantrooms above and below occupied floor levels	0.050 m/s^2
Remote plantrooms	0.100 m/s^2

Airborne sound insulation – external facades

3.21 The degree of airborne sound insulation provided by a facade (or facade element) dictates how much noise from external sources breaks into the building. Hence the facade performance requirement is dependent upon the relevant intrusive noise criterion, and the facade performance itself need not necessarily be specified.

3.22 Under certain circumstances, it may be deemed necessary to specify the actual performance requirement for a facade. Even when the criteria are in terms of intrusive noise limits, the facade performance requirement will have to be identified at some point during the design process. The procedure for calculating facade requirements is laid out below:

a. noise data for external sources should be obtained from surveys, predictive calculations, or a combination of both;

b. the appropriate intrusive noise criterion (or criteria) should be used in conjunction with the external noise data to calculate the facade performance requirement in terms of weighted apparent sound reduction index as defined in BS 5821 Part 3.

Airborne sound insulation – internal partitions

3.23 The airborne sound insulation performance requirements of internal partitions are closely linked to intrusive noise criteria. When an office is to be located adjacent to a noisy plantroom, for example, the procedure for "external facades" should be adopted, taking due account of intrusive noise criteria. The noise from the plantroom intruding to the office should not exceed the intrusive noise criterion given for the office, and the sound insulation performance of the partition would be calculated using the methods referred to above.

3.24 Another very important factor is "privacy", that is, the extent to which conversation and activities in one area are audible in another area. In order to ensure adequate privacy throughout a development, internal partition performance requirements should be established through the use of the "privacy factor" concept.

3.25 Privacy factor is based on knowledge of:

a. the subjective privacy requirement for the areas under consideration;

b. the mechanical services noise levels in the areas under consideration.

In all cases, the most stringent privacy requirements and services noise levels should be used as the basis for determining the privacy factor.

3.26 Privacy factor (PF) is defined as:

$PF = R'_w + B$

where:

R'_w is the site-tested weighted apparent sound reduction index;

B is the total NR noise (mechanical services + intrusive) criterion.

3.27 Table 5 identifies the privacy factor requirements for various subjective situations.

Table 5 Privacy factor categories

Privacy factor(PF)	Resulting Privacy assuming normal speech
<70	Clearly audible and intelligible
70 - 75	Audible but not intrusive
75 - 80	Audible but not intelligible
>80	Inaudible

Table 6: lists recommended privacy factors for various locations within healthcare premises. The PF for each area is for any part of the building envelope enclosing that room, regardless of what is adjacent to it. Once the PF has been used to calculate the required R'_w values for each room, the higher of the two R'_w values should be used where adjacent rooms have different requirements. For example, if a consultation room (PF80, R'_w 50) is next to a cafeteria (PF70, R'_w 35), the dividing partition construction must achieve R'_w 50.

Table 6 Recommended privacy factors assuming normal speech effort

Location	Recommended privacy factor (PF)
Maternity, nursery, A&E	80*
Operating theatre, single bed ward, multi – bed ward, privacy office, meeting and consultation rooms, lecture theatres	80
Laboratory, staff room, general office	75
Waiting room, corridor, wash room, toilet, kitchen, recreation room, cafeteria	70

*These rooms are identified as areas which are likely to have an increased voice effort as a noise source, that is, shouts or screams. 20 dB should therefore be added to the PF of any adjacent room to account for this. Paragraph 3.28(b) gives details of corrections to the PF which may be required in certain areas if an increased voice effort (raised voices, shouts, screams) is anticipated.

3.28 Examples of use of privacy factor:

a. from Table 6, the required PF for private offices is PF80. The mechanical services noise criterion (B) for private offices is NR30 (see Table 3). Therefore the required weighted apparent sound reduction index (R'_w) of all partitions enclosing the office is given by:

R'_w = PF - B

where

B is the mechanical services noise criterion from Table 3

= 80 - 30

= 50 dB

Hence the required site-tested weighted apparent sound reduction index (R'_w) of all the office partitions is R'_w 50 dB;

b. when voices are raised, the sound level in the source room can be increased by up to 20 db, and therefore, to achieve the same level of privacy, the following correction factors should be added to the PF of the adjacent (receiver) room:

Voice effort	Voice effort correction factor
Raised	5
Shout	10
Scream	20

Hence for a different voice effort, say a patient screaming (in a maternity ward for example), the required weighted apparent sound reduction index

(R'_w) of the dividing partition could be increased by 20 dB. Therefore, where the private office in the example above is located next to a maternity ward, the R'_w of the office wall becomes:

R'_w = PF - B + C

= 80 - 30 + 20

= 70 dB

3.29 Similar procedures should be adopted for other construction elements which may affect internal noise transfer, for example suspended floors and ceilings. The performance requirements here would be in terms of weighted suspended ceiling normalised level difference ($D_{n,c,w}$) and weighted floor normalised level difference ($D_{n,f,w}$). For design calculation purposes these parameters would be treated in exactly the same way as R'_w.

Impact sound insulation

3.30 "Impact sound" refers to noise generated in areas due to some form of impact (for example footsteps) on the surface of the floor in the area above. The first step in setting appropriate design criteria is to identify those areas where this should be a consideration. For guidance, it is recommended that all areas in regular use should be effectively insulated from impact sound.

3.31 Impact sound is assessed using the parameter weighted standardised impact sound pressure level ($L'_{nT,w}$), which is defined in BS EN ISO 717-2: 1997. Due to the fact that this parameter relates to noise level measurements in a room as opposed to a characteristic of a building element, impact sound criteria are given in terms of a "not to be exceeded" value.

3.32 The impact sound insulation performance of floors between occupied areas should be such that, when tested, the arithmetic mean of all results for $L'_{nT,w}$ does not exceed 61 dB. Furthermore, no individual value should exceed 65 dB.

Reverberation times

3.33 Internal surface finishes should be selected such that the reverberation times (RTs) at all frequencies between 125 Hz and 4kHz are within the ranges shown on Figure 7. However, at the 125 Hz octave band the RT may be allowed to rise to 2.5 times the mean value.

3.34 The RT of a room can be calculated by use of the following formula:

$$T_{60} = \frac{0.163V}{A}$$

where

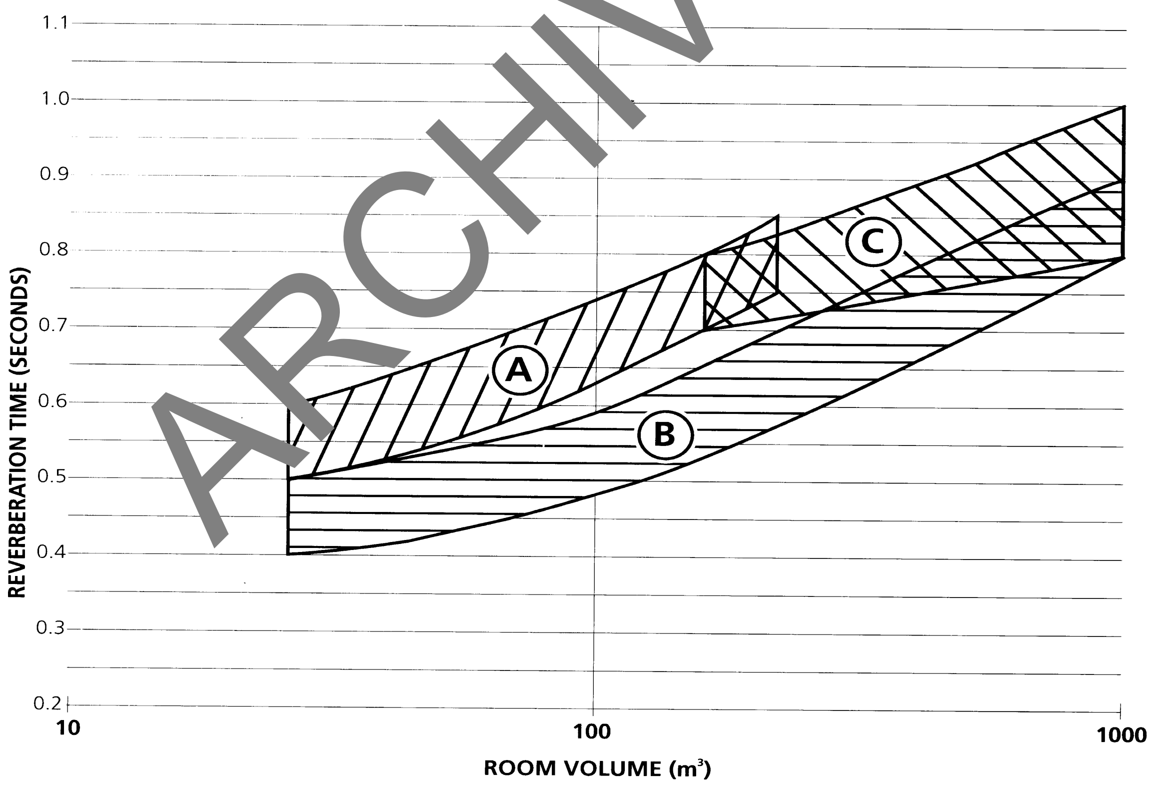
T_{60} is the reverberation time (seconds)

V is the room volume (m^3)

A is the total acoustic absorption (m^2)

The appropriate RT for a specific room also depends on the room function. For example, a lecture theatre needs a reasonably low RT so that speech is intelligible. Figure 7 gives recommended RTs for different room functions and different volumes. For example, a ward 100 m^3 in volume should have a reverberation time of approximately 0.5 seconds.

Figure 7: Reverberation times



Audio system intelligibility

3.35 A minimum standard for intelligibility of audio systems may be found in BS EN 60849 (reference should also be made to BS EN ISO 717-2). This standard requires that audio systems with an emergency function must achieve a minimum speech transmission index (STI) of 0.5 in all coverage zones. STI is a quantity used to assess intelligibility of speech, for example through audio systems and across lecture rooms. An STI of 1.0 indicates 100% intelligibility while 0.0 indicates zero intelligibility.

3.36 It is recommended that **all** audio systems, whether for emergency use or not, should achieve a minimum STI of 0.5 in coverage zones.

3.37 STI may be estimated and measured using the rapid speech transmission index (RASTI) method as defined in BS EN 60268-16. This method is specialised and would normally only be used by an acoustic specialist or public address system designer.

Environmental noise

3.38 Environmental noise criteria may be stipulated by a local authority or planning body. This is particularly true for new developments, which will be subject to the guidance within PPG 24 'Planning and noise'.

3.39 Environmental noise criteria should be specified for set locations over given time periods.

3.40 Such criteria should be presented in one of two ways:

a. as an absolute level, for example, "noise emissions from the site shall not exceed an L_{Aeq} of x dBA when measured at the site boundary over a 15 minute period between 00.00 and 07.00 hours";

b. as a relative level, for example, "noise emissions from the site shall not exceed the existing background noise level at the boundary by more than x dBA between 00.00 and 07.00 hours"; x can be zero, that is, "noise emissions from the site shall not increase the existing background noise level at the boundary".

3.41 In the case of paragraph 3.40(b), compliance with the criteria would require knowledge of the existing background level. Background noise level is expressed as a statistical parameter, L_{A90}, which is defined as the A-weighted noise level exceeded for 90% of a specified measurement period. L_{A90} should be measured at the time of day or night relevant to the operating hours of the noise source.

3.42 For further guidance refer to BS 7445 – 'Acoustics: Description and measurement of environmental noise'.

3.43 Detailed guidance on setting environmental noise criteria is beyond the scope of this document. Where environmental noise criteria have not been established by the relevant authorities, it is recommended that an acoustic specialist be retained to perform the necessary measurements and analyses.

4. Sources of noise and provision of noise control

4.1 This chapter is concerned with measures that can be taken to restrict the generation and propagation of noise. It also gives guidance on the choice and installation of mechanical services plant and machinery.

4.2 Much valuable information on the subjects covered is to be found in the following publications:

a. Noise and Vibration Control – Beranek;
b. Engineering Noise Control – Bies and Hansen;
c. Handbook of Noise Control – Harris;
d. Fundamentals of Acoustics – Kinsler and Frey;
e. The Effects of Noise on Man – Kryter, KD;
f. Noise Control in Building Services – Sound Research Laboratories Ltd;
g. Noise Control in Industry – Sound Research Laboratories Ltd;
h. The Noise Handbook – Tempest;
i. Handbook of Noise and Vibration Control – Warring;
j. Practical Guide to Fan Engineering – Woods of Colchester.

4.3 Four aspects of noise control are discussed in this chapter:

a. planning considerations;
b. constructional techniques;
c. noise control of building services plant and machinery;
d. vibration control.

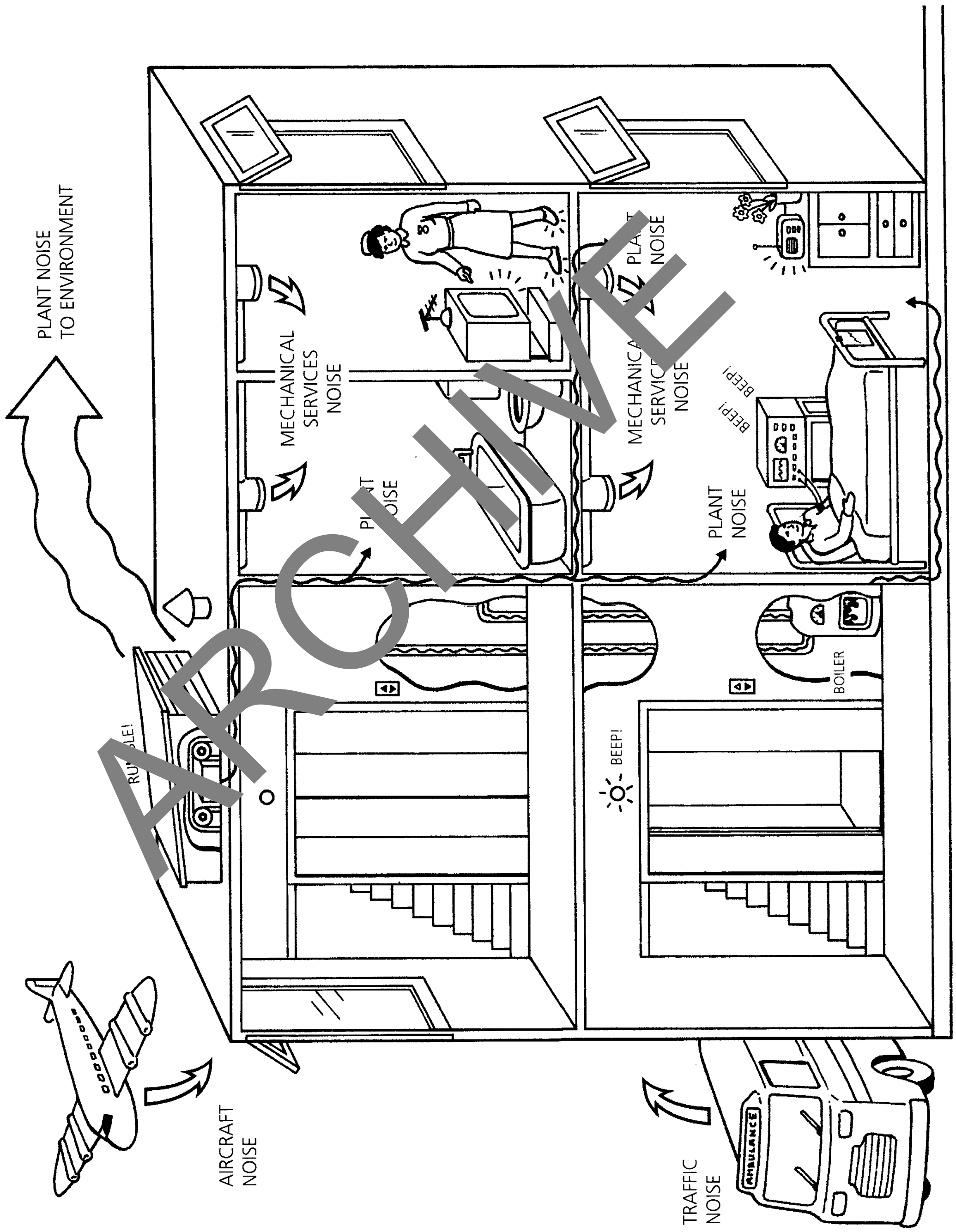
These considerations are interdependent, however, and the degree of protection afforded by any one will affect the need to take other types of precaution. Important as noise control is, it must be recognised that it will sometimes have to be subordinated to other needs such as operational convenience. This makes it all the more important to estimate potential noise nuisance to patients and staff. If the potential sources of noise can be identified, it may be possible to plan so as to achieve the necessary reduction in noise simply and within the cost allowances for building. If such consideration is not given during the early stages of planning and design and the conclusions are not incorporated into the working drawings, the result may be a noise level which is permanently distressing to patients and staff, and considerable further expenditure which could have been avoided may be needed on palliative measures.

4.4 Appendix 3 lists typical sources of noise and suggests the stages at which these should be investigated for new development of healthcare premises.

Planning considerations

4.5 The noise level within a building will depend both on the noise entering it from outside (exterior noise) and on that generated within the building itself and transmitted through the building (interior noise).

Figure 8: Exterior and interior noise



Exterior noise

4.6 Exterior noise is generated by external sources either outside or inside hospital grounds. Examples of sources outside grounds are road traffic, railways, roadworks and, in some locations, football grounds, building operations, industry and aircraft. Examples of sources inside grounds are ambulance bays, car parks, loading bays, boilerhouses, workshops, laundries, kitchens, and heavy equipment of all types. Some of the sources listed may form an integral part of a building, and they may generate noise which, being transmitted through the building structure itself, is strictly interior noise. Areas which are sensitive to exterior noise include wards, operating theatres, delivery rooms, treatment rooms, examination and consulting rooms, and staff sleeping areas.

4.7 In the great majority of cases, particularly in urban areas, most noise from outside the healthcare site will be generated by road traffic. It is not appropriate to give guidance on typical road traffic noise levels, and each situation should be assessed on an individual basis using the results of detailed noise surveys. The value of building high in order to escape from noise generated at street level has often been overrated. Whilst traffic noise will disturb occupants of the first two storeys of a building more than those above, noise does not diminish appreciably with further increases in height above the third floor.

4.8 Noise generated by aircraft and trains, whilst more intermittent than road traffic noise, is often of higher intensity. When sites for healthcare projects are being considered close to airports, the following information should be obtained: the frequency of operation, type and noise levels of aircraft; whether extensions are likely to be made at local airports or aerodromes; whether flight paths are likely to be altered; and what areas are likely to be allocated for maintenance testing. A similar information-gathering exercise should be performed for rail traffic. Note that railway cuttings reduce the spread of noise whereas embankments, viaducts and steel bridges promote it.

4.9 The noise produced by factories and other commercial premises must also be considered.

4.10 Noise from the types of source described above can be assessed comparatively easily and this should be taken into account when choosing a hospital site. Distance provides some defence against noise, and a site as far away from outside noise sources as possible should be chosen if other relevant considerations permit. Within the selected site, buildings should be placed so that noise-sensitive areas are removed as far as practicable from exterior noise sources, and are screened by less sensitive departments. Screening by means of walls and artificial mounds in the hospital precincts can be of some use, particularly in reducing high-frequency sounds. Grass rather than hard paving should be laid wherever it is a possible alternative.

4.11 Exterior noise is also produced through day-to-day activity in and around the hospital, for example by ambulances, cars, service vehicles, fuel and stores deliveries, refuse collection, and the movement of goods about the hospital. Deliveries are a common cause of complaint, and careful siting of service areas and their approaches away from the noise-sensitive areas can do much to reduce the nuisance of unavoidable noise. Certain departments of the hospital can also become considerable noise sources (for example boilerhouses, laundries, workshops and kitchens). The need to protect sensitive areas from these sources is one factor to be taken into account in preparing a development control plan. Where noisy departments do not need to be part of the main hospital building, it may be advisable to group them into a separate service area, carefully sited so that noise is minimised. The measures described in paragraph 4.10 apply to exterior noise created on the hospital site insofar as this is compatible with the efficient running of the hospital. Measures against internal transmission of noise from hospital sources are described in later sections.

4.12 Noise from construction and demolition sites can cause great disturbance and can be particularly troublesome where healthcare developments are phased. There is increasing consciousness in the construction industry of the annoyance and disturbance caused by noise from building sites, and measures are taken to reduce it by attenuating noisy plant, providing screens and hoardings, and good site planning. The best current practice should be emphasised in any contract.

Interior noise

4.13 Where noise-creating departments are part of a main building, care must be taken to separate them as far as possible from sensitive areas such as wards. In particular, when the main kitchen, which is a constant source of both impact and airborne noise throughout the day, has to form part of the main complex, it should preferably be sited below, and not above, sensitive areas to facilitate the insulation of equipment and machinery and to reduce the spread of impact noise.

4.14 Within ward units, much noise is generated from the ancillary rooms. These rooms, being frequently in use, tend to have constantly open doors. Some form of noise attenuation between open wards and rooms of this kind is therefore desirable. Central dish-washing and sterilization facilities can help to reduce noise generated within ward units.

4.15 Special attention must be paid to both siting and internal planning of units such as children's wards, maternity, nursery wards, accident and emergency departments, and out-patient departments, some of which are generators of noise and some of which require protection from noise. It has been found, for example, that the noise level in a nursery can be as high as 80 dB(A) at night. High maximum noise levels are likely to be encountered in for example a delivery room, which should have sufficient privacy between units to minimise distress during labour.

4.16 Noise can easily spread through a building via the corridors, and the use of acoustically absorbent ceilings will help to reduce this transmission (see paragraph 4.35). Noise can also be transmitted through the mechanical services installation where ductwork penetrates partitions and floors/ceilings. Crosstalk attenuators need to be provided in these penetrations to maintain privacy.

Constructional techniques

4.17 As has previously been suggested, the most efficient way of combating noise is to plan to avoid it. However, the planning of a hospital is shaped by many factors, and the most desirable requirements from the point of view of protection from noise will frequently have to be subordinated to other competing requirements, such as the need to place hospitals within busy urban areas, or to establish the most efficient juxtaposition of rooms and departments for nursing care or for service deliveries. The greater the extent to which planning requirements for noise control have to be sacrificed, the greater will be the need to provide adequate constructional protection, and the more difficult it will be to provide such protection.

4.18 When properly applied, constructional techniques can prove most effective in potentially very difficult situations. During site inspections, the competent test person (see the 'Overview and Management responsibilities' part of this SHTM) should check for poor workmanship such as gaps in partitions, bad joints and bridging of acoustic isolating features such as cavities in walls or resilient layers in floors.

4.19 It is important to distinguish between the functions of sound absorption and sound insulation. The former is a quality dependent on the nature of the surface of a material and will determine the degree to which sound, on striking the surface, will be absorbed or reflected. Sound insulation is the prevention of the transmission of sound through a barrier (for example wall, ceiling, floor); the degree of sound insulation obtained will be dependent on the construction of the barrier. There is no direct and necessary relation between the sound insulation value of a partition and the sound absorption values of its surfaces. Insulating materials are used to prevent the spread of noise from one room to another. Sound absorbents are used to control reverberant sound within a room.

Principles of sound insulation

General

4.20 The degree to which a partition, when considered alone and under certain standard conditions, provides sound insulation is known as its sound reduction index, expressed in decibels (dB). For the purposes of this document, sound insulation performance should be quoted in terms of weighted apparent sound reduction index (R'_w), a single number used to describe frequency-dependent performance from 100 Hz to 3150 Hz.

4.21 Sound can be transmitted through the air or through a structure, and can be classified as either airborne or impact sound. Airborne sound is generated in the air and is then transmitted through the air and structures to adjoining rooms. Impact sound is caused by blows on a structure, commonly footfalls, or by moving objects around on a floor above the room in question. The type of insulation needed against sound will vary according to the nature as well as the magnitude of the sound.

Insulation against airborne sounds

4.22 Airborne sound exists as a vibration of air molecules; the heavier the barrier through which sound passes the greater will be its reduction, since there will be more resistance to it. However, the efficiency of sound insulation depends not only on weight but also on the completeness and uniformity of the barrier. Areas of weak insulation within a barrier (such as a door in a partition) will have a marked effect on the efficiency of the barrier as a whole (this aspect is discussed more fully in paragraph 4.27). Sound insulation, particularly in lightweight partitions, is also affected by the "stiffness" of the material. "Flabby" materials consisting of heavy particles weakly held together will form more effective insulators than stiffer varieties. The stiffness referred to here is the stiffness of the barrier as a panel, not the rigidity of the edge fixing; as a rule, firm fixing at the edges is an advantage.

4.23 Sound insulation can also be achieved by a "discontinuity" or separating of the parts of a structure. The principle behind a discontinuous structure is to allow one structure to vibrate without too much disturbance of any neighbouring structure by providing a cushion of air between the two structures (or, in the case of floating floors, a resilient cushioning material) and a restricted number of fixed links between the two structures. However, a narrow enclosed volume of air gives only a moderate degree of cushioning, particularly against low-frequency sounds, and cavities in discontinuous constructions should be as wide as possible. All walls give better insulation of high- rather than low-frequency noise. For a given weight of partition, a cavity wall construction gives higher insulation at the middle and high frequencies than that given by a single leaf-construction, but not at the low frequencies unless the spacing is relatively large, say 150 to 200 mm.

Insulation against impact sounds

4.24 Impact insulation is best provided by a resilient layer, for example carpet in direct contact with the impacting force. For functional reasons it may be necessary to provide the resilient layer under a harder-wearing surface (for example foam-backed vinyl sheet), the surface layer being in the form of a raft. Much more resilience is needed under a floating raft than is needed in a direct floor-covering to gain comparable sound reduction. Unfortunately a material such as carpet, which effectively reduces impact sounds, will not provide good insulation against airborne sound and, conversely, increasing the weight of a floor will not necessarily improve its ability to reduce impact noise. Equally, the noisiness of a floor for walking on should not be confused with its efficiency for impact insulation – a wooden raft may be noisy to walk on but may provide a good reduction of impact noise transmitted to the floor below.

Direct and indirect sound transmission

4.25 Sound is transmitted between rooms both directly by the shortest route for example through a partition between the source and the receiving room and indirectly, by any other path such as windows, flanking walls or corridors. It is essential to know the relative amounts of sound transmitted via the direct and indirect paths if appropriate sound insulation measures are to be taken. The weakest path is always the critical one.

Application of sound insulation

General

4.26 The great variety of departments or units in typical healthcare premises, each with different requirements for quiet and with varying potential for making noise, makes the correct specification of sound insulation requirements quite complicated. The privacy factor concept introduced in paragraph 3.24 provides a method for calculating requirements using privacy and background noise levels as a basis. In general, this method will require the majority of internal partitions to have a weighted apparent sound reduction index(R^{l}_{w}) somewhere in the range of 40 to 50 dB. Lower values would rarely be acceptable, whilst higher values place onerous requirements on construction.

4.27 The effect of windows, doors, and other openings in walls and partitions must be borne in mind. A good sound insulation barrier can easily be compromised if the effects on insulation of openings incorporated in walls are not properly appreciated. The tables in Appendix 4 illustrate the effect of different types of window and door on the insulation values of walls and partitions. Decisions taken regarding the required or desirable insulation value of walls and partitions must always be made with full knowledge of the openings contained within them. When calculating the overall R^{l}_{w} of a room, it should be noted that the average sound insulation of all elements is below the insulation value of each individual element, for example an R'_w40 floor, R'w40 all and R'_w40 ceiling would give an overall R'_w of 35 dB.

Doors

4.28 Doors should be of solid construction and have as few perimeter gaps between the door and frame as possible. A heavy, well-fitting door in an R'_w 40 partition would typically give an overall R'_w of 35 dB. Significant gaps would decrease this by 6 dB or more. Higher insulation values for a single door cannot be obtained without the use of expensive "refrigerator" methods of closure. Double swing doors, whilst they may frequently be necessary in hospitals, have little insulation value because of the air gap round the doors. The fitting of an edge sealing of rubber or plastic will increase the insulation value. Automatic door closers, rubber or plastic gaskets and stops can help to ensure quieter operation of doors; the former also help to make the door a more efficient sound barrier. Quiet action latches are also necessary. PVC and rubber doors can be quiet in operation but have little insulation value due to air gaps and low weight. If rooms requiring quiet have to be sited near noisy areas, it may be necessary to screen the quiet area by providing an extra door with a baffle lobby lined with absorbent material. This can provide an insulation value of up to R'_w 40 dB. If space does not permit the construction of a lobby in conditions where a door or doors of high insulation value are needed, twin doors may be fitted, either single or double; these doors should always, however, be more than 100 mm apart and as much sound-absorbent material as possible should be introduced into the air space. If the air space is narrow at least one door surface should be covered by the treatment. It should be possible in this way to provide an overall insulation value of R'_w 40 dB.

Windows

4.29 Appendix [illegible] gives a table of typical insulation values for different types of window against admission of exterior noise. It will be seen that the degree of sound insulation of single windows is comparatively small, particularly if windows are open. These figures show the importance of planning and the need to consider noise at development control plan stage. Sealing or double-glazing increases the insulation and may be suggested. The following factors should be borne in mind:

a. in order to maximise sound insulation performance, gaps between panes of glass in double window configurations should be as large as possible;

b. if one leaf of a double-glazed window is efficiently sealed shut, the second leaf may be openable for cleaning purposes, provided it is fitted tightly when shut. Due consideration must be given to potential problems of condensation in these circumstances;

c. the use of sealed windows will require the provision of mechanical ventilation.

Walls and partitions

4.30 Typical values for the sound insulation performance of differing wall/partition constructions are given in Appendix 6. Note that the performance figures are quoted in terms of R'_w which is a **site** measurement parameter. For design purposes, laboratory data in terms of weighted sound reduction index (R_w) may be utilised. However, laboratory data for R_w should be at least 5 dB higher than the R'_w site requirement in order to make allowance for site effects.

Solid constructions

4.31 Solid constructions of block and brick can provide very effective noise barriers. However, very high performance requirements may require constructions so heavy and thick as to be unacceptable.

Cavity constructions

4.32 Cavity constructions can combine high sound insulation performance with relatively low weight. This is particularly true of metal stud plasterboard partitions.

4.33 Folding/sliding partitions can possess good insulation qualities only if fitted to extremely close tolerances. Where suspended ceilings are used, care must be taken to ensure that the effectiveness of the partition as a barrier to noise is not inadvertently lost. In other words, the insulation path through the ceiling of one room via the ceiling space and down through the ceiling of the adjacent room should be as effective as the partition itself.

Floors

4.34 Particular attention must be paid to the insulation value of floors, especially those between noisy parts of the building and wards. Floors should be considered together with ceilings to ensure that the needs of sound insulation and other requirements are met in the most economical way.

Principles of sound absorption

4.35 The distinction between sound absorption and sound insulation has already been made. Generally the use of sound absorbents is to reduce the overall noise level in the room where the sound is generated, rather than to act as acoustic insulation. Their effectiveness in sound insulation is minimal.

4.36 Doubling the amount of acoustic absorption present in a room halves the total sound energy, leading to a 3 dB reduction in reverberant noise level. The efficiency of sound absorption of any particular material varies with frequency. A good absorber should perform well over a wide range of frequencies. Absorbent treatments give most benefit in large rooms where noise sources are confined to some parts of the room only. It is normal to provide most of the absorbent material on the ceiling, this being the surface most exposed. The use of absorbent ceilings is particularly important in corridors to reduce the spread of noise about a building or department.

Application of sound absorption

4.37 When selecting absorptive materials for healthcare premises, due consideration must be given to all hygiene requirements.

4.38 When acoustically absorptive materials are being considered, other factors must be examined such as maintenance and resistance to fire and impact.

Noise control of building services plant and machinery

General

4.39 The effective control of building services noise and vibration is essential to the provision of a satisfactory acoustic environment. The fundamentals may be summarised as follows:

a. judicious selection of plant and equipment;

b. good installation practice;

c. correct operation and maintenance.

4.40 Paragraphs 4.42 to 4.66 below outline some typical sources of mechanical services noise in healthcare premises, along with outline details of appropriate noise control measures.

4.41 Whilst each item is discussed individually, in practice a number may be installed in any one plant area associated with the various environments served. It is therefore the overall noise potential which must be considered by the designer and, to make this possible, manufacturers of plant and equipment should be asked to provide an octave band analysis indicating the sound power level of their product in appropriate cases, defining the conditions of test.

Boilers

4.42 Some noise is usually emitted from the boiler itself, caused by steam blow-down and associated drainage, and also from the combustion chamber, particularly when oil is the fuel medium. In the case of oil burning, the noise generated is predominantly low-frequency and can be most annoying even some distance away from the boilerhouse.

Oil burners

4.43 Some types of oil burner can be particularly noisy, and relative noise production should be taken into account when selecting both boiler and burner for new installations. Where blower-type fans are proposed, the air inlet can often be effectively attenuated by the use of an acoustic plenum/ attenuator or by siting the air intake in a screened position. In some cases the air intake can be connected to the floor trench system, accommodating oil pipework and utilising the system, as a duct for the air supply to the burners.

Oil storage tanks

4.44 Oil storage tank filling connections should be sited away from “quiet zones” to avoid disturbance when deliveries are made.

Pumps

4.45 Particular care should be taken with the installation of boiler feed and condensate return pumps and piping, to avoid water hammer and cavitation, since these can cause severe noises in associated pipework. It is essential that:

a. they and associated pipework are secured on resilient mountings;

b. flexible connections are provided between all pumps and headers or piping;

c. steam-driven feed pump exhausts should be fitted with an approved type of attenuator.

Ventilation and extract fans

Centrifugal fans

4.46 Centrifugal fans used for induced draught, forced draught, air supply and exhaust are often noisy. The following precautions are usually necessary:

a. the fans should be fixed on suitable anti-vibration mountings;

b. they should be designed in relation to the duct installation in order to ensure that they operate on a stable portion of the fan's characteristic curve;

c. the fan housing should, if necessary, be acoustically insulated;

d. suitable bracing should be provided to prevent drumming;

e. flexible sleeving or jointing should be inserted between the fan and ductwork as a standard practice;

f. when choosing a suitable centrifugal fan, preference should be given to the model which, in addition to complying with the above requirements, has the lowest sound rating;

g. for most applications, both room-side and atmosphere-side attenuators should be fitted.

Axial flow fans

4.47 These fans should operate at an efficiency of not less than 80%. Resilient mountings will generally be provided as an integral part of the fan support. Streamlined fairings assist smooth running and reduction of vibration. For most applications, this type of fan will need to be fitted with both room-side and atmosphere-side attenuators.

Propeller fans

4.48 If air noise from these fans is to be avoided, the blade tip speed should be less than 20 lineal metres per second. When the air is allowed a free discharge it should be directed away from any nearby noise-sensitive area, particularly wards. Sufficient distance should be allowed between the fan and weather louvres to avoid risk of obstruction to the air flow.

Ventilation ductwork

4.49 Ventilation ducts are potentially very efficient paths for the transmission of noise. Noise may enter the duct system from outside the building through the main inlet or extract openings and travel against the main airflow; or it may enter from inside the building either through the ventilation openings or direct through the duct wall; or it may be generated within the duct system itself by fans, motors, etc. In hard-surface ducts, noise can travel long distances with very little attenuation, and may be transmitted through ventilation openings and duct walling.

4.50 The reduction of noise per unit length along a duct is a constant and can be calculated. It is very small for unlined ducts, but some attenuation is given by sharp bends if the duct dimensions are larger than about 1 wavelength of the sound concerned. For appreciable noise reduction a length of duct should be internally lined with good sound-absorbing material; in the case of large ducts it may be necessary to subdivide into smaller channels by the use of sound-absorbent splitters. For a given length of treatment, and with the proviso given above, the greatest sound reduction can be achieved by lining a length that contains a bend.

4.51 It is important at the design stage to select suitable air velocities in order to minimise noise transmission. Mean air velocities in ducts should generally be carefully graded. Table 7 lists guideline maximum duct velocities for conventional low-velocity systems.

Table 7 Recommended duct velocities

	Maximum Velocities (m/s)		
NR design levels	Main ducts	Branch ducts	Final run - out
20	4.5	3.5	2.0
25	5.0	4.5	2.5
30	6.5	5.5	3.5
35	7.5	6.0	4.0
40	9.0	7.0	5.0
45	10.5	8.0	6.0

4.52 Ventilation systems should be designed to avoid air turbulence, which can produce airflow generated noise. Grilles and diffusers should generally be of the directional type carefully selected from manufacturers' catalogue data regarding neck velocities, "throw" and noise values. The choice of individual diffusers for a certain NR value in a room will depend on the number of diffusers in the room. For example, if there are four diffusers in a room the NR criterion for each diffuser will need to be 6 dB stricter than the NR criterion for the room.

4.53 The sound insulation of the duct walls should be adequate at every point to sustain the sound reduction achieved via other paths. Where they pass through the walls and floors, ducts should be suitably isolated from the building structure. All holes around ductwork should be packed with suitable sound-absorbent and fireproof material. "Out of flow" type fire dampers should be provided across ducts at points where they pass from one fire compartment to another; in addition, the packing round the ductwork will be required to have a fire resistance equal to that of the compartment wall.

4.54 Ductwork should be suitably braced or stiffened to prevent drumming; if suspended from ceilings it may rest on resilient supports to prevent mechanical vibration being transmitted to the structure. Badly-fitted joints in ductwork will cause noise even at comparatively low velocities.

Pipework for mechanical services

4.55 In order to prevent vibration from equipment being transmitted via pipework it may be necessary to support larger pipework with resilient hangers. Multi-storey buildings may require hot and cold domestic water to be pumped to high levels. Considerable noise can be transmitted from the risers, unless they are insulated from the structure of the building; in some instances it may be necessary to insulate the pipes. High velocities should be avoided.

4.56 Low velocities for steam flow in pipes should be allowed for at design stage. Average velocities may vary between 15 and 30 m/s. Steam traps, automatic air vents, and condensate lifting traps fitted to pipework should be specifically designed to prevent escape of steam or condensate, to minimise noise. If possible, the installation of steam traps and reducing valves should be avoided in noise-sensitive areas. If this is not possible, such plant should be properly insulated. The discharge point of steam and condensate should be sited away from noise-sensitive areas. Boiler "blow-down" piping should be firmly anchored but provision should be made for expansion. The boiler escape valve "blow-off" should be provided with a suitable terminal and be fitted with an attenuator when the boilerhouse is sited adjacent to wards or residential accommodation. Water hammer in steam systems may be reduced if all connections to steam mains are taken from the top of the pipes, the piping laid to fall in the direction of steam flow, and the pipework provided with adequate drain points. Exceptionally, it may be necessary to operate at reduced pressure or to install air vessels in suitable positions.

Diesel-driven standby electric generators

4.57 These are sometimes in or adjacent to the boilerhouse, but they may also be in a suitable room within the hospital buildings and thus near noise-sensitive areas. Noise may be caused by the engine exhaust (an attenuator should be fitted), and by mechanical noise from the engine and housing; to combat this within sensitive areas, the room containing the generator should have good insulation. To lessen noise caused by vibration, the generator set should be mounted on a concrete plinth of adequate mass which rests on suitable anti-vibration mounts. Insulation may be required around the block to prevent the transmission of lateral vibration. Attenuated ventilation should be provided to the room to allow the set to operate satisfactorily without opening doors and windows. Care should be taken in the positioning of the air intake and exhaust.

Air compressors

4.58 Air compressors of both the reciprocating and rotary vane types generate considerable noise. It is preferable to site compressors away from the main hospital building; where two or three larger compressors are placed together it may be necessary to provide a wall of suitable thickness to act as a barrier between the doors of the compressor room and the rest of the hospital.

Mechanical noise from the compressor shell, and the transmission of vibration to the building structure from pipework, can be avoided by the following precautions:

a. the set should be mounted on a concrete block of adequate mass and placed on suitable anti-vibration mounts. A concrete block or inertia base may not be required if the compressor is already heavy and stable enough;

b. the intake should be fitted with an efficient attenuator; large reciprocating compressors can set up high levels of subsonic noise, which may well rattle windows and doors in the vicinity. This cannot be attenuated by ordinary methods, and special measures will therefore be needed to reduce this noise;

c. pipework and conduits should be fitted with flexible connections to break metallic continuity.

Transformers within the hospital building

4.59 Electrical transformers are often sited in rooms or chambers within the hospital building. Although they are stationary, they generate a low-frequency hum which, while hardly noticeable during the day, can be very annoying at night. Transformers should be provided with anti-vibration mounts, and vents should be fitted with attenuated ducts to limit the escape of noise and to attenuate the low-frequency sounds. Where louvres alone are thought to be satisfactory, they should deflect the noise in a downward direction away from occupied areas.

Switchrooms within the hospital

4.60 These are sited in many areas within the hospital building for electrical distribution purposes. Noise from switchgear, contactors, relays etc. may be transmitted through walls and openings unless the following points are considered:

a. free-standing or wall-mounted switchboards should have suitable resilient mountings;

b. open louvres fitted to doors and walls for ventilation should be avoided;

c. technological improvements should be used to ensure that the quietest possible switches and other devices are used.

Lifts

4.61 Lifts should operate quietly and within the vibration limits set out in paragraph 3.18. Lifts sited adjacent to noise-sensitive areas should have electromechanically-operated doors with rubber buffers. The motor room is better located on the roof than in the basement, and internal entrance doors should be well fitted. The lift machine and motor generator (if fitted) should be insulated from the building by resilient mountings. The reversing control gear should be enclosed. The worm gearing should be enclosed and run in an oil bath. Anti-friction sleeve bearings or roller bearings should be provided and have easy means of lubrication. Guide-rail lubricators should be installed on top of the car and counterweight. Reference should be made to SHTM 2024; *Lifts*.

Main kitchen mechanical equipment

4.62 Generally, the main kitchen should be sited away from the wards and other noise-sensitive areas. Some of the machines causing noise are dishwashing machines, food mixers, steam ovens, vegetable-parers, refrigerators, and extract ventilation plant. The installation of fans and ventilation ductwork should follow the principles laid down previously.

Vacuum pumps

4.63 These often cause a noise nuisance when running during operations, and due care should be taken when a selection is made.

Pressure steam sterilizers

4.64 These machines cause airborne and structure-borne noise when working. It is recommended that:

a. the vacuum pump and motor assembly be fixed on separate resilient mountings. If the sterilizer is situated within the TSSU or CSSD it may be necessary to provide a sound insulation jacket for the vacuum pump assembly;

b. the whole sterilizer assembly be secured on anti-vibration mounts;

c. all pipe connections to the sterilizer, for example for steam, water, vacuum, compressed air, and condensate, should be of the flexible type;

d. open louvres in doors and walls of the sterilizing rooms should be avoided, and doors should be self-closing and well sealed. Steam and heat are given off in the sterilizing room, and it is important that adequate ventilation be provided to remove this heat.

Ultrasonic washers

4.65 These can cause severe annoyance to staff working in the vicinity, and due care should be taken in their location and installation.

Laundries

4.66 Noise from laundries is caused by the loading and unloading of linen, tumble-driers, presses, ventilation systems, air compressors, and other equipment. Most of the noise will be airborne through open windows, doors and louvres. However, since the laundry is usually grouped near the boilerhouse and remote from sensitive areas, the siting (together with careful positioning of unloading bays, doors etc.) will usually be sufficient to reduce laundry noise to an acceptable level. In the case of air compressors, however, the precautions outlined in paragraph 4.58 may be needed. Noise levels within such facilities may be high enough to necessitate action being taken under the Noise at Work Regulations 1989 (see the 'Operational management and responsibilities part of this SHTM).

Vibration control

4.67 Sources of vibration which may need consideration are:

a. mechanical equipment such as fans, chillers, pumps, located within the building;

b. railway trains or heavy vehicles passing close to or underneath the building. Occasionally, adjacent industrial premises will emit sufficient ground-borne vibration to make it necessary to assess whether control measures are required;

c. normal activities of the building's occupants.

4.68 Equipment that generates significant levels of vibration is generally located in separate plantrooms. Vibration from such equipment may be expected to be continuous and most evident in the plantroom structure. In practice it is preferred to limit vibration in the plantroom structure, as well as when specifying limits for occupied areas. However, it must be made clear that both sets of limits are to be met. Specialist areas having equipment particularly sensitive to vibration will have their own criteria, which may be an overriding limit. Although microscope manufacturers may be able to give vibration limits for their equipment, specialist advice should be sought with respect to vibration criteria for these areas.

4.69 Vibration from mechanical services installations should be controlled at source, that is, where the equipment is supported from the building structure. Suitable vibration isolation mountings or hangers should be incorporated in all supports. These should be designed to provide adequate isolation efficiencies to achieve the vibration limits in the plantroom structure, taking into account:

a. stability of the mounted equipment;

b. flexibility of the supporting structure: for example, the isolation efficiency of a particular machine/mounting arrangement is less when supported on a suspended concrete slab than on a concrete ground slab.

4.70 Where ductwork or pipework is connected to the plant it will probably be necessary to provide both flexible connectors and vibration isolation ductwork/pipework from the building structure for some distance from the machine.

4.71 The resilience of vibration isolation mountings is generally provided by a steel spring or neoprene element. Where steel springs are used, which can provide higher isolation efficiencies, precautions also need to be taken to prevent higher frequencies which can travel through the spring, being evident as structure-borne noise.

4.72 Vibration from external sources should be assessed carefully, as it is expensive to attenuate. Vibration from road traffic is usually acceptable except in critical areas, which should be kept away from the side of the building adjacent to main roads. Rail traffic may be expected to generate higher levels of vibration. If sensitive areas cannot be located far enough away, the viable solution is to support the areas on isolation pads independent of the rest of the building, that is, without rigid connections. In many cases the only practicable measure is to support the entire building on isolation pads at foundation level.

4.73 Where part or all of a building is vibration-isolated, it is necessary to take other precautions to provide a fail-safe construction which prevents rigid service connections or backfill short-circuiting the isolation. Details of such precautions are given in BS 6177.

4.74 The selection and design of the isolation system should be carried out by a structural engineer, with specialist advice. An on-site survey of vibration levels is essential to determine the level and frequency content of the vibration on which the design would be based.

4.75 It is not generally necessary to control vibration generated by the activities of occupants, and limits are not practicable. The only exception to this is in and immediately adjacent to specific areas, for example audiological test suites and areas containing high-powered microscopes, in which cases specialist advice should be sought.

Appendix 1: Glossary

Absorption coefficient
The proportion of sound lost when incident at a surface.

Absorptive attenuator
Attenuator that incorporates glass-fibre and mineral-wool materials, effective over a wide range of frequencies.

Ambient noise
Encompassing sound (at a given place), being usually a composite of sounds from many sources near and far. Should not be confused with "background noise".

Attenuation
Noise reduction.

Attenuator
Noise-reducing device – often colloquially and incorrectly known as a "silencer".

Background noise
Total of interference from all sources in a system used for the production, transmission, detection, measurement or recording of a signal acoustically quantified using L_{90}.

Breakout
The escape of sound from any source-enclosing structure such as ductwork, metal casings and building envelopes.

Broad-band (or random) sounds
Oscillation due to the aggregate of a large number of elementary disturbances randomly occurring in time.

Crosstalk
The transfer of airborne noise from one area to another via secondary air paths such as ventilation ductwork or ceiling voids.

Decibel (dB)
One-tenth of a bel. A bel is the unit of level of a quantity proportional to power when the base of the logarithm is 10. Also, the unit of level of a field quantity when the base of the logarithm is the square root of 10.

dB(A)
Specific measuring scale achieved by a weighting network fitted in a sound level meter. Gives a single-figure rating to a broad-band sound. dB(A) is approximately equivalent to the human ear frequency response.

Dynamic insertion loss (DIL)
A measure of the acoustic performance of an attenuator when handling the rated flow. Not necessarily the same as Static Insertion Loss, because it may include regeneration.

Equivalent continuous sound pressure level (L_{eq})
Logarithm of the ratio of a given root-mean-square sound pressure, during a stated time interval, to the reference sound pressure. Average sound pressure level in decibels is 20 times the logarithm to the base 10 of that ratio. Unless otherwise specified, the reference sound pressure for airborne sound is 20 mPa (20 micropascal).

Excitation frequency
A frequency at which a machine produces vibration. Often the speed of rotation of the machine.

Flanking transmission
Transmission of sound from a source room to an adjacent receiving room but not via the common partition.

Flutter echo
Rapid but nearly even succession of echoes originating from the same sound source. Often occurs in empty rooms. An echo is defined as a sound wave that has been reflected and arrives with such a magnitude and time interval after the direct sound as to be distinguishable as a repetition of it.

Free sound field
Sound field in a homogeneous isotropic medium where boundaries exert a negligible effect on the sound waves.

Frequency (Hz) – sound
The number of sound waves to pass a point in one second.

Frequency (Hz) – vibration
The number of complete vibrations in one second.

Hertz (Hz)
The unit of frequency equivalent to one cycle per second.

Insertion loss
The reduction of noise level by the introduction of a noise control device; established by the substitution method of test.

Insulation (sound)
The property of a material or partition of opposing sound transfer through its thickness.

Inverse square law
The reduction of noise with distance. In terms of decibels, it means a decrease of 6 dB for each doubling of distance from a point source when no reflective surfaces are present.

Isolation (vibration)
The reduction of vibrational force into a structure.

Isolation efficiency
The amount of vibration force absorbed by an isolator and thus prevented from entering the supporting structure, expressed as a percentage of the total force applied to the isolator.

L_{eq}
See "Equivalent continuous sound pressure level"

$L'_{nT,w}$
See "Weighted standardised impact sound pressure level"

L_{90}
See "Background noise"

Masking noise or sound conditioning
Extra noise introduced into an area to reduce the variability of fluctuating noise levels and improve the intelligibility of speech.

Mass law
Heavy materials stop more noise passing through them than light materials. For any airtight material there will be an increase in its "noise-stopping" ability of approximately 6 dB for every doubling of mass per unit area.

Natural frequency
Frequency of free oscillation of a system. For a multiple-degree- of-freedom system, the natural frequencies are the frequencies of the normal mode of oscillation.

Near sound field
Sound field near a sound source where instantaneous sound pressure and particle velocity are substantially out of phase. The inverse square law does not apply in the near sound field.

Noise
1. Erratic or statistically random oscillation.
2. Disagreeable or undesired sound or other disturbance.

Noise criterion (NC) curves
A US set of curves based on the sensitivity of the human ear. They give a single figure for broad-band noise. Used for indoor design criteria. They are similar to NR curves but have different frequency characteristics.

Noise rating (NR) curves
A set of curves based on the sensitivity of the human ear. They are used to give a single-figure rating for a broad band of frequencies. Used for interior design criteria. They are similar to NC curves but have different frequency characteristics.

Noise reduction
Used to define the performance of a noise barrier. Established by measuring the difference in sound pressure levels adjacent to each surface. (See also Sound Reduction Index)

Octave
Unit of logarithmic frequency interval: two sounds, the ratio of whose fundamental frequencies is 2, have a logarithmic frequency interval of 1 octave.

Octave bands
A convenient division of the frequency scale. Identified by their centre frequency, typically 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz.

Periodic sounds
A signal containing a finite number of pure tones which repeats itself at regular intervals.

Pure tone
Sinusoidal acoustic oscillation.

Reactive attenuator
An attenuator in which the noise reduction is brought about typically by changes in cross-section, chambers and baffle volumes, for example a car exhaust silencer.

Regeneration
The noise generated by airflow turbulence. The noise level usually increases with flow speed.

Resonance
State of a system in forced oscillation such that any changes, however small, in the frequency of excitation result in a decrease in a response of the system.

Resonant frequency (Hz)
Frequency at which resonance exists.

Reverberation
The sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source of the sound has stopped.

Reverberation time
Of an enclosure, for a sound of a given frequency or frequency band. The time that would be required for the sound pressure level in the enclosure to decrease by 60 dB, after the source has been stopped.

Room constant
The sound-absorbing capacity of a room, usually expressed in m^2.

R^{l}_{w}
See “Weighted apparent sound reduction index”.

Sabine’s formula
Predicts the reverberation time of a room or enclosure from known room volume and absorption characteristics. Becomes inaccurate when absorption is high.

Silencer
Colloquialism for attenuator.

Solid state (bottoming)
Vibration isolation, that is, when a spring can be compressed no further and the coils are in contact.

Sound insulation
The property of a material or partition to oppose sound transfer through its thickness.

Sound level meter (noise meter)
An instrument for the measurement of sound level, with a standard frequency weighting and standard exponentially-weighted time-averaging.

Sound power
A measure of sound energy in watts. A fixed property of a machine, irrespective of environment.

Sound power level (L_w)
Logarithm of the ratio of a given sound power to the reference sound power. Power level in decibels is ten times the logarithm to the base 10 of the ratio. Unless otherwise specified, the reference sound power is 1pW.

Sound pressure level (L_p)
Logarithm of the ratio of a given sound pressure to the reference sound pressure. Sound pressure level in decibels is 20 times the logarithm to the base 10 of the ratio. Unless otherwise specified, the reference sound pressure is 20 mPa for airborne sound and 1 mPa for a sound in media other than air. Unless otherwise specified, the sound pressures are understood to be expressed in root-mean-square values.

Sound reduction index (SRI)
Of a partition, for a specified frequency band. Difference in decibels between the average sound pressure levels in the reverberant source and receiving rooms, plus ten times the logarithm to the base 10 of the ratio of the area of the common partition to the total sound absorption in the receiving room.

Sound spectrum
Representation of the magnitudes (and sometimes of the phases) of the components of a complex sound as a function of frequency.

Speech transmission index (STI)
A specialised design and measurement parameter used for the quantification of audio systems. A high value STI indicates a high degree of speech intelligibility.

Standing wave
Periodic wave having a fixed distribution in space that is the result of interference of progressive waves of the same frequency and kind. Such waves are characterised by the existence of nodes or partial nodes and antinodes that are fixed in space.

Static deflection
The distance that vibration isolators compress when loaded.

STI
See "Speech transmission index".

Third-octave bands
A small division of the frequency scale, three to each octave. Enables more accurate noise analysis.

Transmissibility
The amount of vibratory force that is transferred to the structure through an isolator, expressed as a percentage of the total force applied.

Turbulent flow
A confused state of airflow that may cause noise to be generated inside, for example, a ductwork system.

Vibration dose value (VDV)
A parameter used to reflect the disturbance and/or annoyance caused by variable vibration.

Vibration isolation
Any of several means of reducing the transfer of vibrational force from the mounted equipment to the supporting structure, or vice versa.

Wavelength
The distance between two like points on a wave shape, for example distance from crest to crest.

Weighted apparent sound reduction index (R'_{w})
A single-number index which characterises the frequency-dependent airborne sound insulation performance of building elements.

Weighted standardised impact sound pressure level ($L'_{nT,w}$)
A single-number index which characterises the frequency-dependent impact sound insulation performance of building elements.

Appendix 2: Sample acoustic specification

This appendix contains a sample acoustic specification which illustrates how design criteria may be presented. It is intended for guidance only.

1. Introduction

The development consists of a new hospital wing containing a multi-bed ward (120 m^3), a consultation room (36 m^3) and a toilet block. Each area shares a common wall with both of the other areas in the wing.

Other relevant points relating to the new wing are as follows:

a. mechanically ventilated;
b. overlooks a noisy road, no other external noise sources nearby;
c. no occupied areas either above or below;
d. no audio system to be incorporated;
e. no noisy plant associated with the new development.

2. Acoustic design criteria

Mechanical services noise

2.1 Noise from mechanical services must not exceed the following values:

	Mechanical services noise rating (NRL_{eq})
Multi-bed ward	35
Consultation room	30
Toilet	45

Intrusive noise

2.2 Intrusive noise from all sources other than the mechanical services installation must not exceed the following values:

	Intrusive noise rating (NR L_{eq})
Multi-bed ward	40
Consultation room	35
Toilet	50

Vibration

2.3 Where continuous vibration is present, it must not exceed the following values for RMS frequency-weighted acceleration:

	Vertical plane (z axis) (m/s^2)	Vertical plane(x,y axis) (m/s^2)
Multi-bed ward: day	0.01	0.007
Consultation room	0.007	0.0049
Toilet	0.02	0.014

Where intermittent vibration is present, it must not exceed the following values

	Vertical plane (z axis) (m/s^2)	Vertical plane (x,y axis) (m/s^2)
Multi-bed ward: day	0.2	0.14
Multi-bed ward :night	0.13	0.09
Consultation room	0.2	0.14
Toilet	0.4	0.28

Internal partitions

2.4 The internal partitions must achieve the following minimum values for weighted apparent sound reduction index (R'_w):

From:	To:	R'_w(dB)
Multi-bed ward	General office (Lowest criterion NR35)	45
Consultation room	Consultation room (Lowest criterion NR30)	50
Toilet	Staff room (lowest criterion NR35)	40

(See chapter 3, paragraph 3.27 and table 6)

Reverberation times

2.5 Reverberation times between 100 Hz and 4 kHz must lie within the following ranges:

	Reverberation time (sec)
Multi – bed ward (120 m^3)	0.5 – 0.6
Consultation room (36 m^3)	0.5 – 0.6

(See chapter 3, paragraph 3.34 and Figure 7)

3. Commissioning

All acoustic design criteria shall be checked in accordance with the guidance given in the ‘Validation and verification’ part of this SHTM.

Appendix 3: Noise sources to be considered during the development of healthcare premises

Stage of design team operators	Noise source	Points to be considered
A Proposed location of development	Airport	Noise from: 1. Operational aircraft on ground. 2. Aircraft landing and taking off. 3. Aircraft maintenance areas. 4. Air traffic lanes. 5. Whether preferential runway system available. 6. Any extensions envisaged. 7. Any runway alterations likely.
	Road traffic outside boundary of hospital development	Existing level and noise climate. Future traffic or highway engineering proposals.
	Rail traffic outside boundary of hospital development	Existing level and noise climate. Future proposals.
	Industry outside boundary of hospital development	Existing levels – night time operations. Future development proposals in area.
B Development control plan	Sources within the development	Noise producing areas, for example laundry, boilerhouse, workshops, car parks, kitchens etc. Supply and service routes external to buildings housing noise – sensitive areas.
C Sketch drawings (Scheme design)	Sources within the development	Plantrooms. Departments in vicinity of noise – sensitive areas. Plant and equipment in ancillary accommodation serving noise –sensitive areas. Equipment proposed for use in noise – sensitive areas. Effect of internal supply and service routes and their association equipment.

Appendix 4: Effects of windows and doors in external walls and internal partitions

Table 1: Effect of window size on the sound insulation of walls

Percentage of glazing in walls	Primary glazing only R'_w (dB)	Primary and secondary glazing R'_w (dB)
100	20	40
75	21	41
55	23	43
33	25	44
25	26	45
10	30	47

Notes

(i) The values given for weighted apparent sound reduction index (R'_w) assume a 225 mm thick brick or block wall, surface mass 425 kg/m^2 with the specified percentage of glazing. The performance of the homogeneous wall construction (that is, without windows) is R'_w 50dB.

(ii) The values for "primary glazing only" assume closed (but openable) 4 mm thick plain glass. The values for "primary and secondary glazing" assume two leaves of 4 mm thick plain glass either side of a 200 mm cavity with absorbent lined reveals.

Table 2: Effect of doors on the sound insulation of partitions

Construction		Typical values for R'_w(dB)					
R'_w for partition only		25	30	35	40	45	50
Effects of adding:	Any door with large gaps around perimeter	23	25	27	27	27	27
	Hollow core door with perimeter seals	24	28	30	32	32	32
	Solid core doors with perimeter seals	25	29	33	35	37	37
	Solid core doors either side of a lobby	25	30	35	40	43	49

Note: The values given for weighted apparent sound reduction index (R'_w) assume that the area of the door is about 7% of the area of the partition in which it is incorporated.

Appendix 5: Typical sound insulation values of glazing

Table 1: Primary glazing only

Construction	R'_w(dB)
4 mm single glass in heavy frame(eg solid wood)	25
4 mm single glass in light frame (eg hollow aluminium)	21
8 mm single glass in heavy frame	29
12 mm single glass in heavy frame	31
6.4 mm laminated glass in heavy frame	29

Notes

(i) The values given for weighted apparent sound reduction index (R'_w) assume sealed windows or openable windows with effective seals.
(ii) The effective R'_w of an open window would generally be in the range 5 to 10 dB.

Table 2: Primary and secondary glazing

Construction	R'_w(dB)
3 mm glass – 50 mm cavity – 3 mm glass	31
3 mm glass – 100 mm cavity – 3 mm glass	35
3 mm glass – 200 mm cavity – 3 mm glass	39
6 mm glass – 100 mm cavity – 6 mm glass	36
6 mm glass – 100 mm cavity, reveals lined with 50mm absorbent – 6 mm glass	39
6 mm glass – 100 mm cavity, reveals lined with 100mm absorbent – 6 mm glass	40
6 mm glass – 200 cavity – 6 mm glass	41
6 mm glass – 200 cavity – reveals lined with 50 mm absorbent - 6 mm glass	44
10 mm glass – 200mm cavity, reveals lined with 50 mm absorbent – 6 mm glass	46

Note: The values given for Weighted Apparent Sound Reduction Index (R'_w) assume sealed windows in separate heavy frames.

Table 3: Thermal double glazing units

Construction	R'_w (dB)
6 mm glass – 12 mm cavity – 6 mm glass	29
10 mm glass – 12 mm cavity – 6 mm glass	31
10 mm glass – 16 mm cavity – 6 mm glass	35
10 mm glass – 12 mm cavity – 6.4 mm laminated glass	38

Note: The values given for Weighted Apparent Sound Reduction Index (R'_w) assume sealed proprietary double glazing units in heavy frames.

Appendix 6: Typical sound insulation values of wall and partition construction

Table 1: Brick and block

Construction	Nominal mass per unit area (kg/m^2)	R'_w (dB)
100 mm lightweight concrete block	75	34
100 mm dense concrete block with 12 mm plaster both sides	185	43
200 mm dense concrete block with plaster either side	330	47
100 mm dense concrete block – 50 mm cavity, butterfly wire ties, 100 mm dense concrete block, 12 mm plaster both sides, 12 mm plaster both sides	330	50
115 mm brick	210	43
225 mm brick	430	49
225 mm brick 12 mm plaster both sides	470	50
275 mm cavity brickwork, butterfly wire ties, 12 mm plaster both sides	470	54
115 mm brick – 35 mm cavity, butterfly wire ties – 100 mm block – 12 mm plaster to block only	300	50

Table 2: Plasterboard on studwork

Construction	Nominal mass per unit area (kg/m^2)	R'_w (dB)
12.5 mm plasterboard either side of 75 mm timber stud, 25 mm mineral wool quilt in cavity	24	35
Two layers of 12.5 mm plasterboard either side of 75 mm timber stud, 25 mm mineral wool in cavity	45	41
12.5 mm plasterboard either side of 48 mm metal stud, 25 mm mineral wool quilt in cavity	22	38
Two layers of 12.5 mm plasterboard either side of 48 mm metal stud , 25 mm mineral wool quilt in cavity	43	46
Two layers of 15 mm plasterboard either side of 48 mm metal stud, 25 mm mineral wool quilt in cavity	55	48
Two layers of 12.5 mm plasterboard either side of cavity formed by alternative staggered stud, 25 mm mineral wool quilt in cavity	44	52
Two layers of 12.5 mm plasterboard either side of double 92 mm stud with 52 mm space between studs, 100mm mineral wool quilt in cavity	48	62

Note: Generally, performance of plasterboard stud partitions can be improved by:

a. increasing the mass of the plasterboard;

b. increasing the width of the cavity;

c. increasing the thickness of the cavity quilt;

d. structurally decoupling the two leaves of the partition.

References

NOTE:
Where there is a requirement to address a listed reference, care should be taken to ensure that all amendments following the date of issue are included.

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
Acts and Regulations				
	The Building (Scotland) Act	HMSO	1959	
	Clean Air Act	HMSO	1993	
	Control of Pollution Act	HMSO	1974	
	Electricity Act	HMSO	1989	
	Environmental Protection Act	HMSO	1990	
	Health and Safety at Work etc Act	HMSO	1974	
	Noise and Statutory Nuisance Act	HMSO	1993	
	Registered Establishments (Scotland) Act	HMSO	1998	
	The Water (Scotland) Act	HMSO	1980	
SI 2179 & 187	The Building Standards (Scotland) Regulations (as amended)	HMSO	1990	
	The Building Standards (Scotland) Regulations: Technical Standards Guidance	HMSO	1998	
SI 1460	Chemicals (Hazard Information and Packaging for Supply) Regulations (CHIP2)	HMSO	1997	
SI 3140	Construction (Design and Management) Regulations	HMSO	1994	
SI 437	Control of Substances Hazardous to Health Regulations (COSHH)	HMSO	1999	
SI 635	Electricity at Work Regulations	HMSO	1989	
SI 1057	Electricity Supply Regulations (as amended)	HMSO	1988 (amd 1994)	
SI 2372	Electromagnetic Compatibility Regulations (as amended)	HMSO	1992	
SI 2451	Gas Safety (Installation and Use) Regulations	HMSO	1998	
SI 917	Health & Safety (First Aid) Regulations	HMSO	1981	

Publication ID	**Title**	**Publisher**	**Date**	**Notes**
SI 682	Health & Safety (Information for Employees) Regulations	HMSO	1989	
SI 2792	Health and Safety (Display Screen Equipment) Regulations	HMSO	1992	
SI 341	Health and Safety (Safety Signs and Signals) Regulations	HMSO	1996	
SI 1380	Health and Safety (Training for Employment) Regulations	HMSO	1990	
SI 2307	Lifting Operations and Lifting Equipment Regulations (LOLER)	HMSO	1998	
SI 3242	Management of Health and Safety at Work Regulations	HMSO	1999	
SI 2793	Manual Handling Operations Regulations	HMSO	1992	
SI 1790	Noise at Work Regulations	HMSO	1989	
SI 3139	Personal Protective Equipment (EC Directive) Regulations (as amended)	HMSO	1992	
SI 2966	Personal Protective Equipment at Work (PPE) Regulations	HMSO	1992	
SI 2306	Provision and Use of Work Equipment Regulations (PUWER)	HMSO	1998	
SI 3163	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)	HMSO	1995	
SI 3004	Workplace (Health, Safety and Welfare) Regulations	HMSO	1992	

British Standards

Publication ID	**Title**	**Publisher**	**Date**	**Notes**
BS 4142	**Method for rating industrial noise affecting mixed residential and industrial areas**	BSI Standards	1997	
BS 5363	**Method for measurement of reverberation time in auditoria**	BSI Standards	1976	
BS 5821	**Methods for rating the sound insulation in buildings and of building elements** **Part 3**: Method for rating the airborne sound insulation of façade elements and facades	BSI Standards	 1984	
BS 5969	See BS EN 60651	BSI Standards	1991	

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
BS 6177	**Guide to selection and use of elastomeric bearings for vibration isolation of buildings**	BSI Standards	1982	
BS 6472	**Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)**	BSI Standards	1992	
BS 7445	**Description and measurement of environmental noise** (ISO 1996)	BSI Standards		
	Part 1: Guide to quantities and procedures		1991	
	Part 2: Guide to the acquisition of data pertinent to land use		1991	
	Part 3: Guide to application to noise limits		1991	
BS 7482	**Instrumentation for the measurement of vibration exposure of human beings**	BSI Standards		
	Part 1: Specification for general requirements for instrumentation for measuring the vibration applied to human beings		1991	
	Part 2: Specification for instrumentation for measuring vibration exposure to the whole body		1991	
	Part 3: Specification for instrumentation for measuring vibration exposure to the whole body		1991	
BS EN 20140	**Acoustics. Measurement of sound insulation in buildings and of building elements**	BSI Standards		
BS EN 20140-2	**Determination, verification and application of precision data**	BSI Standards	1993	
BS EN 60268-16	**Sound system equipment. Objective rating of speech intelligibility by speech transmission index**	BSI Standards	1998	
BS EN 60651	**Specification for sound level meters**	BSI Standards	1994	
BS EN 60849	**Sound systems for emergency purposes**	BSI Standards	1998	
BS EN 61260	**Electroacoustics. Octave band and fractional-octave band filters**	BSI Standards	1996	

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
BS EN ISO 140-3	**Acoustics. Measurement of sound insulation in buildings and of building elements. Laboratory measurement of airborne sound insulation of building elements**	BSI Standards	1995	
BS EN ISO 140-4	**Acoustics. Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation between rooms**	BSI Standards	1998	
BS EN ISO 140-5	**Acoustics. Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation of façade elements and façades**	BSI Standards	1998	
BS EN ISO 140-7	**Acoustics. Measurement of sound insulation in buildings and of building elements. Field**	BSI Standards	1998	
BS EN ISO 717-1	**Acoustics. Rating of sound insulation in buildings and building elements. Airborne sound insulation**	BSI Standards	1997	
BS EN ISO 717-2	**Acoustics. Rating of sound insulation in buildings and of building elements. Impact sound insulation**	BSI Standards	1997	
BS EN ISO 717-4	**Acoustics. Rating of sound insulation in buildings and of building elements. Impact sound insulation**	BSI Standards	1997	
BS EN ISO 8253	**Acoustics audiometric test methods** **Part 1**: Basic pure tone air and bone conduction threshold audiometry	BSI Standards	1998	
ISO 1996	See BS 7445	BSI Standards		
Scottish Health Technical Guidance				
SHPN 1	Health service building in Scotland	HMSO	1991	
SHPN 2	Hospital briefing and operational policy	HMSO	1993	
SHPN 34	Estate maintenance and works operations	HMSO	1998	
SHTN 4	General Purposes Estates and Functions Model Safety Permit-to-Work Systems	EEF	1997	
SHBN 4	Supplement 3 – ENT and audiology clinics: hearing and centre	HMSO	1994	
PPG 24	Planning and noise	Dept. of Env.	1994	

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
	NHS in Scotland – PROCODE	P&EFEx	2001	Version 1.1
NHS in Scotland Firecode				
SHTM 81	Fire precautions in new hospitals	P&EFEx	1999	CD-ROM
SHTM 82	Alarm and detection systems	P&EFEx	1999	CD-ROM
SHTM 83	Fire safety in healthcare premises: general fire precautions	P&EFEx	1999	CD-ROM
SHTM 84	Fire safety in NHS residential care properties	P&EFEx	1999	CD-ROM
SHTM 85	Fire precautions in existing hospitals	P&EFEx	1999	CD-ROM
SHTM 86	Fire risk assessment in hospitals	P&EFEx	1999	CD-ROM
SHTM 87	Textiles and furniture	P&EFEx	1999	CD-ROM
SFPN 3	Escape bed lifts	P&EFEx	1999	CD-ROM
SFPN 4	Hospital main kitchens	P&EFEx	1999	CD-ROM
SFPN 5	Commercial enterprises on hospital premises	P&EFEx	1999	CD-ROM
SFPN 6	Arson prevention and control in NHS healthcare premises	P&EFEx	1999	CD-ROM
SFPN 7	Fire precautions in patient hotels	P&EFEx	1999	CD-ROM
SFPN 10	Laboratories on hospital premises	P&EFEx	1999	CD-ROM
UK Health Technical Guidance				
EH 40	HSE Occupational Exposure limits	HSE	Annual	
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