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SYSTEMS NOISE IN BUILDINGS

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SYSTEMS NOISE IN BUILDINGS-'TERMINOLOGY AND DEFINITIONS'

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Noise

Noise is commonly defined as "sound which is undesired by the recipient" and from this definition it is clear that noise is purely subjective. In order to deal with problems of noise it is necessary to establish relationships between the physical characteristics of the noise and the amount of annoyance caused. These relationships give rise to the various criteria which exist and will be discussed in detail in the next paper.

Let us consider the basic quantities involved in the measurement of noise and the various analyses which can be carried out on these measurements.

Acoustic Scales and Levels

Consider a simple sound source radiating uniformly in all directions and suppose the acoustic power being radiated is W watts. If we assumed that there are no losses in the air then all the power radiated must pass through any surface which completely encloses the source. The power passing through unit area of the surface is defined as the intensity I and if the source is at the centre of a spherical surface of area S the intensity is the same at every point on the surface and is given by:-

$$I = W/S$$

In practice intensity is difficult to measure directly and the most convenient quantity to measure is the root mean square sound pressure fluctuation associated with an acoustic wave. For free progressive plane and spherical waves the intensity and root mean square pressure are related by the expression:-

$$I = p^2/\rho c$$

where p = root mean square sound pressure

ρ = density of air

c = velocity of sound in air

The human ear can cope with an extremely large range of sound intensities - from 10^{-12} watt/m^2 to 10 watt/m^2 - and as the ear's response tends to be logarithmic it is convenient to express sound intensity on a logarithmic scale. Sound Intensity Level is then defined as:-

$$10 \log_{10} I/I_o$$

where I_o is a reference intensity normally taken as 10^{-12} watt/m^2 which is approximately the lowest sound intensity which the ear can detect.

Since it is normally sound pressure which is measured intensity can also be expressed by:-

$$10 \log_{10} P^2/P_o{}^2 = 20 \log_{10} P/P_o$$

where P_o is a reference pressure taken as 2×10^{-5} newtons/m^2. This is known as Sound Pressure Level. The unit of sound intensity level and sound pressure level thus defined is the decibel and the range of the scale is from 0 to about 130 dB. Typical levels for various sources of noise are given in figure 1.

One of the disadvantages of using a decibel scale is that sound levels can not be added arithmetically. To determine the resultant of two or more sound levels the antilog of the levels must be taken in order to get back to energies which can be added arithmetically and then the logarithm taken again to obtain the resultant sound level.

e.g. if three levels L_1, L_2 and L_3 are to be combined the resultant level L_r is given by:-

$$L_r = 10 \log_{10} \left(\text{antilog} \frac{L_1}{10} + \text{antilog} \frac{L_2}{10} + \text{antilog} \frac{L_3}{10}\right)$$

We have now defined a sound scale and sound pressure levels can be measured with an appropriate instrument but these levels do not relate directly to what is heard because of the complex nature of the hearing process. The ear possesses a specific threshhold of audibility at which perception begins and this threshold level is highly dependent on frequency. This is shown by the lower dotted curve in figure 2. To evaluate the ear's performance above this curve a subjective analysis is carried out comparing one sound with 'a standard sound' which has been perceived equally loud. This defines the loudness level of any sound and the unit of loudness level is the phon. The loudness level of a sound is expresses as n phons when it is judged by observers of normal hearing to be as loud as a pure tone of frequency 1,000 Hz, the sound pressure level of which is ndB.

For all pure tones the loudness levels have been measured accurately in phons[1] and the equal loudness contours shown in figure 2 are the subject of an I.S.O. Recommendation[2].

It is very seldom that noises which are encountered in practice are pure tones and it is not possible to obtain directly the resultant loudness level of two or more pure tones. Also the numerical values of loudness level in phons do not relate to subjective perception of loudness i.e. a loudness level of 60 phons is not perceived as twice as loud as a loudness level of 30 phons. From the results of a number of investigations it was concluded[3] that a doubling of loudness corresponded to an increase in loudness level of approximately 10 phons over the range 20 to 120 phons and as a result the sone scale of loudness was introduced.

It is defined by the expression:-

$$S = 2^{\frac{(P - 40)}{10}}$$

or $\log_{10} S = 0.03(P - 40)$

where S is the loudness in sones

P is the loudness level in phons

This relationship is internationally accepted and is covered by an appropriate British Standard[4].

The Sound Level Meter

Ideally the simplest method of measuring loudness level would be to devise an instrument with exactly the same sensitivity and frequency response as the ear. The response of the ear however is so complex that this is practically an impossible task but an attempt to simulate the frequency response of the ear is made with the sound level meter. This basically consists of a microphone which detects the pressure fluctuations associated with the sound, an amplifier to bring the output to a measurable level and a filter network designed to give the required frequency response. As can be seen from figure 2 the frequency response of the ear changes with increase in sound intensity so in fact three networks are used to represent low, medium and high intensity sound. These are called A, B and C weighting networks respectively and they correspond approximately to the 40,70 and 100 phon equal-loudness contours. Their frequency response curves are shown in figure 3. The sound levels obtained with the sound level meter are expressed as dBA, dBB or dBC depending on the weighting network used although the tendency now is to use the A weighting scale no matter what the intensity of the sound.

Specifications covering both the electrical and acoustical performance of sound level meters have been internationally[5,6] agreed so it is possible to compare noise measurements made from different laboratories throughout the world.

Stevens Method for the Calculation of Loudness

The sone scale and the sound level meter can give reasonably accurate results for pure tones and for sounds containing frequencies which are widely separated but they are not accurate for complex sounds. This is mainly because these methods do not take any account of masking effects. Masking is the effective reduction in loudness level of one sound due to the presence of another sound. Masking effects are most noticeable at frequencies close to but above the frequency of the masking sound.

Various methods have been developed to obtain a more accurate assessment of loudness and there are now two recognised methods[7,8] of doing this. One of these methods was developed by Stevens[9] and the basis of his analysis is an empirical set of equal loudness contours for bands of noise in a difuse field as shown in figure 4. The noise is analysed in 1/3, 1/2 or octave bands and a sound pressure level obtained for each band. The loudness index S for each frequency band, is obtained from the equal loudness chart. The band having maximum loudness is the most important as this will have the most masking effect on all other bands and in calculating the total loudness the maximum loudness index is given preference over all other values. The expression for the total loudness is then:-

$$S_t = S_m + F(\Sigma S - S_m)$$

where S_m is the greatest loudness index

ΣS is the sum of the loudness indices of all the bands
F is the masking factor
F = 0.15 for third octave analysis
F = 0.2 for half octave analysis
F = 0.3 for octave analysis

The total loudness S_t in sones can then be converted to loudness level in phons by using the loudness function.

Perceived Noise Level

The scales and methods described so far are all used to assess loudness but Kryter[10] has produced a method whereby he assesses noisiness or annoyance rather than loudness, with particular reference to aircraft noise. His analysis is exactly the same as that of Stevens but instead of using equal loudness contours he has produced contours of equal noisiness and these are shown in figure 5. The units of noisiness he calls noys and the total annoyance of a noise is obtained from the expression:-

$$N_t = N_m + F(\Sigma N - N_m)$$

where N_m is the greatest value in noys obtained from any band

ΣN is the sum of the values obtained from all bands
F is the masking factor which takes the same values as in Steven's method.

The total noisiness N_t in noys is then converted to perceived noise level in PNdB by the same function which relates sones to phons

$$\text{i.e. } N_t = 2^{\frac{(PN - 40)}{10}}$$

$$\text{or } PN = 40 + 33.3 \log_{10} N_t$$

Noise and Number Index

If a noise is intermittent in nature then the annoyance caused by this noise depends both on its average level and the number of times it occurs. Studies carried out on aircraft noise[11] has shown that a fourfold increase in the number of aircraft is equivalent on an annoyance scale, to an increase in perceived noise level of 9 PNdB. The zero on the annoyance scale occurs at about 80 PNdB and the noise and number index is then defined as:-

$$N.N.I. = (\text{Noise level measured in PNdB}) + (15 \log_{10} N) - 80$$

where N is the number of flights per day.

The noise and number index thus defined is directly related to the degree of annoyance caused and this relationship is shown in figure 6.

Transmission of Sound Between Adjacent Enclosures

A sound source placed in an enclosed space will produce a certain sound intensity I_1. Suppose that in an adjacent enclosure a sound intensity I_2 is produced due to the transmission of sound through the common wall. If it is assumed that there is no other sound path and that a fraction τ of the sound energy incident on the wall is transmitted through it, then the total power radiated into the second enclosure is $I_1 \tau S$ where S is the area of the common wall.

If the total absorption present in the second enclosure is A then the total power absorbed is $I_2 A$

$$\therefore \quad I_1 \tau S = I_2 A$$

$$\therefore 10 \log_{10} \frac{I_1}{I_2} = 10 \log_{10} \frac{A}{\tau S}$$

$$\therefore 10 \log_{10} \frac{1}{\tau} = L_1 - L_2 + 10 \log_{10} \frac{S}{A} = R$$

where L_1 and L_2 are the sound pressure levels in the two enclosures

$R = 10 \log_{10} \frac{1}{\tau}$ is called the sound reduction index or transmission loss of the wall.

If the wall consists of a number of sections having different sound transmission coefficients an average coefficient can be obtained from

$$\tau_{ave} = \Sigma \tau S / \Sigma S$$

References

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9. Stevens, S.S., J. Acoust. Soc. Am. 1956, 28, 807-832
10. Kryter, K.D., J. Acoust. Soc. Am. 1959, 31, 1415-29
11. Wilson report on Noise 1963.

Noise	Decibels (relative to 2×10^{-5} N/m^2)	Description
large rocket engine pneumatic hammer boilermaker's shop	100 - 120	Deafening
car horn at 5 m Noisy factory loud music	80 - 100	Very loud
typewriter radio average factory	60 - 80	loud
quiet motor car average office average house	40 - 60	Moderate
public library quiet conversation watch ticking	20 - 40	Faint
still night in country sound-proof room threshold of hearing	0 - 20	Very Faint

Figure 1

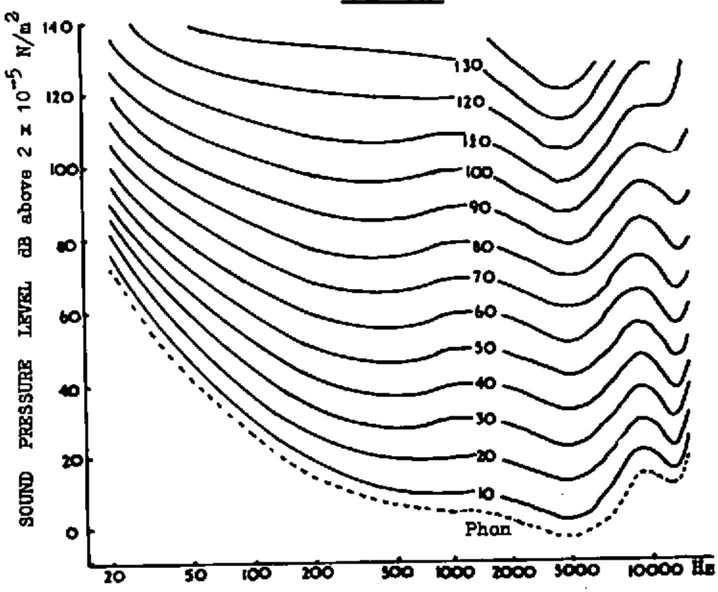

Figure 2

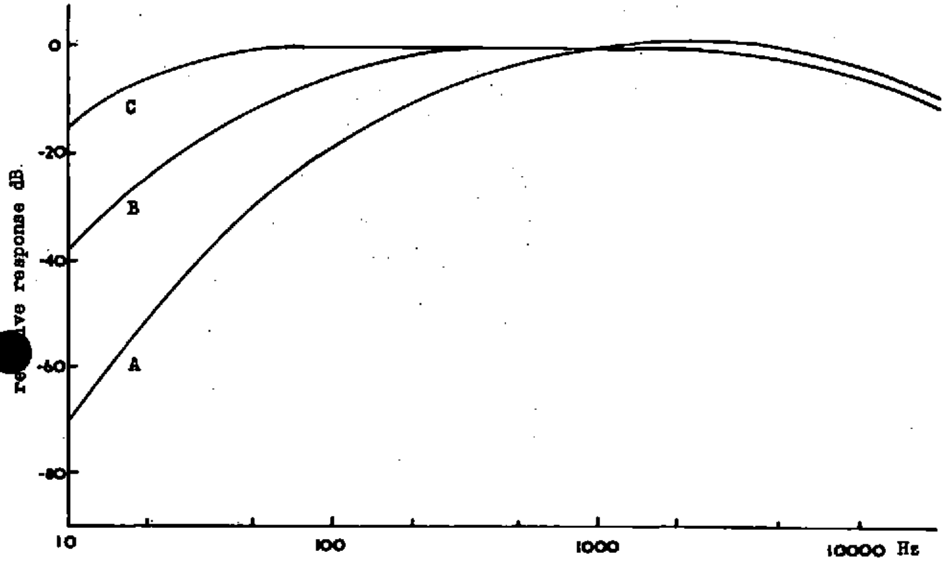

Figure 3

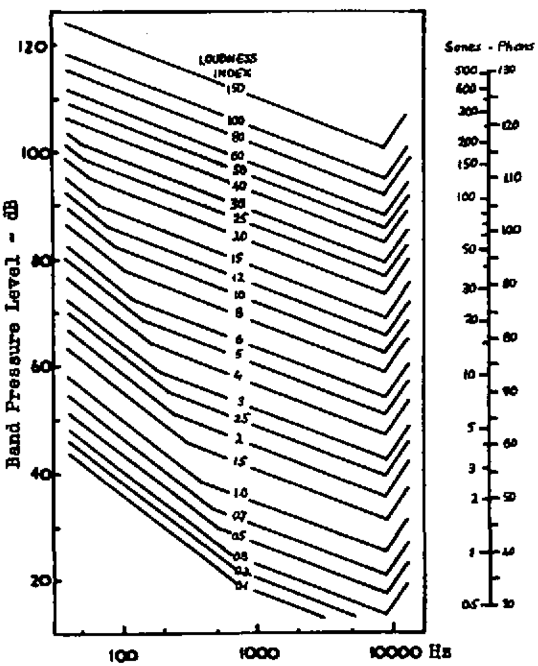

Figure 4

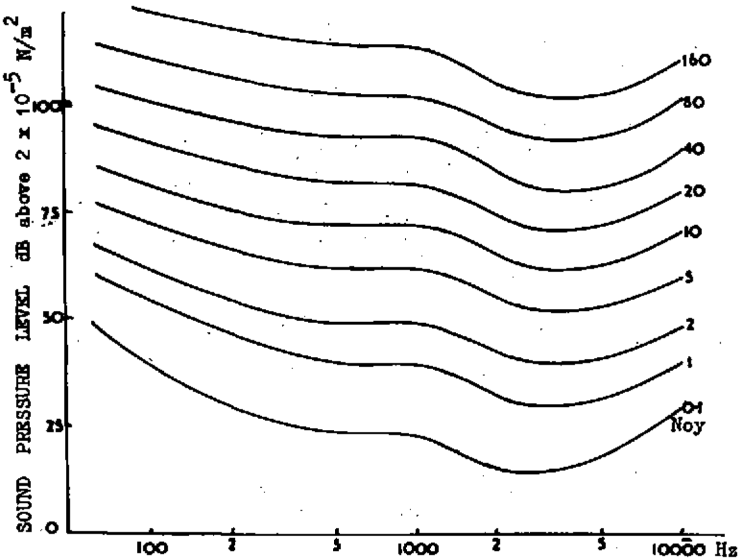

Figure 5

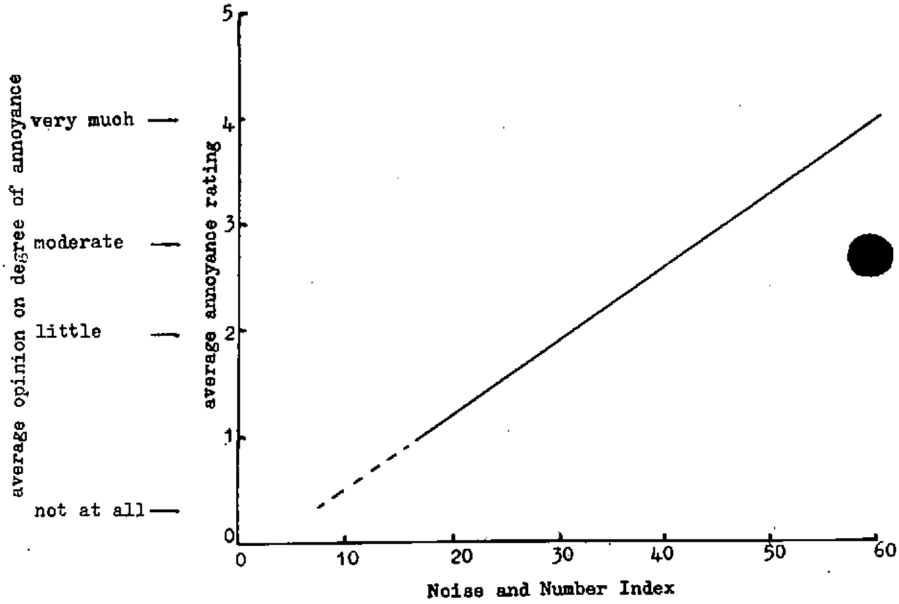

Figure 6