Sound.DOC

In the last decade more effort has been devoted to the measurement and control of noise in the environment than ever before. Attempts have been made to reduce noise at source by better mechanical design, to improve the insulation of buildings, and to investigate the reactions of people to noise in their environment at home and at work. Legislation has been passed dealing with various aspects of noise, ranging from the emission of noise by motor vehicles to grants for sound insulation of houses. In spite of all this effort, noise levels inside and outside some buildings are so high that they disturb many people.

SOUND GENERATION AND RECEPTION

Sound is produced when something vibrates. These vibrations produce local variations in air pressure due to a squeezing of the air in immediate contact with the object in vibration, and this motion is then transmitted to adjacent air molecules. With increasing distance from the source, there is a loss of energy and the sound decays.

Within a well defined range, the ear is able to detect these changes from normal atmospheric pressure (the reference at all times) even when they are minute, that is above 0.00002 N/rn^2 at 1000 Hz, the threshold of human hearing.

The dominant parameters of sound are frequency, wavelength and energy level (Figure 22.2).

Frequency is the number of complete vibrations which occur in each second. Subjectively, high frequencies are high pitched sounds (treble) and low frequencies are low pitched sounds (bass).

Wavelength is the distance occupied by one complete vibration. Low pitched sounds have longer wavelengths than those of high pitch.

Energy level is a consequence of the amplitude of sound vibrations. Loud sounds produce greater amplitudes (bigger pressure changes) at normal atmospheric pressure than quiet sounds. These amplitudes are indicative of the energy levels, measured in decibels (dB); the range of interest is from 0 dB (threshold of hearing) to around 120 dB (threshold of pain) (Figure 22.3a).

The human ear is able to detect sound frequencies in the range from 20 to 20000 vibrations per second (hertz, symbol Hz). The corresponding wavelengths in air are from 17m down to 17mm (Figure 22.3b).

With older persons, it is the discrimination of high frequencies which is impaired; the low frequency response remains virtually unchanged. Frequencies above and below the human range are detected by some animals, for example dogs.

Even though people are able to detect sounds within the broad frequency range of 20 to 20000 Hz, their reception of them is not uniform. Because of the physiology of the ear, the corresponding response is not linear. The ear is more sensitive to high frequency sounds than to lower ones, so that when measuring sounds with equipment, such as a sound level meter (Figure 22.4), corrections must be built in to mimic the ear's response. The readings thus obtained can then provide a reliable guide to human subjective reaction to sounds of different mixes of frequencies. Sound readings, so modified, are measured in dBA, the letter A signifying the application of this selective frequency modification. The units dB and dBA should not be confused, or used together in calculations; consistent units are essential (Figure 22.5).

Some important approximate relationships between changes in sound pressure level and the corresponding changes in apparent loudness are as shown in Figure 22.6.

Figure 22.6 Relationship between sound pressure changes and loudness Change in dB or dBA Apparent loudness change

just noticeable

clearly noticeable

doubling (+) or halving (—) of loudness

THE CHARACTER OF SOUND AND SUBJECTIVE RESPONSE

All the preceding comment has been relevant to sound in general, but noise may be simply stated as 'unwanted sound'. Sound is the process of generating acoustic energy and of its reception by the ear, whereas noise is our subjective reaction to it. Music may be enjoyable, but when intruding in a conversation it can be distracting and so become a noise.

Loud noises do not always produce complaints, and neither are quiet environments always preferred. Reactions are influenced by factors other than energy level and include frequency of occurrence, frequency mix of the sound (its spectrum) and other environmental signals (too hot, too cold, glare etc.). These factors are often as important as the more easily measured and defined parameters.

Subjective response in any noise environment is not best related to the average or mean noise level which prevails. Research has shown that the $L_{,0}$ level (the noise level exceeded for 10% of the relevant or chosen time) is a much more reliable indicator. Often, as in the case of UK legislation on sound proofing grants for dwellings, the L_{10} 18 hour index is used as the best descriptor. This is the $L_{,0}$ value established over the period from 6 a.m. to midnight (Figure 22.7).

The L10 value is useful in defining the relevant noise climates for a wide variety of situations but is gradually being superseded by another concept, the equivalent noise level Leq. This is the notional continuous noise level whose total energy over a given period is equal to that of the real varying sound (or noise) over the same period. This index is better able to compare noises which differ in level and in their variation with time. Thus the impact of continuous road traffic noise can be compared with that from intermittent aircraft or railway noises.

Because transportation noises are the main offenders in buildings, it is of interest to compare the different characteristics of the principal sources (Figures 22.8a, b).

Figure 22.8a Road, railway and aircraft noise

Road traffic noise The noise spectrum of road traffic noise will be influenced by factors such as the percentage of heavy vehicles, speed, nature of road surface, road gradient etc., but the overall typical spectrum will always exhibit the strongest components at low frequencies. city centre noise is typically at around 80 dBA, as is the noise close to motorways.

Railway noise This is principally influenced by wheel/track interactions, track type (welded or jointed), sleeper type (timber or concrete), local terrain, cuttings etc. Peak noise can be high, perhaps of the order of 100 dBA, but reaction to this is not as adverse as might be expected. The noise is intermittent sometimes with long periods of silence. Also, trains warn of their approach by gradual noise build-up, and arrival is followed by a predictable decay. Hence people’s tolerance to train noise is around 10—1 5 dBA higher than for the road traffic spectrum, i.e. 95 dBA of railway noise
similar level of disturbance *80-85* **dBA of** *roa traffic noise*

Aircraft *noise* The spectrum of aircraft noise varies widely according to aircraft type, load ratio, and whether taking off or landing, and is critically dependent on the location of the hearer with respect to the aircraft’s flight path. Aircraft in flight generally have an even mix of sound frequencies. On the ground, their noise is most often dominated by the high pitched whine of the auxiliary power unit from the tail of the aircraft. This variability of aircraft noise makes it difficult to define typical noise levels. Until recently, contours of noise and number index NNJ were prepared for all major UK airports to aid the planning of development around them. The composite index NNI takes account of peak noise level and also the number of occurrences. The L is now considered to be more indicative of annoyance and is gradually superseding NNI.

Industrial and other noise sources Because of the wide variability of industrial machinery and processes, it is impossible to adopt a single noise spectrum as representative for design purposes. Expert advice is necessary in order to establish the dominant components to be attenuated.

IN DICES OF ACOUSTIC PERFORMANCE

Analyses of acoustic problems involve measuring the level and frequency of all the noise components and determining their modification by the glazing at all frequencies, in order to derive a residual transmitted spectrum. This may then be judged against notional targets or criteria. These procedures are time consuming and may involve expertise.

As expedient alternatives, single figure indices have been developed which give quick, approximate indications of the acoustic efficiency of materials, including glazing. They should be used with caution and should not be regarded as complete substitutes for full analyses.

In considering the definition of these indices it should be noted that the range of frequencies encompassed varies nationally. Typically the British Standard range covers 100—31 50 Hz (16 values) in third octaves and 125—4000 Hz (6 values) in full octaves; the American standards cover 125—4000 Hz in both third octave (16 values) and full octave (6 values) analyses.

MEAN SOUND INSULATION R
values of the measured sound insulation of the glazing. Because of the slight difference between the British Standard and American Standard frequency ranges (namely a shift upwards by a third octave in American data compared with British) there may be a small discrepancy in their comparison. Typically, the American Rm is I dB higher than the corresponding British Rm derived from the same data.

R INDEX (ISO 717,BS 5821)

To take account of the ear’s response, this more complicated index has evolved. It involves plotting the sound insulation curve on a series of reference curves, whose shape approximates to that of the ‘A weighting’ or ear’s response curve. By finding the reference curve which is closest to that under investigation, the Rw index is derived according to prescribed rules, the main one of which is that the total shortfall (where the actual sound insulation is less than the reference curve chosen) must not exceed 32 dB. The Rw index is characterized by the sound insulation of this matching reference curve at 500 Hz (Figure

22.9).

STC VALUE

The sound transmission class index originated in the USA and formed the basis of the Rw index calculation procedure. The main difference is in the frequency range considered, so that typically STC values are about 1 dB greater than Rw indices derived from the same data.

RTRA INDEX

The Rm, Rw and STC indices are derived from the basic sound insulation performance of the glazing across the frequency bands. In order to obtain better correspondence with people's reaction to the transmitted noise, it is also necessary to take account of the dominant components of the incident noise. The RTRA index is calculated by adopting a spectrum shape of typical road traffic noise, and then modifying it, frequency by frequency, according to the sound insulation data of the glazing. The residual aggregate level, in dBA, is the RTRA index. Unlike the indices above, it may be used directly in simple calculations to yield approximate levels of interior noise in dBA:

It has also been found that simple correction factors may be applied to RTRA to derive realistic estimates of corresponding attenuation to railway and aircraft noises. This is currently under consideration as part of a European (CEN) standard.

INTERIOR NOISE LEVEL CRITERIA

Rooms are not necessarily designed to have the lowest possible background noise levels, since this could lead to unsatisfactory environments and would be costly. The glazing should attenuate the outside noise to a level which does not annoy, but is still sufficient to mask the ambient, internally generated noises. This target noise level will be dependent upon the nature of the activity inside the building (workshops do not demand as high attenuation from the glazing as would conference rooms). Recommended background noise levels are identified in national standards for a wide range of situations, for example in BS 8233:1987, which adopts the Laeq (equivalent noise level, measured in dBA) as an appropriate index. Approximate conversion to L10 (dBA) is simple:

$L10 = La\ eq + 3$.

Examples of the Laeq targets for common locations are shown in Figure 22.10

Figure 22.10 Laeq targets for common locations

Large offices (including open plan)	45—50
Private offices, small conference rooms	40—45
Living rooms	40—45
Bedrooms	30—40
classrooms (15—35 people, with communication distance not more than 9m)	

SIMPLE ASSESSMENT OF GLAZING REQUIREMENTS

Because it is usual to derive ambient outside noise levels in dBA, the required acoustic performance of the glazing may be determined by comparison with the appropriate recommendation of background noise level. For example, if an open plan office is located in a city centre where the ambient traffic noise is 80 dBA, the glazing needs to provide an attenuation of 80 minus 50 dBA (or 80 minus 45 dBA if preferred), i.e. RTRA must be 30 (or 35) dBA. Reference to glazing performance data is then able to establish satisfactory alternatives.

THE PERFORMANCE OF GLASS

The fundamental principle of the sound insulation of glass and windows is the Mass Law, which demonstrates that, with each doubling of glass thickness, the corresponding sound insulation is increased by about 4 dB. This is not exact and takes account of intrinsic resonance phenomena which impair the acoustic performance at certain frequencies.

Single glazing shows two main types of resonance. One is related to its size (low frequency) and the other to its thickness (medium to high frequency). This latter resonance is very sensitive, the frequency being inversely proportional to thickness, so that, for example, 12 mm float glass resonates at I kHz whereas 6 mm float glass resonates at 2 kHz (Figure 22.11).

One means of suppressing some of the characteristic resonances is to laminate two or more glass panes together with resilient plastic interlayers, which absorb some of the incident sound energy, reducing that which passes through it. The most common laminating material for this purpose is polyvinyl butyral, and it reduces the loss in sound insulation at the resonant frequencies (Figure 22.12).

Other materials, including polymethyl methacrylates, are even 'softer' and so are able to reduce further the losses of sound insulation at the basic frequencies and the component glass panes are decoupled so efficiently that the associated resonant frequencies are shifted to a higher position in the noise spectrum, where they are less troublesome.

Double glazing units or secondary sashes exhibit two additional resonances. One is caused by the interaction of vibrations of the two individual panes, which may be enhanced or suppressed by the precise distance between them. The other is produced because of interreflections of sound trapped between the two panes, and is a high frequency phenomenon. If dissimilar glass thicknesses are used in double glazed units, there are acoustic benefits, because as one pane tends to resonate, the other provides acoustic stability. High acoustic performances for double glazed units are achieved when lamination and asymmetric construction are employed simultaneously. The addition of more panes of glass to form glazed units with more than two panes may impair the corresponding acoustic performances owing to the generation of further resonances with each extra pane.

Other gases may be used as the cavity fill in place of dry air, for their thermal benefits. For example, argon filled units show no change in acoustic performance from standard air filled units, for the same basic construction. Sulphur hexafluoride (SF6) gas, however, may be used for acoustic purposes. Its heavy molecular structure tends to enhance the middle frequency performance (about 630—2000 Hz), but it introduces a resonance at low frequencies (around 200 Hz) which limits its effective application where low frequency insulation is the dominant requirement (transportation noises).

Potentially the highest acoustic insulation may be attained by separating the two main glass components with a large air space in excess of 100 mm, creating a double window. The interactions between the panes are minimized and each acts more independently as an effective barrier. However, unless all air gaps are fully sealed by employing either fixed lights or hinged windows which have compressible seals and multi-point locking to avoid the frames twisting, the actual in-service performance of these windows is likely to be no better than that of a sealed double glazed unit. For this reason, sliding sashes are not compatible with high acoustic performance (Figure 22.13).
a façade (walls) are considered to have a sound insulation at least 10 dB higher than the window, then each halving of window area increases the effective sound insulation by 3 dB. If, for example, a 100% (fully) glazed façade had a sound insulation of 30 dB, changing to 50% and 25% glazed façades would secure corresponding aggregate sound insulations of 33 dB and 36 dB, respectively.

EFFECT OF DISTANCE

With increasing distance from a noise source, there is a corresponding decrease in noise level. The decay rate is dependent upon whether the source originates at a point or over an area, which, in turn, depends on its shape and the distance at which the sound is heard.

Noise from an aircraft or a single vehicle may be considered to be a point source, and the decay rate approximates to 6 dB per doubling of distance. Noise from a line of traffic or railway train does not diminish as rapidly; 3 dB per doubling of distance is a typical decay rate.

For example, if a roadside noise measurement, 5 metres from the vehicles, indicates a level of 78 dBA, this would reduce correspondingly to 75 dBA at 10 metres, to 72 dBA at 20 metres and to 69 dBA at 40 metres. This 9 dBA drop in level from the initial measurement is almost equivalent to a halving in its perceived loudness at the kerbside.

EFFECT OF HEIGHT

With increasing building height, there should be an associated decrease in received street noise level, but the acoustic horizon of the upper floors is correspondingly increased. These are opposing trends, and the result is that the vertical noise field is almost uniform.

BARRIERS

Sound waves have long wavelengths, as mentioned earlier. Therefore diffraction effects are significant; that is, bending around obstacles is relatively easy. Fences, earth mounds and screens are therefore relatively ineffective, unless positioned either close to the source or close to the reception point. Window furniture, like blinds, has no influence on the noise transmission through windows.

OTHER GLAZING TYPES

Apart from lamination, other glass types do not exhibit any departures from the sound insulation of ordinary clear float glass. Thickness for thickness, toughened, wired, coated and tinted glass products have exactly the same acoustic performance. Patterned glass products, which have surface indentations, behave identically to ordinary clear float glass of the same average thickness.

FIXING EFFECTS

Better sound insulation is achieved by installing glass in resilient gaskets instead of tightly clamping it with beads. Any structural vibrations are then less able to be transmitted to the glass, thus maintaining its acoustic integrity.