Sound and noise

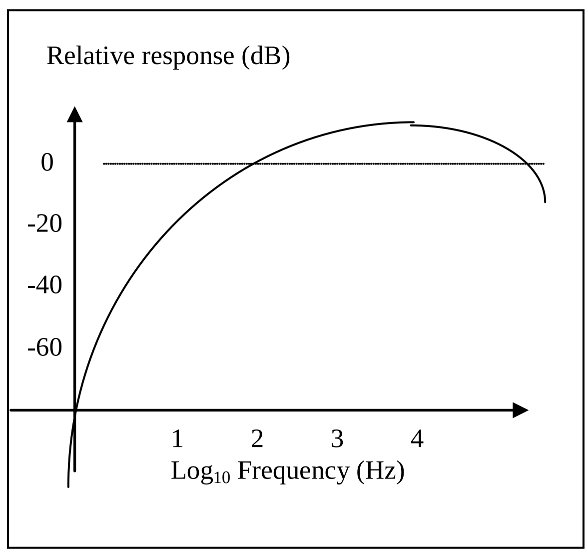
A crude definition of 'noise' is sound when and where it is not wanted. It is a legislated pollutant. The level of noise deemed to be acceptable depends on

1. *The type of environment* (office, factory, stadium)
2. *The frequency*. High 'whining' frequencies are less tolerable than lower frequencies
3. *Duration.* This is linked to human ear damage.

The threshold of hearing of the human ear is (in energy terms) about 10^{-12}Wm^{-2} (corresponding to a pressure difference of 2×10^{-5} Pa.). The threshold of pain is about 100 Wm^{-2} (200Pa). This is complicated by the fact that sensitivity is also frequency dependent. If the frequency is less than 100Hz (bass notes) the ear can tolerate higher energy densities before damage occurs. The ear is most sensitive in the range 1-5kHz. A logarithmic scale is used to define the sound pressure level. Note that the *intensity, I,* of sound corresponds to the square of the pressure.

$$L_P = 10 \times \log_{10} (P_{\mathrm{rms}}^2 / P_{\mathrm{ref}}^2) = 10 \times \log_{10} (I_{\mathrm{rms}} / I_{\mathrm{ref}}) = 20 \times \log_{10} (P_{\mathrm{rms}} / P_{\mathrm{ref}}) \qquad (1)$$

where $P_{\mathrm{ref}} = 2 \times 10^{-5}$ Pa; the pressure fluctuation just audible to the human ear at a frequency of 1kHz. The *unit of sound pressure level* is the decibel (dB). At the threshold of hearing at 1kHz ($P_{\mathrm{rms}} = P_{\mathrm{ref}}$), $L_P = 0$ dB. Doubling P_{rms}^2 implies an increase of L_P of 3dB. Thus a doubling (or halving) of the *sound energy* but not the *intensity*. An increase of 10dB makes a sound seem twice as loud; 20dB increases the loudness four times.



Most environmental noises are not steady, Examples of *unsteady noise* can be *impulses* where the noise level is 40dB or more for half a second or less (slamming a door or a sonic boom) , *single events* of fairly long duration (aircraft flying overhead), or *fluctuating noise* (traffic at a busy crossroads). It is therefore usual to average out the sound level to obtain a measure of the noise impact. Further, to obtain the noise impact on human beings, we need to take into account the human ear. These factors gives rise to a large number of empirical measures of noise impact. We shall consider only one; the *A-weighted sound level,* L_A (expressed in dBA or dB(A)). This assigns a 'weight' to each frequency that is related to the sensitivity of the ear at that frequency. A graph of the standard correction is shown on the right. This is the commonest measure because it is easy to obtain and gives a reasonable representation of perceived sound. The table gives some values for common sounds.

Sound level (dBA)	Source of the noise
110-120	Discotheque
100-110	Jet flying over at a height of 300m
90-100	Petrol-driven lawn mower (measured at the operator)
80-90	Heavy lorry (40mph) measured at 15 feet from the road
70-80	Car (65mph) at 25 feet from the road Washing machine
60-70	vacuum cleaner
50-60	Light traffic at 100 feet from the road
40-50	Quiet residential (daytime)
30-50	Quiet residential (night-time)
20-30	Quiet countryside

The figure measurements of noise for a typical community both during the day and at night. The distribution is not Gaussian; the long tail represents rare, noisy events. The length of the tail varies greatly with location, often being more extended near a factory. The measurement of environmental noise should depend on the total energy received, the number of noise events in a given time and the size of noisy, single events. How these are weighted depends on the scale used, of which there are many. A few of the common ones are

- *Equivalent continuous sound level* (L_{Aeq}); the steady-state sound that has the same A-weighted level as the time-varying sound averaged in energy over a specified time interval
- *Daytime average sound level* (L_{Ad12}); L_{Aeq} calculated using the time interval 07.00 to 19.00 (similarly, the *Evening average sound level* (L_{Ae}) takes the time interval 19.00 to 22.00 and the *Night average sound level* (L_{An}) the interval 22.00 to 07.00.
- *Noise exposure level* (L_{Aex}); the level of the time integral of the squared, A-weighted sound pressure over a stated time referenced to $(1\text{sec}) \times (20\mu\text{Pa})^2$

These are often used to determine the compatibility of land use with the noise environment. For example, a playground should not have a value of L_{Aeq} > 75dBA; houses should not have L_{Aeq} greater than about 40dBA and so forth.

It is possible to give empirical estimates for traffic noise. For example, most noise for a moving vehicle comes from the tyres. For cars and light vans, a useful relationship is

$$L_A = 71 + 32 \log (v / 88)$$

where v is the speed of the vehicle in km/hr. Expressions of a similar kind are available for motorcycles and heavy lorries. A similar, but more complex analysis can be performed for aircraft and airports. This must consider takeoffs and landings as well as the noise flying overhead. Each aircraft must be rated separately for noise and a weighted average constructed. To give one simple example, the expression for the community noise equivalent level (*CNEL*) used in California has the form

$$CNEL = 10\log(1/24)\left(\sum_{0700-1900} 10^{L_{Ah}} + 3 \sum_{1900-2200} 10^{L_{Ah}} + 10 \sum_{2200-0700} 10^{L_{Ah}} \right)$$

where L_{Ah} is the L_{Aeq} value averaged over an hour. This then has to be linked to the question of what level of noise a community will (or for that matter should) put up with. In practice, noise levels of 45dBA seem to be acceptable; anything over 65dBA is certain to cause trouble.

One interesting measure of noise level is when it interferes with speech. A number of studies have been done on this. Speech is highly redundant, thus it is easier to follow sentences than individual words. The figure shows the intelligibility of sentences and words as a function of the relative A-weighted sound levels of speech and noise. To get a 95% intelligibility for sentences, the speech level must at least equal the noise level. At this point only about 60% intelligibility is obtained for individual one-syllable words. Individual words matter in travel directions; place names cannot be guessed from context. A paging system should have an intelligibility of at least 85%; implying that the sound level must be at least 6dBA above the background noise. This is not commonly achieved.

Another major concern is the effect (temporary or permanent) of noise levels on hearing. The most important effect is the shift in dBA rating of the softest sound that can be heard (*hearing theshold*). This is not a constant for all sound frequencies (see the figure). Moreover, impairment begins at those where the human ear is most sensitive (about 4kHz). The effect of continuous industrial noise exposure for 8hr each working day for 10 years is shown in the Table below.

80dBA or less	no discernable hearing loss for 85% of the population
80-85dBA	shifts in the hearing theshold begin to appear at 3kHz and 6kHz
85-90dBA	shifts of 10dB occur in the hearing theshold at 3kHz and 6kHz; shifts of 15-20dB may occur in sensitive individuals
90dBA	shifts of 20dB in the threshold expected between 3 and 6kHz
>90dBA	shifts in the threshold at 0.5, 1 and 2kHz appear. This is defined as hearing impairment

Domestic noise and the design of partitions..

The sound level in a room is determined by a number of factors (see the figure). If there is *no internal source of noise*, then these factors are

- direct transmission (from neighbouring rooms or from outside)
- flanking transmission (by walls, floor or ceiling)
- contact noise (through floors or ceilings)

Direct transmission

The degree of transmission from outside is determined by the insulating properties of the separating walls. The *transmission loss* (*TL*) is defined as

$$TL = 10 \log (P_{in} / P_t) \qquad (2)$$

where P_{in} is the power incident on the wall and P_t is the power transmitted through it. Another, more common measure is the *noise insulation* R. This is defined as

$$R = 10 \log (I_{\text{in}} / I_t) \qquad (3)$$

where I_{in} intensity of noise incident on a wall and I_t is the intensity transmitted. These two measures can be related. The power incident on a partition of area A is $P_{in} = I_{in} A$. The power transmitted into the receiving room is equal to the rate at which energy is absorbed in the receiving room (assuming that no energy is transmitted onwards) and so $P_t = I_t W$ where W is the sound absorption of the receiving room. Thus, putting these together,

$$TL = R + 10 \log (A / W) \qquad (4)$$

R is usually measured for a band of frequencies. To reduce noise level, R must be large. To achieve this, it is necessary to (i) use absorbing materials (such as foams) (ii) have hollow (cavity) walls (iii) double glazed windows. It is necessary to avoid *resonances* (i.e. must not set up a standing wave in the cavity).

For a planar, non-porous, homogeneous, flexible wall it can be shown that

$$TL = 20 \log (f\rho_A) \qquad (5)$$

where f is the frequency in Hertz and ρ_A is the mass per unit area. This is often called the *mass law*. This usually gives an overestimate of the transmission loss since it ignores the effect of the stiffness of the panel. The point is that the panel can support flexural waves that, above a critical frequency, can be excited by the sound waves. The incoming sound wave couples effectively to these flexural waves which transmit sound through the panel. A properly designed panel must ensure that these flexural waves (which are unavoidable) cannot couple to sound waves within hearing range. Even if problems with direct partitions are solved (sometimes by using double partition walls), there remain two other basic difficulties:

- *Reflected* (*flanking*) *noise*. This can be reduced by
1. covering walls with absorbing materials (tapestries) or objects that break up the wave front (pictures, china ducks etc).
2. internal cavity walls
3. special dishes in walls which use destructive interference to remove reflected waves.
4. remove all direct paths (i.e. fit draught excluders)
- *Contact noise* This can reduced by using sprung floors. Also it helps to place vibrating equipment on shock absorbers (e.g. rubber mats).