Technical Note No 37

Introduction to building envelope acoustics

CENTRE FOR WINDOW AND CLADDING TECHNOLOGY

This Technical Note is one of four on building envelope acoustics. The series comprises:

TN 37 Introduction to building envelope acoustics
TN 38 Acoustic performance of windows
TN 39 Sound transmission through building envelopes
TN 40 Sound environment behind a building envelope

Introduction

This Technical Note introduces the reader to the basic principles of acoustics that are required to understand the acoustic performance of building envelopes.

Information is given on methods of measurement, material properties and general design principles.

A guide to relevant UK legislation and standards is also given.

Sound and noise

Sound is the human perception of vibrations in the air around us. Noise is unwanted sound.

Noise can be annoying, can interfere with the enjoyment of everyday activities and in the extreme can be harmful. It may also be beneficial at low levels where it can serve to mask sounds and aid privacy.

Sound Characteristics

Sound originates when air is vibrated. It travels outwards from the source as pressure waves just as ripples travel outwards on a still pond.

A 'pure' sound is characterised by its frequency and its sound pressure level.

Frequency determines the pitch of the sound. It is the number of vibrations that occur in one second and is measured in Hertz (Hz). The distance between consecutive waves is the wavelength measured in metres.

Sound pressure level (SPL) is a measure of the peak pressure created as a sound pressure wave passes. Sound pressure levels are expressed in decibels (dB), a logarithmic scale.

Decibels

Table 1 below shows typical sound pressure levels in dB.

	Sound pressure level (dB)
Live pop concert	115
Pneumatic drill at 3m	100
Noisy factory	90
Heavily trafficked street	80
Lightly trafficked street	70
Restaurant/store	60
Public office	50
Bedroom at night	30
Recording studio	10
Threshold of hearing	0

Table 1. Sound pressure levels

The amplitude of sound can be measured either as an acoustic pressure or as a sound intensity. Sound intensity is a measure of acoustic energy, it is the power flow across unit area measured in W/m^2.

For sound levels measured in decibels, for sound travelling in a straight line the sound pressure level and sound intensity level are numerically equal.

The decibel is defined as:

$$L_p = 10 \log_{10} \left(\frac{i}{i_o} \right)$$

or

$$L_p = 10 \log_{10} \left(\frac{p}{p_o} \right)^2 ,$$

where i is the intensity and i_o is the reference intensity (10^{-12} W/m^2). p is the sound pressure and p_o is the reference pressure (2.10^{-5} Pa). L_p is measured in dB.

The relationship between L_p *and p* is shown in Table 2.

SPL (dB)	Pressure (Pa)	
0	0.00002	Reference pressure
80	0.2	
140	200	

Table 2. Decibels and pressure

The non-linearity of the decibel scale has the effect that a doubling of intensity gives an increase of 3dB while a tenfold increase in intensity gives an increase of 10dB.

The ear can just detect a 3 dB change, whilst a 10 dB change is heard as a doubling of loudness.

Sound weighting

A ‘pure’ sound vibrates at only one frequency, for instance a single musical note. However, most sounds are made up of a whole range of frequencies.

The ear is sensitive to frequencies in the range 20 to 20,000Hz. It responds differently to different frequencies and is more sensitive to higher frequency sounds.

When measuring sound it is useful to weight the different frequencies so that those having greatest impact on the ear are given a greater weighting. This is achieved by measuring the sound pressure level associated with different frequencies and increasing or decreasing their contribution to the total sound pressure level.

For normal human listening the A-weighting scale is used. This reduces the SPL associated with frequencies below 1000 Hz and increases the SPL associated with higher frequencies. Weighted values are expressed in dBA.

Octaves and banding

To simplify weighting of sounds, the frequencies are separated into full octaves or the smaller, more detailed third octaves.

An octave is a band of frequencies where the highest frequency is exactly double the lowest frequency.

Noise spectra are based on sound pressure levels measured at the frequencies shown in Table 3. The use of third octave values for SPL is more accurate but requires more data than the use of full octave values.

Octave bands	Third octave bands
	100
125	125
	160
	200
250	250
	315
	400
500	500
	630
	800
1000	1000
	1250
	1600
2000	2000
	2500
	3150
4000	4000
	5000
	6300
8000	8000
	10000

Table 3 Octave bands

Figure 1 shows a typical sound spectrum using both third octave and full octave values. Figure 2 shows the comparison between the sound spectrum in dB and the A-weighted values in dBA.

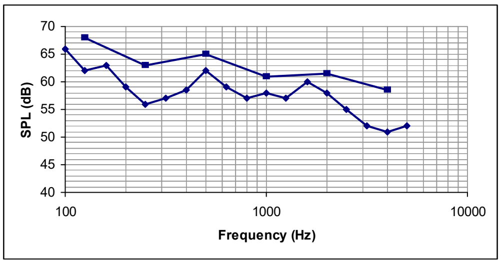

Figure 1. Sound spectra

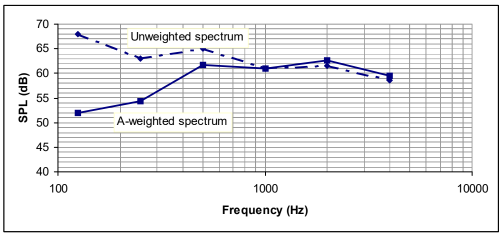

Figure 2. Weighted sound spectra

Common sound sources

Sound is generated when vibrations are created in the air. Vibrations of interest to façade engineers include external sources such as: transport noise and people, and internal sources such as people and impacts.

Sound pressure waves in air follow a number of laws.

Road traffic noise is biased towards low frequencies, being influenced by the number of vehicles, the proportion of heavy vehicles, vehicle speed, road surface, local topography, etc.

Railway Noise has a broadly similar spectrum to road traffic, except that more middle frequency tones are present and, generally, there is a more rapid fall off in high frequency content. Dominant influences here include number of trains and the number of vehicles in the trains, speed, type of rail, mix of rolling stock, embankments or cuttings, etc. Though noise levels adjacent to railways can be very high, people's tolerance is greater than for road traffic noise, because the rise and decay of each noise is predictable and of short duration. Railway noise can exceed road traffic noise by more than 2 dBA for the same degree of annoyance or disturbance.

Aircraft Noise changes significantly with number of aircraft movements and the type of aircraft, altitude of the aircraft, climatic conditions etc.. Take-off noise is usually greater and is dominated by low frequencies, whereas landing noise contains strong high frequency components, characteristic of the engines being in reverse thrust.

Speech contains frequencies between 100 and 8000Hz, the most important being between 500-2000Hz. It is the suppression of the higher frequencies which is most important in providing privacy of conversation because these contain the essential aural clues of intelligibility in the consonants.

Sound transmission

Sound may be transmitted as airborne sound or through the structure of a building.

Reflection and diffraction affect sound as it meets a boundary. Sound is reflected from surfaces in the same way as light. Diffraction allows a pressure wave to bend around a corner. This means that sound can be heard when there is an obstacle, such as a barrier, between the source and the listener. Note that the sound may take several paths around the obstacle.

Propagation of sound in a free field (such as outside away from the ground) behaves according to an inverse square law. For a point source the sound energy is distributed over the area of a sphere which is proportional to the radius squared. Doubling the distance results in the same energy being spread over four times the area, with a sound intensity of one quarter. This corresponds to a 6dB decrease per doubling of distance.

Damping is the loss of sound energy to other forms of energy. There is normally little damping as sound travels through air. Porous materials, which can be efficient sound absorbers, convert acoustic energy into heat.

Reverberation occurs in rooms due to repeated reflections off the walls, floor and ceiling. When a sound source is switched off, the sound level in the room decays. The time it takes the sound to decay 60dB is known as the **reverberation time**. The decay can easily be heard in spaces like cathedrals, which have a reverberation time of several seconds.

Resonance occurs where a system has a large response at a particular frequency. Musical instruments of the string and wind families rely on resonance. Panels vibrate at resonance frequencies. Reverberation is often referred to as resonance, which can be confusing. There are thousands of resonance frequencies in a room, but the average behaviour is best viewed as a reverberant decay.

Combined sounds

Two sounds that combine will NOT result in a sound with an SPL equal to the sum of their separate SPL values.

The procedure for combining sounds is based on Figure 3. The difference in SPL between the two combining sounds determines the value in dB to add to the louder of the two sounds.

Note that within a room two equal windows will act as equal sources and the sound transmitted into the room will be only 3dB greater than the sound transmitted into the room by a single window.

Addition of sound in this way is appropriate for adding two dBA levels, or levels within individual octaves. Where more than two sounds are to be added, two sounds can be combined and the resultant sound further combined with other sounds.

Noise reduction methods

Reduction at source can be an economical solution where the problem is noise emitted from a building. The use of acoustic enclosures for machinery may be cheaper than detailing the building envelope for noise containment. Ventilation air inlets and outlets should include attenuators.

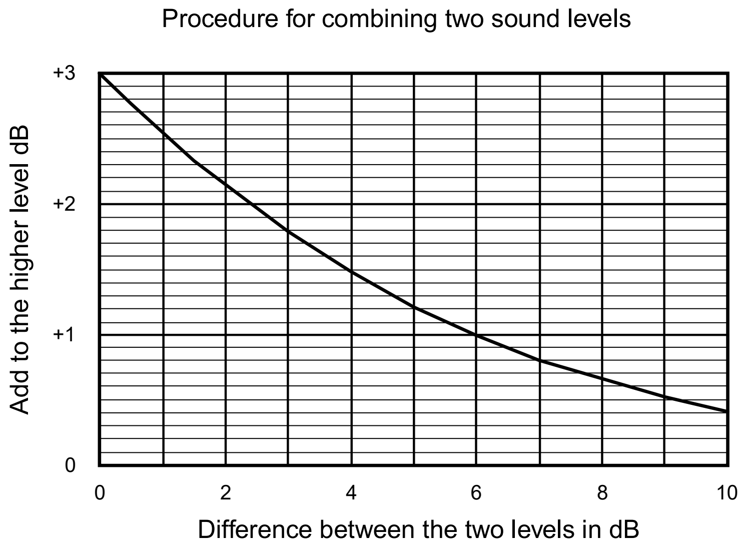

Figure 3. Combination of two sounds

Distance from source affects the sound intensity. In an industrial environment it may be possible to separate offices and plant.

Sound insulation reduces the sound transmitted through a building envelope or component. The level of sound insulation is called either the sound reduction index (SRI) or the transmission loss (TL) – they are two names for the same thing. The sound reduction index can be increased (sound transmission reduced) by increasing the mass of a wall or by reducing the coupling between the inner and outer surfaces (as in a double window).

Sound insulation

The sound reduction index of a material or construction is measured either in a specialist acoustic test facility with the test material located between two reverberation chambers or in the field between two rooms. The SRI is determined from the sound level difference between either side of the test material. The measurement in the laboratory is made in the 16 1/3 octaves between 100 and 3150Hz, or if in the field generally in octaves.

Sound reduction is not uniform across the whole sound spectrum. Most materials are better at reducing high frequency noise.

Given a set of sound reduction index values for the whole spectrum, an internal sound spectrum can be established by deducting the SRI values from the external sound spectrum and making corrections for the influence of the receiving room.

To simplify comparison of products a number of single figure sound reduction indices have been standardised. These may be used to compare products in the absence of a precise knowledge of the external sound spectrum.

R_m (Mean value) is the simplest approach, involving an arithmetic mean of the sound reduction indices measured at the 16 1/3 octaves.

R_w (Weighted reduction) is the most common way to classify sound insulation. It takes account of typical spectra of disturbing noises and our sensitivity to different frequencies. The R_w index is detailed in EN ISO 717: Part 1: 1996 and the associated curves are shown in Figure 4.

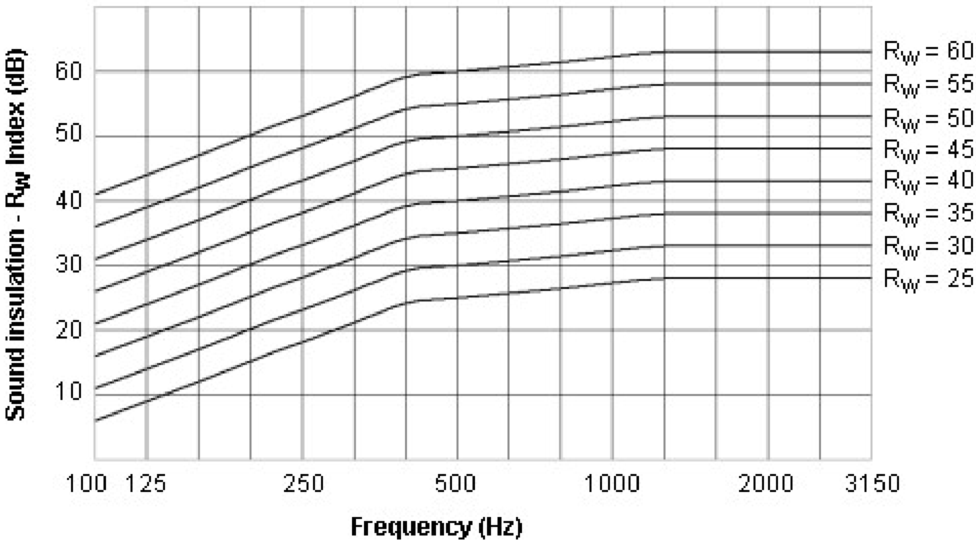

Figure 4 Airborne sound insulation R_W Index

R_{tr} (Traffic noise reduction) is biased towards lower frequencies and is used to compare products where the external noise arises mainly from road traffic. It is detailed in EN ISO 717: Part 1: 1996.

STC (Sound Transmission Class) value as defined in the American Standard ASTM E413, is occasionally used in the UK. Its derivation is the same as the R_w index, except that the relevant frequency range is 125 - 4000 Hz (i.e. shifted upwards by 1/3 octave from the European Standard). For this reason STC is, typically, around 1 dB higher than its R_w equivalent, owing to panel materials being generally better performers at high frequencies.

Detailed considerations of sound insulation are given in:

TN38 Acoustic performance of windows
TN39 Sound transmission through building envelopes
TN40 Sound environment behind a building envelope

Sound environment

Building envelopes should control sound transmitted into the building to create an acceptable internal noise environment. The envelope may also be required to limit noise emission from a building to avoid disturbing neighbours.

External noise is seldom constant but varies through the day and as a result of sporadic events such as the passing of trains. To simplify the consideration of non-constant sounds, the equivalent continuous A-weighted sound pressure level is used.

$\boldsymbol{L_{Aeq,T}}$ is the A-weighted sound pressure level, in dBA, that over the time interval, *T*, has the same mean squared sound pressure as the real time-varying noise. T has to be specified sensibly. For domestic dwellings, the L_{Aeq} is often assessed over a 16-hour daytime period and an 8-hour night-time period.

BS 8233 makes recommendations for acceptable sound levels in internal spaces as follows:

Space	Design range $L_{Aeq,T}$ (dBA)
Dwellings	
Living room	30-40
Bedroom	30-35
Offices	
Private office	35-40
Large office	40-50
Teaching spaces	
Classroom	35-40
Lecture theatre	30-35
Other	
Cafeteria	50-55
Light workshop	65-75

Table 4 Design environments

Note that designing for sound levels greater than these may lead to intrusive noise levels that impact on comfort and efficiency. In spaces with several occupants, designing to achieve sound levels below the ranges given can give rise to problems of privacy as there is insufficient noise to mask conversations.

Building Regulations Approved Document Part E

Part E of the Building Regulations is concerned primarily with resisting the passage of sound within dwellings and schools.

No guidance is given on the design or construction of the building envelope or the performance of windows in external walls.

Other guidance

The most relevant source of information on the acoustic performance of building envelopes is BS 8233:1999, 'Sound insulation and noise reduction for buildings – Code of practice'. This gives advice on acceptable internal environments, noise sources, sound insulation and issues of design and testing.

BS EN 12354-3:2000, 'Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Airborne sound insulation against outdoor sound' gives a method of calculating the sound insulation of a collection of building elements comprising a building envelope.

BS 7643-3:1993, 'Building construction – Expression of users' requirements – Acoustical requirements' gives advice on how to specify acoustical performance.

Standards

BS EN 12354-4:2000
Building acoustics. Estimation of acoustic performance in buildings from the performance of elements. Transmission of indoor sound to the outside

BS EN 20140-10:1992, ISO 140-10:1991
Acoustics. Measurement of sound insulation in buildings and of building elements. Laboratory measurement of airborne sound insulation of small building elements

BS EN ISO 140-1:1998
Acoustics. Measurement of sound insulation in buildings and of building elements. Requirements for laboratory test facilities with suppressed flanking transmission

BS EN ISO 140-3:1995, BS 2750-3:1995
Acoustics. Measurement of sound insulation in buildings and of building elements. Laboratory measurement of airborne sound insulation of building elements

BS EN ISO 140-4:1998
Acoustics. Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation between rooms

BS EN ISO 140-5:1998
Acoustics. Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation of facade elements and facades

BS EN ISO 717-1:1997
Acoustics. Rating of sound insulation in buildings and of building elements. Airborne sound insulation.

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