SELECTED PRESENTATIONS

Informal Regional Consultation Meeting on Noise Pollution

2 - 5 September 1991, Amman, Jordan

World Health Organization
Eastern Mediterranean Regional Office
Regional Centre for Environmental Health Activities
CEHA
Amman, Jordan
1995

CEHA Document No. TLM-8

Selected Presentations

Informal Regional Consultation Meeting on Noise Pollution

World Health Organization
Eastern Mediterranean Regional Office
Regional Centre for Environmental Health Activities
CEHA
Amman, Jordan
1995

For inquiries and more information please write to:

Coordinator,
WHO, Regional Centre for Environmental Health Activities (CEHA)
P.O. Box 926967 Amman 11110, Jordan
Tel. 684655/684657
Fax 686591
Telex 21109 WHOCEH JO

ACKNOWLEDGEMENTS

This document includes presentations from the Informal Regional Consultation on Noise Pollution organized by CEHA 2 to 5 September 1991, in Amman, Jordan. Acknowledgements are extended to the noise pollution experts namely Dr D. J. Oldham, School of Architecture and Building Engineering, University of Liverpool, U.K., and Dr J. Lang, Versuchsanstalt fur Warme-und Schalltechnik an YGM, Austria, for assisting and implementing the consultation. They also provided the participants from the WHO Eastern Mediterranean Region with the valuable notes and lecture materials for future reference, including this document.

Special acknowledgements are extended to the Central Secretariat of the International Organization for Standardization (ISO) for their kind permission to reproduce the following ISO standards free of charge: 1996-1: 1982, 1996-2: 1987, 1996-3: 1987 and 2204: 1979.

Mr S. Atallah, Director Environmental Health Programme, EMRO, Dr M. Z. Ali Khan, Regional Coordinator, CEHA, and Mr M. Malkawi, Technical Assistant, CEHA, provided their valuable time and contributions towards the review, compilation and printing of this document.

INTRODUCTION

The World Health Organization's (WHO) Regional Centre for Environmental Health Activities (CEHA), Eastern Mediterranean Region, organizes training and learning activities at the regional and national levels to develop manpower in its 22 Member States in the field of "Health and Environment". The Informal Consultation on Noise Pollution, held in Amman 2 to 5 September 1991 was the first activity of its kind in the Region. The aim was to introduce and promote the understanding of the problems of noise pollution, its measurement, control and impacts on health as well as to encourage the development of national strategies, legislation, approaches, standards and regulations.

This document includes working papers and lectures prepared and presented by the experts during the Informal Consultation on Noise Pollution. It is hoped that the document will serve as a supplemental study material in educational curricula as well as in training programmes for professionals in the ministries of health, environment and development as well as NGOs involved in the area of noise pollution.

Contents

NOISE FUNDAMENTALS

1. Introduction

1.1 What is noise?

An old riddle asks: 'What comes with a carriage and goes with a carriage, is of no use to the carriage and yet the carriage cannot move without it?'

Given the context of this paper you have an advantage over someone who is faced with this riddle out of the blue and it is easy for you to arrive at the answer, 'noise'. The riddle also gives the correct impression of the inevitability of noise in association with mechanical movement. When work is carried out by a heat engine, electric motor or some other prime mover it is inevitably accompanied by energy conversion and degradation. A minute quantity of the work done is not converted directly into useful work or heat but is radiated as sound. Eventually this in turn becomes heat which is the ultimate end of all work. Noise is a term that we use to mean something more than sound. It is **unwanted sound.**

One view of pollution and polluting processes is that it represents waste and bad resource management. Unfortunately this is not true of noise itself since sound accounts for a very small fraction of the mechanical energy transformed during any process. Noise control is not justified solely on grounds of waste reduction. On the other hand a noisy process is often a wasteful one. High noise levels in industry are unwanted because they are hazardous to hearing, because they are a hindrance to communication and because they cause unnecessary stress. Noises associated with environmental sources such as transport systems and industrial plants are unwanted because they impose a burden of annoyance, distraction, intrusion and interference upon people who receive no immediate or direct benefit from the noise producing system. This can be true of any sound in any context. It is simply that, in this mechanical age, there are a greater variety of man-made sound sources than at any other period of history.

1.2 What does noise do to people?

The effects of noise on human health vary according to the susceptibility of the individual exposed to noise, the nature of the noise and the duration and location of his or her exposure to it.

The primary effect of prolonged exposure to high levels of noise in the workplace is the development of industrial or occupational deafness. This is often called Noise Induced Hearing Loss (NIHL) to distinguish it from hearing loss due to increasing age. NIHL requires prolonged exposure over the order of a working lifetime, although sufficiently intense impulsive noise could produce instantaneous damage-blast deafness. Short periods of exposure to high noise levels produce temporary hearing loss, followed by a gradual recovery of hearing.

Vaso-constriction - a tightening of the blood vessels, cutting down the flow of blood to various parts of the body, is a well-documented circulatory response to noise. It is a 'startle reaction'. Other physiological manifestations accompany sudden or transient sounds and may be related to natural responses and reflexes to audible warning signals. These include muscle tension, acceleration or deceleration of heart rate, general constriction in the peripheral blood flow (e.g. to the skin), changes in the secretion of saliva and gastric juice and reflex movements of the gastro-intestinal tract. There is some evidence to suggest that prolonged exposure to intense noise may have a noticeable effect on digestion.

Interference with rest or sleep and the consequent lack of concentration, irritability or reduced efficiency, are obvious and annoying effects of noise. These are most likely to be significant among the older age groups. Note that it is not necessary that people have to be woken up to suffer loss of the correct type of sleep. Unfortunately, the effect of such sleep disturbance is not readily identified or quantified.

One of the most common and undesirable effects of noise is interference with communication. In industry the disruption of communication can result in inefficiency and, possibly, fatal accidents. In people's homes and leisure activities noise may exist at high enough levels to make speech unintelligible and audible warnings unheard. At least the spoken or broadcast word could be less easily understood and warnings made incomprehensible.

Speech interference is a particularly important consideration in schools and other educational establishments. Even at levels where hearing damage risk is not large, noise in the working environment can affect concentration, efficiency and output. Most annoyance with noise in the home seems to be associated with its impact on radio and TV enjoyment or conversation.

Finally, most of us will be aware that exposure to unaccustomed high levels of noise tend to change our emotional responses. We tend to become more agitated or less reasonable than usual. There is some evidence, but not conclusive, that noise is associated with mental illness. In particular, it may lead to general psychological distress, and this in itself will mean an increased susceptibility to noise, precipitating some sort of crisis.

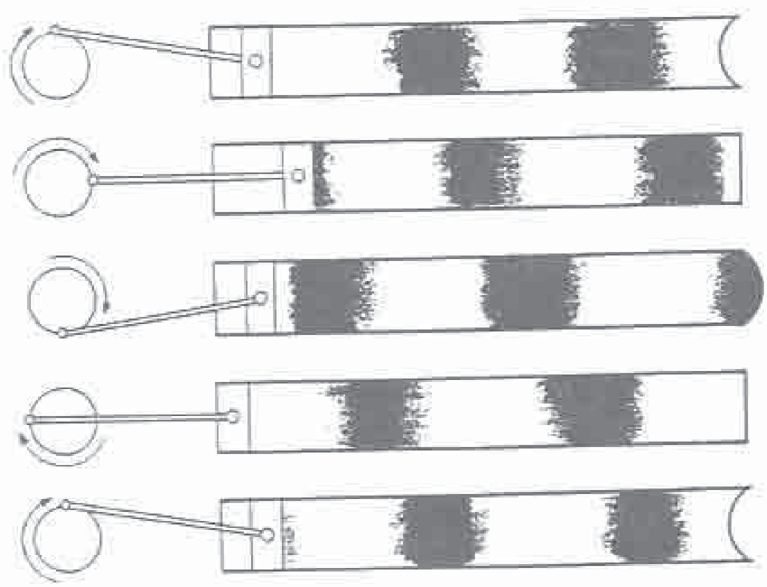
On the other hand we should not aim for the complete elimination of noise even if it were possible. Complete silence for prolonged periods can be very disturbing as a result of sensory deprivation. Moreover the noise of industrial machinery or of vehicles can often be used by their operators to judge their general working-order.

2. Steady Sound and its Description

2.1 The nature and speed of sound

Since noise is unwanted sound, to understand the ways in which noise can be measured, and how the measurement depends upon where you measure it, it is necessary to know something about the nature of sound. As was said in the introduction, sound is a form of energy. The aural sensation that we call sound is caused by the interaction between small pressure variations in the air around us and our hearing mechanism. The small pressure variations are associated with the oscillations of the particles of which air is composed. These oscillations will originate with the disturbance of air-particles adjacent to any vibrating surface in air which we call a sound source and are transmitted subsequently through the air from particle to particle as a consequence of the forces that exist between the particles of the air. The particles are not carried along with the disturbance, they simply oscillate to and fro about their equilibrium or average undisturbed positions as the disturbance passes. We describe the way in which the disturbance moves from one place to another as the propagation of a sound wave.

Figure (1) Piston Sound Source



Consider the simple example of a sound source as shown in Figure 1. It consists of a piston which can be driven backwards and forwards in a regular manner at one end of a circular cylindrical tube. As the piston is driven forward the air-particles next to its surface will bunch together producing a region of compression. As the piston moves backwards the air-particles next to its surface will spread out producing a region of rarefaction. In the compression, the air pressure will be a little higher than the equilibrium value, and in the rarefaction, it will be a little lower. If the to and fro movement of the piston is made continuous and regular, then a series of regularly-spaced compressions and rarefactions will form and travel along the tube. In other words, there will be a pressure wave in the tube, and, if you were to put your ear to the opposite end of the tube to the piston, and the piston were to be moving rapidly enough, you would hear this pressure wave as sound.

The speed at which the sound wave propagates down the tube will not depend upon the rate at which the piston moves. It is a fundamental property of air and is related to the forces between the air-particles, that were mentioned earlier, and to the density of the air. Since these properties are affected by the equilibrium pressure and the temperature, the speed of sound is influenced by pressure and temperature also. At an equilibrium pressure of one atmosphere and a temperature of 20 °C, the speed of sound in air is about 344 m/s.

2.2 Power, pressure and intensity

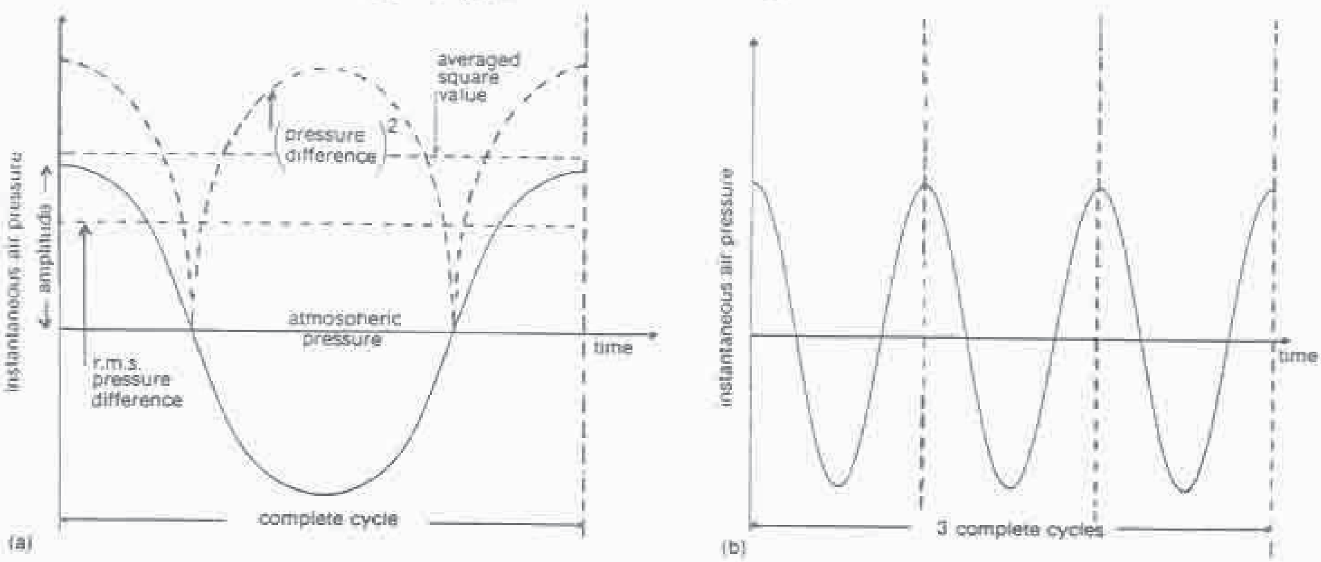
In the pistonphone example above, the greater the displacement of the piston, the greater will be the pressure changes in the associated sound wave. Consequently, as the power of the piston motion increases, so does the power of the resulting sound. In other words the sound power of a sound source depends upon the power input to the source. Both are expressed in watts (W).

It is possible to quote accurate empirical relationships for the sound power of many source types, including fans, pumps, gears, bearings, valves and ventilation grilles.

It is difficult to measure the sound power of a sound source directly. The quantity that can be measured is the air-pressure, or more strictly, the difference between the fluctuating value of air-pressure and its equilibrium or mean value.

Considering the piston in a tube example again, suppose that some means of measuring the pressure-difference-fluctuations is placed in the tube downstream of the piston. Figure 2(a) shows how a plot of the variation of pressure-difference with time might look. At one moment the point of measurement might be in a region of compression and at the next moment it might be in a region of rarefaction. In the rarefaction the values of pressure- difference are negative. This explains the maxima and minima on the curve of pressure-difference with time. The maximum excursion of pressure-difference is called the amplitude of the sound wave. The amplitude is indicated in Figure 2(a) together with one complete cycle of pressure-difference values. As the piston vibrates more and more rapidly the readings on the pressure-detector would cycle more and more quickly. Figure 2(b) shows the result of increasing the rapidity of vibrations by a factor of three. As the rapidity of vibration increases the pressure variation becomes more and more difficult to follow.

Figure (2) Sound Pressure Against Time



Even for the slowest rate of vibration that produces audible sound, some kind of average over time is required as a measurable indication of amplitude. The way in which this average is obtained is, firstly, to square every value of the pressure-difference over any cycle. This has the effect of making positive all the values otherwise registered as negative. These squared values are then averaged and finally the average is square-rooted. The consequences of each of these steps are shown in Figure 2(a). The final result is known as the rootmean-square (r.m.s) sound pressure. Henceforth whenever the phrase sound pressure is used you should understand it to mean r.m.s. pressure-difference.

Sound pressure has the same units as any other pressure. The units are newtons per square metre (Nm^{-2}) or pascals (Pa). Typical sound pressures are a small fraction of a pascal, whereas atmospheric pressure has a typical value of 100,000 or 10^5 Pa. The ear responds to sound pressure and so does the microphone of a sound level meter. A microphone converts the detected sound pressure into an electrical signal.

Sound intensity represents the power transmitted per unit area at right angles to the direction in which the sound is propagating. As long as the sound wave is not very close to its source and is able to propagate without hindrance from any obstructions, its intensity is proportional to the square of the sound pressure. For air at atmospheric pressure and 20 °c the constant of proportionality is 1/410. So, for example, if the sound pressure registered at a point were to be 10^{-4} Pa, then the sound intensity of the unhindered sound wave at the point would be: 2.4×10^{-11} Wm^{-2} at 1 atmospheric pressure and 20 °C. The units of sound intensity are consistent with its definition as power (in watts) per unit area (square metres).

2.3 Frequency and pure tones

A cycle of compression and rarefaction is shown in Figure 2(a). The length of time occupied by that cycle will influence the pitch of the sound that you hear from the pistonphone. One measure of the length of time occupied by each compression-rarefaction cycle is the number of such cycles that occur in each second. This measurement is known as the frequency of sound and it will depend upon the rate of vibration of the piston in the pistonphone. The more rapidly the piston vibrates, the higher the frequency will be. Figure 2(b) shows a sound wave of the same amplitude but of a higher frequency than that depicted in Figure 2(a). The unit of frequency is the hertz for which the abbreviation is Hz. Very few man-made noises or naturally-occurring sounds are pure tones. Even sounds from a musical instrument that appear to have a single pitch, an apparently clear single note, contain more than one frequency. Usually our impression of their pitch will correspond to the frequency at which there is most sound power the dominant frequency.

2.4 The decibel and sound pressure level

Our hearing system is non-linear with regard to sound pressure. In other words, if the pressure of a 1000 Hz pure tone is doubled it will not elicit twice the response in the listener. It will not sound twice as loud. In fact the pressure would have to be increased by more than a factor of three for a sound to be twice as loud. Furthermore, the range of sound pressures, from the minimum detectable to the highest bearable, is quite large (from about 2×10^{-5} Pa to 20 Pa). For both of these reasons it is convenient and helpful to use a logarithmic scale of sound pressure. The common logarithm of a number is the power-to which-10-has-to-be-raised to produce that number. For example, $100 = 10^2$ so that the logarithm-to-the-base-10 of a hundred, which is written in shorthand form as $\log_{10} 100$, or more simply as log 100 or lg 100, is 2. Similarly log 1000 = 3. So on a logarithmic scale the difference between 1000 and 100 is reduced to the difference between 3 and 2. One problem with logarithms is that the logarithms of numbers less than 1 are negative. It would be somewhat confusing to represent a sound pressure measurement of a fraction of one pascal by a negative number. This problem can be overcome by introducing a small reference quantity and always dividing by this before taking logarithms.

The chosen reference sound pressure is 2×10^{-5} Pa, which corresponds to the lowest sound pressure detectable on average by people with normal hearing at 1000 Hz. If we denote any sound pressure of interest by P, then the logarithmic value is calculated from:

$$20 \log \{P/2 \times 10^{-5}\}$$

and is called the sound pressure level measured in decibels relative to 2×10^{-5} Pa.

In practice we use the abbreviation SPL or Lp for sound pressure level, and dB for decibels relative to 2×10^{-5} Pa. The factor of 20 appears because the energy in the sound wave or the sound intensity is proportional to the square of the sound pressure. It follows from the properties of logarithms is that it is possible to have zero SPL even in the presence of sound! Consider the SPL corresponding to a sound pressure of 2×10^{-5} Pa. This happens to be the same as the reference pressure. and the corresponding SPL is $= 20 \log 1 = 0$ dB. Consequently, the range of sound pressure levels with which we are concerned in the study of noise and noise control, is from 0 dB to somewhat less than l40 dB. This is less daunting than the range 2×10^{-5} to 20 Pa and, as mentioned earlier, is one of the reasons for employing the logarithmic scale.

2.5 Frequency response of the hearing system; dB(A)

Many advertisements for hi-fi equipment will describe the performance of amplifiers by statements like 'the gain is flat plus or minus 1 dB from 20 to 20,000 Hz'. What such statements are trying to indicate, is that these amplifiers, when used to connect a good tape deck, turntable or microphone to good loudspeakers, will offer the facility of more or less perfect reproduction of sounds within the stated frequency range. No frequency within this range will be preferentially amplified and no frequency will be discriminated against by more than 1 dB, which is a negligible amount in subjective terms. The range of frequencies quoted does, in fact, correspond to the range of frequencies that are audible to a healthy youth with normal hearing. It is called the audio-frequency range. Sometimes this range is considered to begin at 16 Hz.

At the extremes of this range the sound pressures would have to be very high to be heard by someone with normal hearing. In between these extremes, however, there is a range in which the ear is particularly sensitive. These frequencies correspond roughly to the frequencies of importance in speech intelligibility. The hearing system, therefore, does not behave like a perfect amplifier over the audio-frequency range. The sensitivity varies from frequency to frequency. A plot of the lowest sound pressure at any frequency that can be detected by someone with normal hearing is called the threshold of hearing and is shown in Figure 3. Notice that it has the expected high values (20 Pa) at the extremes of the audio-frequency range, the expected low value, 2×10^{-5} Pa, at 1000 Hz, and that there is greatest sensitivity to frequencies between 2000 and 5000 Hz. If the frequencies between 20 Hz and 20,000 Hz were to be present at the sound pressures required to make both 20 Hz and 20,000 Hz pure tones sound audibly, then an uncomfortable tickling sensation very near to pain would be experienced in the ears. It is possible to plot the normal onset of this sensation as a curve of sound pressure versus frequency known as the threshold of feeling. This is also shown in Figure 3.

Each of the thresholds of hearing and of feeling indicate different frequency responses. Between these two thresholds, the frequency response of the ear depends upon the sound level. Curves can be drawn known as curves of equal loudness. These are shown in Figure 4.

Figure (3) Thresholds of Hearing and Feeling

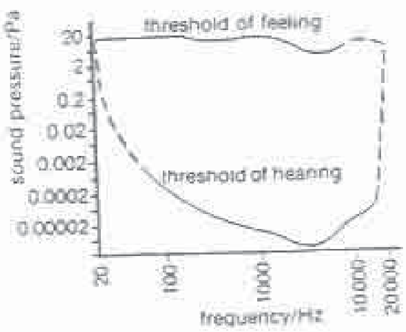
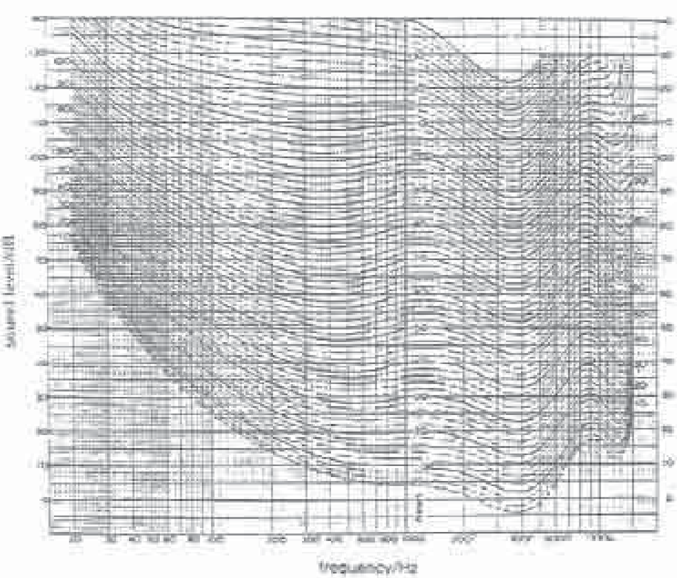


Figure (4) Equal Loudness Contours

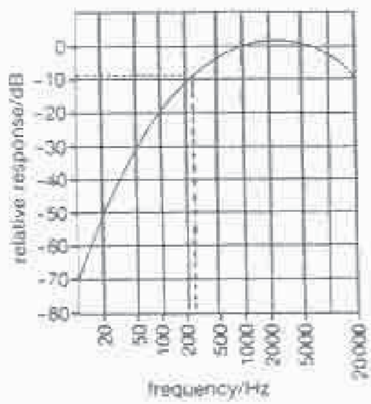


Notice that the vertical axis in Figure 4 is marked in SPL rather than sound pressure, so it corresponds to a logarithmic scale rather than a linear one. Each of the curves links hypothetical pure tones that seem as loud as each other. It makes sense to try and measure noise levels in a way that corresponds to the frequency response of hearing. The difficulty arises however of deciding which frequency response to choose. When noise is very loud, the response of the ear is more like the flat response of the expensive amplifier, than when the noise is relatively quiet. In practice, several different frequency responses have been selected.

Frequency responses can be thought of in a different way. Consider for example the result of measuring two pure-tones, produced with the same SPL in dB at the measuring point, but at

250 Hz and 1000 Hz respectively. Suppose that the measuring instrument has the same frequency response as the curve highlighted in Figure 4. Suppose further than the 1000 Hz tone gives a reading of l00 dB. What reading will the 250 Hz tone give? According to the curve it will be somewhat less, about 3dB less, than that for the l000 Hz tone. In other words the response at 250 Hz is weighted with respect to that at l000 Hz. It is possible to show frequency responses as weighting curves. Of particular importance is the A-weighting curve shown in Figure 5. This is a standard weighting applied to acoustical equipment so that they respond to sound in a similar way to the human ear.

Figure (5) The A-Weighting Curve



Note that for measurements of sound level, it is important to state the location of the measurement. The sound level of a source, like its sound pressure level, sound pressure, and sound intensity, depends upon the location of the measuring position with respect to the source. Only sound power is independent of the distance of measurement from the source and is a characteristic of the source itself.

2.6 The addition of sounds and sound levels

Having introduced the meaning of frequency-weighting and of A-weighting in particular, we now move on to another important topic-that of the addition of sound levels. Suppose that you were to be measuring the sound level at a point equidistant from two sound sources. How would the resulting reading differ from that you would obtain from either source alone?

The result is obtained, usually, by adding the two sound intensities. You will recall that sound intensity is proportional to the square of sound pressure as long as the sound is propagating without obstruction. Suppose that each of the sound sources produces an intensity I at the measuring position. Then the total intensity when both sources are operating simultaneously will be $2I$. This will be proportional to $2p^2$ where p is the r.m.s. sound pressure corresponding to the intensity I of each source. The r.m.s. sound pressure corresponding to an intensity of $2I$ will be $(2p^2) = p\sqrt{2}$

The sound pressure level for simultaneous operation will be the SPL due to a single source plus 3 dB. So the result of adding two identical sound pressure levels is a total level that is only 3 dB higher than either individual level. This is an important feature of the logarithmic scale.

If two identical but separated sound sources each produce a sound pressure level of 90 dB at a measuring point, then operation of both sources at the same time will not produce 180 dB but result in a reading of 93 dB at the measuring point. Although we have discussed addition of unweighted sound pressure levels, this rule of addition will apply to frequency-weighted sound levels. For example the result of adding two sound levels of 80 dB(A) will be a total sound level of 83 dB(A).

The addition of two identical sound levels is the simplest example of the addition of two sounds that we could have considered. The addition of two different sound levels is more complicated. In general, if the separate levels of two sound sources are known, then to find the combined level, it would be necessary to do the following:

* Calculate the mean square pressure corresponding to each level.
* Add the mean square pressures.
* Calculate the level corresponding to this sum.

Since this is a rather tedious exercise, use of ready-made calculations embodied in Tables is more convenient.

2.7 Frequency weighting and spectra

The frequencies that are present in a sound from a particular source are ascertained from a source frequency spectrum, sometimes simply called source spectrum, which is a plot of the sound pressure level at each frequency over the range of interest.

A detailed source frequency spectrum enables a choice to be made between various noise control possibilities each of which is most effective in a particular frequency range. This is important particularly for noise control in industry.

A broad-band noise is one that has an almost constant sound pressure level for all the frequencies of interest. The description narrow band refers to spectra where the main energy lies in a small narrow range of the frequencies. If the sound is tonal then it is possible to pick out discrete frequencies or pure tones in its spectrum.

2.8 Loudness, annoyance and perceived noise level

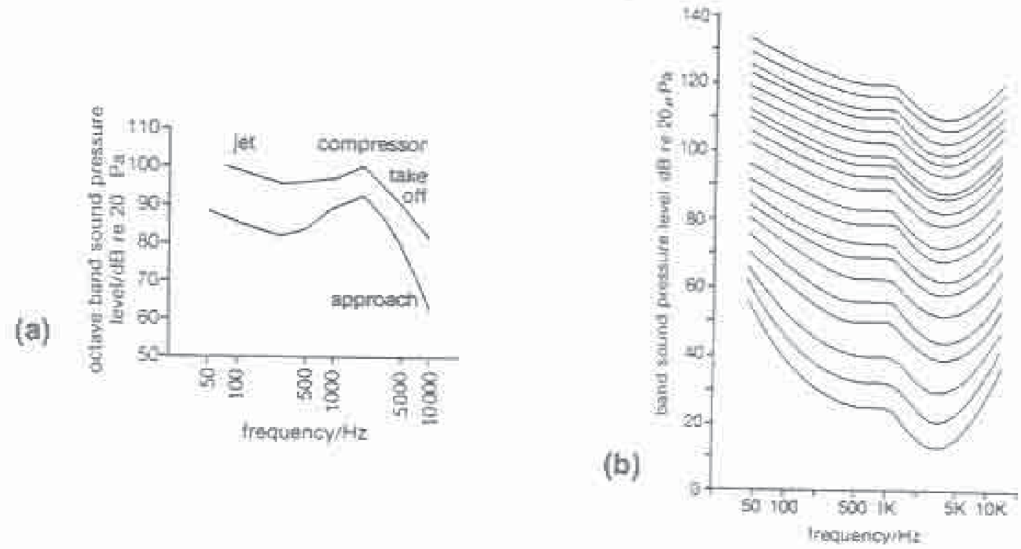
A consequence of A-weighting is that two apparently dissimilar frequency spectra may be measured as having the same A-weighted level. Although this means that these two sounds will seem to be equally loud, it does not mean that they will be equally annoying.

The noise of a circular saw at 10 m might only be as loud as that from a bus at 2 m and give the same A-weighted SPL, but the circular saw will be more annoying. Apart from the frequency sensitive contribution to annoyance there will be contributions from many other non-acoustic factors.

The loudness of a sound is the listener's auditory impression of the strength of the sound, whereas annoyance with a sound can be defined as the feeling of displeasure with the sound when it is realised or believed by listeners as adversely affecting them.

This is a difficult concept to quantify. A particular study has been made of annoyance with aircraft noise. Of course the noise from aircraft, except during some ground operations, is not steady; but ignore this variation with time for a moment, and consider the frequency spectrum of aircraft noise, an example of which is shown in Figure 6a.

Figure (6) Aircraft Spectrum and Equal Noisiness Contours



Notice that there is an appreciable proportion of the total sound power concentrated at frequencies above 1000 Hz. Usually, single frequencies above 1000 Hz are judged to be more annoying than frequencies below 1000 Hz even when their SPLs have been adjusted so that they are judged to be equally loud. Contours of equal noisiness (figure 6b) can be drawn in the same way as the equal loudness contours shown in Figure 4. The differences between these and the equal loudness contours mean that a better correspondence or correlation has been obtained between weighted SPL and annoyance using a frequency-weighting different from either A-weighting or C-weighting. The resulting weighted SPL is known as perceived noise level (PNL). The units of PNL are Perceived Noise Decibels (PNdB). PNL is used only in standards for aircraft noise in the UK.

A-Weighted sound pressure level or sound level is used in standards for most noise annoyance since the advantages of PNL have proved sufficiently great to warrant its wider use. In fact, in the UK, aircraft noise is measured by the Civil Aviation Authority in db (A) and then converted to PNdB by the addition of a correction.

PNL can be related typically to A-weighted SPL by the approximate relationship PNL = SPL (A-weighted) + 13 but the relationship depends upon the type of aircraft noise being measured.

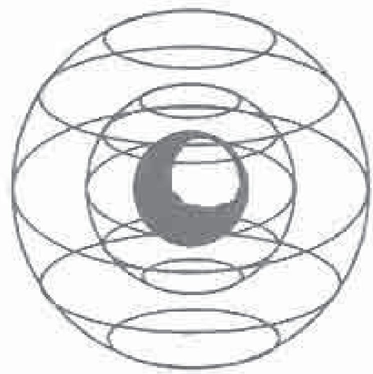
When sound levels are high enough to pose a risk of hearing damage to people exposed to them for long periods, the A-weighted level corresponds fairly closely to the risk. Consequently A-weighted levels are used also to assess industrial noise problems.

3. Sound Propagation

3.1 Unobstructed spreading

When you throw a pebble into still water, you notice ripples spreading out in circles centred upon the splash. This experience allows us to imagine the areas of compression and rarefaction, associated with a sound wave, spreading out from a sound source (Figure 7).

Figure (7) Sound Waves from a Point Source



In the case of a source that radiates sound equally in all directions, called an omnidirectional source, the sound wave will spread out spherically. Since the sound spreads out as though from a point, such a source is sometimes called a point source. At any given distance from the source, the power of the source W will be spread over the surface of a sphere of radius r. This surface area is $4\pi r^2$. The sound intensity (I), which is the sound power per unit area, will be given by:

$$I = W/4\pi r^2$$

This is the so-called inverse square law and applies to the radiation of many kinds of energy; it means, for example, that every time the radius of the sphere (which is the distance from the source) is doubled, the intensity will decrease by a factor of four. Remember, however, that the intensity is proportional to the square of the sound pressure.

This can be interpreted, the other way around, and implies that sound pressure is proportional to the square root of intensity. Since intensity is proportional to the inverse square of distance from the source, pressure must be proportional to the inverse of distance. This idea can be employed in the definition of sound pressure level.

$$\mathbf{SPL = 20 \log (P/P_o)\ dB}$$

To calculate the decrease in SPL with doubling of distance. If the sound pressure at distance r is P_1, then P_I is proportional to 1/r. At distance 2r, the pressure P_2 must be proportional to the inverse of 2r, i.e. 1/2r.

The change in SPL between distance r and distance 2r is given by:

$$\text{change in SPL} = 20 \log (P_I/P_2) = 20 \log ((1/r)/(1/2r)) = -20 \log 2$$
$$= -6\ dB.$$

For the ideal situation of spherical unobstructed spreading of sound from an omnidirectional source, therefore, the sound pressure level decreases at a rate of 6 dB per doubling of distance.

Another kind of idealised sound source, called a line source, is one from which the sound waves spread cylindrically. A noisy pipeline is an industrial example of a line source. A continuous stream of road traffic is another example of such a source. The road traffic will act as a line source as long as the measurement point is sufficiently far away for the sounds from the individual vehicles to have merged together.

From a line source the sound pressure level decreases at a rate of 3dB per doubling of distance and this is the attenuation rate near to acoustically hard ground such as asphalt that is used in the prediction of noise from freely-flowing road traffic. This is a slower rate than that from a point source.

Over grassland, the rate of decrease of sound pressure level from freely flowing road traffic is somewhat more than 3dB because of the influence of the ground surface. There are also meteorological factors to be considered, but we will discuss these details later .

The final instance of idealised sound propagation that should be mentioned is that in which the sound pressure level does not change with distance at all. This will be the case for plane waves of sound. The sound waves generated by a piston inside a tube which was the idealised example with which we started this study of sound are plane waves. The regions of compression and rarefaction are parallel and do not spread. Consequently, sound travels very well along tubes and passage ways of all sorts. In practice of course the sound intensity will decrease as a result of absorption at boundaries and through the air.

Most individual items of noisy machinery are more like point sources than line sources. But they differ from point sources in important ways:

they may be large;
they may be inherently directional;
they may be positioned close to sound-reflecting surfaces.

As a result the sound pressure level will be highly dependent upon the position in which it is measured. It is important to be able to predict this variation in any given environment. On the other hand, in setting standards for the noise produced by any appliance or mechanical system, i.e. its noise emission, and in devising methods of monitoring the noisiness of processes as part of quality control, it is important to be able to deduce the sound power level from measurement of sound pressure level in a given position. The sound power level is a logarithmic measure of the sound power and is a fundamental attribute of the source, in the same way, for example, as the power-rating of an electrical appliance.

Sound Power Level (SWL) is defined by: $SWL = 10 \log (W/W_o)$ dB

Where W and W_o are the source power and the reference power respectively, and $W_o = 10^{-12}$ W. Although both sound power level and sound pressure level are measured in dB they are not numerically equal.

Note:

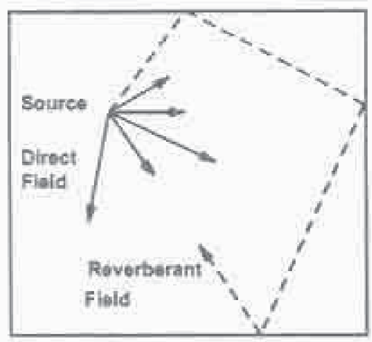
1- sound power level values, like sound pressure level, may be frequency weighted

2- that the rules of propagation; 6 dB per doubling of distance from a point source and 3dB per doubling of distance from a line source are equally valid for frequency-weighted and unweighted sound pressure level and

3- that dB(A) is used as a unit of measurement of both sound pressure level and sound power level; the context should always make plain, however, which quantity is being quoted or measured.

3.2 Sound in rooms

Figure (8) Reverberation in a Room

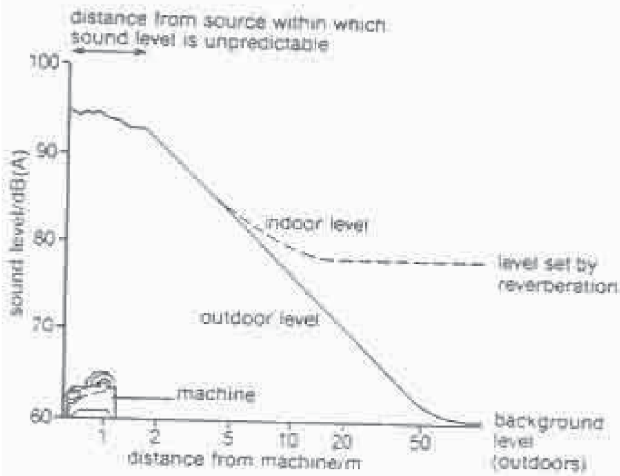


The sound absorbing property of any surface is represented by the fraction of incident sound power that is not reflected by it. This fraction is called the absorption coefficient and will have values near one for any good sound absorbing materials (called absorbents) and values near zero for any surfaces that are good sound reflectors. The walls, ceiling, floor and furnishings within a room will each have different absorption coefficients. In order to calculate the contribution of each material surface to the total absorption within a room it is necessary to multiply the absorption coefficient of that material by its surface area. The result may be called the absorption of the surface in absorption units which incorporate the area in (m^2). The total absorption within the room is obtained then by summing the separate absorptions. Another useful quantity is the average absorption coefficient. This is calculated by dividing the total absorption in the room by the total surface area of the room and enables the estimation of the influence of reverberation on the noise level within an enclosed space.

Outdoors, at distances from a machine that are sufficiently great, i.e. at least twice its largest dimension, the sound level will decrease at a rate of 6dB per doubling of distance until the decrease is limited either by some vertical reflecting surface or by the background noise level. When limited by background level, eventually the sound level becomes independent of distance from the machine. If the same machine is placed in a factory, then reverberation within the factory will reduce the region in which the sound level decreases with distance. These two contrasting situations, outdoors and indoors, are shown in Figure 9.

Indoors therefore, where the level due to the operation of a single machine becomes independent of distance form the machine, the level is determined by the power of the sound source and by the reverberation.

Figure (9) Variation of Sound Levels with Distance for Indoor and Outdoor Sources



NOISE MEASUREMENTS

1. Instrumentation

1.1 Standards for sound level meters

The basic noise measuring device is the sound level meter which in its simplest form consists of a microphone, amplifier and read-out device. Such a unit can be made to provide a direct reading of the sound pressure level due to a noise source at a given point. In order to allow for the characteristics of human response to sound, a frequency weighting network will be typically employed ("A" weighting).

As a sound level meter is the basis for many measurements in the implementation of noise standards, it is important that it is reliable and accurate. Furthermore, it is important that the difference between corresponding readings made with various makes of instrument is reduced to the lowest practical minimum. For these reasons there are various national and international specifications or standards for sound level meter performance.

Typically these specify:

1- The directionality of the instrument. Ideally, the instrument would be equally sensitive to sound from all angles. In practice, the sensitivity is greatest to sound that is incident directly. The standards lay down the maximum deviations with angle that may be permitted.

2- The frequency response (for random incidence, that is, for sound incident from all directions simultaneously). This requires a certain frequency range and weighting. The response depends, primarily, upon the microphone.

3- The scale-length, graduation density, accuracy and movement characteristics of the read-out meter.

4- The electrical 'noise' produced by the internal circuitry of the instrument. This must not interfere with the input sound signal.

5- The method of checking the sensitivity adjustment (and hence the accuracy) of the instrument.

6- The dynamic span for integrating sound level meters i.e. the range of levels over which the meter can acquire data.

These standards specify four different types or grades. These are:

Type 0 laboratory-for research
Type 1 precision-for legal measurements and for professional work
Type 2 general purpose for industrial and environmental noise
Type 3 survey-for initial appraisal of a problem

The main difference between each of these types is the accuracy of the frequency response. Usually, the more expensive the meter the more accurate it will be.

1.2 Operational tests

Before and after each series of measurements, an acoustic calibrator or pistonphone complying with appropriate standards should be applied to the microphone to verify the correct operation of the measuring equipment and to allow adjustments if necessary. The results of such tests should always be recorded. In addition, if measurements are made over a prolonged period, the calibration should be verified at least twice daily using either the method described above or using an integral calibration system.

1.3 Traceabiltity

In addition to the tests above, tests of the compliance of the calibrator or pistonphone and of the compliance of the complete measuring equipment with the relevant parts of the appropriate national or international standards for type 1 or type 2 systems, should be carried out at least every 2 years either by a calibration laboratory accredited for such compliance tests or by testing the instrumentation against a reference set that has been confirmed within the last 2 years by such an accredited laboratory, as having met the standard for a type 1 instrument. The reference set should include a calibrator or pistonphone.

1.4 Measurement positions

Measurement positions should be chosen that are outside buildings and give results that are representative of the specific noise at the buildings where people are likely to be affected. The preferred measurement height is 1.2m to 1.5m above the ground. To minimise the influence of reflections, the measurements should be made at least 3.5m from any reflecting structure other than the ground or the facade in question. Where it is necessary to make measurements above ground floor level, a position at 1 m from the facade at each relevant floor of the building should be selected.

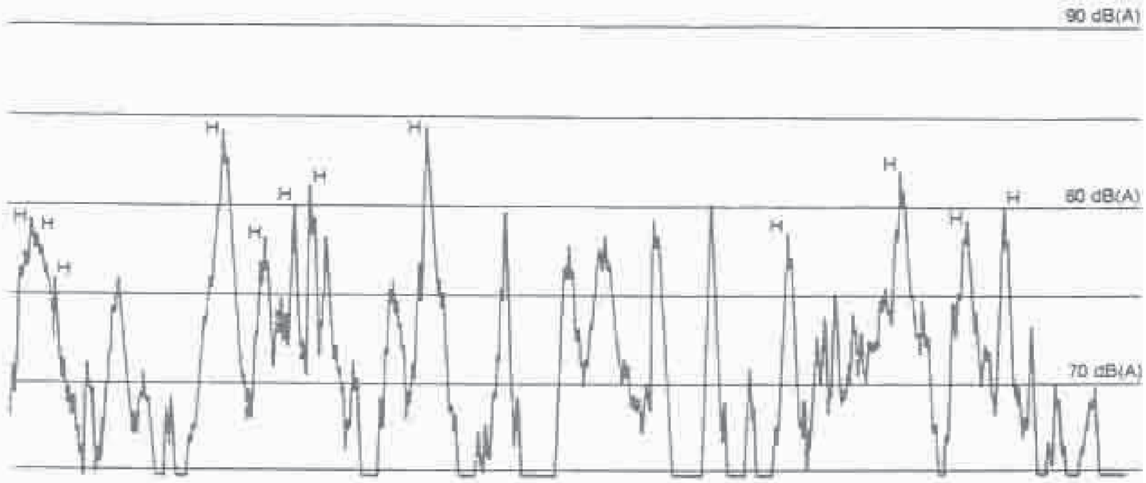
1.5 Influences on noise level readings and predictions

Weather conditions may affect noise measurements either by generating extraneous noise or by influencing sound propagation. Noise level measurements should generally not be made under extreme weather conditions such as high winds (greater than 5 ms^{-1} average), low temperatures (less than 30°c) or rain. Weather conditions prevailing during measurements should be recorded. Precautions should be taken to minimize the influence on the readings of wind, rain and electrical interference. Measured noise levels are considered valid only if they exceed readings due to the above influences by at least l0 dB.

2. Unsteady Sound and its Measurement

Unsteady noise such as traffic noise (see Figure 1) may be characterised by the statistical distribution of levels over the time of measurement; in particular, the level exceeded for ten percent of the time (L_{10}) and that exceeded for ninety percent of the time (L_{90}) are used to describe noise levels. These two levels define the noise climate for the duration of the measurement. In the United Kingdom L_{10} in dB(A) measured over 18 hours has been found to correlate with annoyance from road traffic noise.

Figure (1) Variation of traffic noise with time



2.1 Noise dose, SEL and L_{eq}

Use of any single percentile level such as L_{10} as a method of describing the time-history of a noise, means that much information about that time-history is lost. L_{10} gives an indication only of noise levels at the upper end of the range during the given period. The sound energy in lower levels of noise during this period is ignored effectively. In a noisy factory even the lower levels will be contributing to hearing damage over a long period of exposure.

Another way of obtaining a single number to describe varying noise level is to measure the total energy in the noise over some given period in the same way as an electricity meter monitors the total electrical energy received. The risk of noise induced hearing loss is closely related to the total sound energy received by someone working in a noisy environment. This total energy is called the noise dose and is measured in units of (Pa^2 hrs) - that is power or $(pressure)^2$ multiplied by time.

Another quantity that is related to noise dose is the equivalent continuous sound level or L_{eq}. It is that constant sound level which would result in the reception of the same total energy as the actual varying level over the period of interest, expressed in dB(A). Consequently L_{eq} is a logarithmic measure of the noise dose divided by the time over which the dose has been received. Returning to the analogy of the measurement of electricity consumption, whereas noise dose is analogous to total consumption and is what is paid for, L_{eq} is analogous to an average power consumption.

Instruments that measure L_{eq} perform a summation of all the sound energy that they detect over the period of their use, since the process of summing a continuously varying quantity is that of integration; such instruments are called integrating sound level meters. The result of measuring L_{eq} on A-weighting is the A-weighted L_{eq} in dB(A) sometimes denoted by L_{Aeq}.

Note that in referring to L_{eq} it is essential to refer also to the period over which the measurement is being taken. In assessing hearing damage risk, an 8-hour L_{eq} is used, the 8 hours corresponding to the working day. For the assessment of annoyance due to environmental noise, a 24-hour L_{eq} is more relevant.

Time periods of one hour and 12 hours (usually from 7.00 to 19.00 hours) have been used as measures of noise from construction sites. Samples over shorter periods (e.g. 5 minutes and 20 minutes) are sometimes used in order to estimate these longer period L_{eqs}.

In the USA a day-night noise level (L_{DN}) in dB(A) is used for planning purposes. It represents a 24-hour L_{eq} in which a special allowance is made for night-time exposure by increasing the actual measured night-time levels by l0 dB(A) to allow for the extra annoyance caused by noise at night-time. The index is the average A-weighted sound pressure level over a 24 hr period, but with 10 dB added to the night time levels (from 22.00 to 07.00 hours).

Other weighting factors are possible, and in another American index, the Community Noise Equivalent Level (CNEL) an evening (19.00-22.00 hours) weighting of 5 dB is used, as well as the 10 dB at night-time.

The above examples illustrate the point that the total sound energies involved in different noisy events are rather difficult to compare by using period L_{eq} because of the differing durations of the events. A single-number index that enables such comparison is the Sound Exposure Level (SEL or sometimes denoted by L_{AE} or L_{AX}). Essentially a measurement of SEL is a measurement of noise dose. It represents the total sound energy in a fluctuating noise however long it is, compressed into one second. So for the passage of a train lasting several seconds a measurement of SEL would be an indication on a logarithmic scale of the total energy received. This will have a higher numerical value than the sound pressure level of the train at any instant.

SEL has been found to be particularly useful in comparing different components of construction site noise.

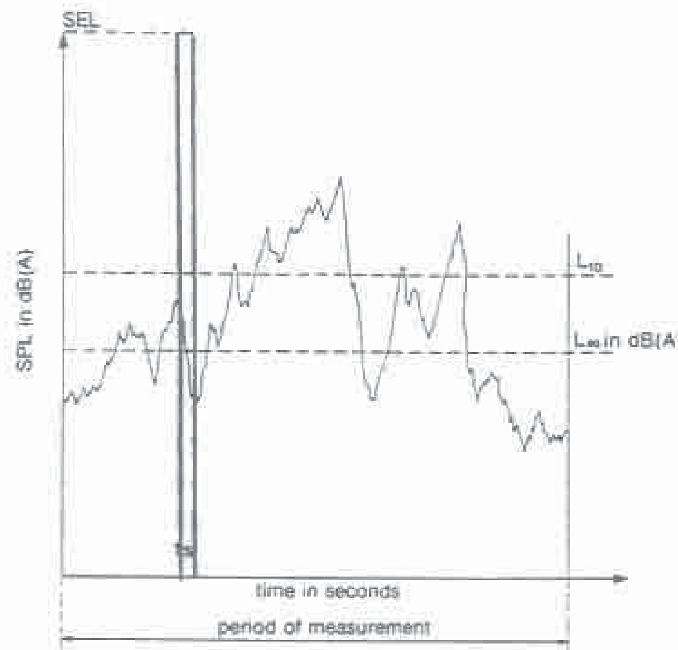
It is instructive to think about the implications of the definitions of SEL and L_{eq} when measuring an ambient level that is fairly constant. Let us start with SEL. It represents the total energy compressed into one second, whatever the length of the measurement period. As the measurement period increases, then so does the total sound energy received by the sound level meter. The consequence of this is that the SEL reading will increase. The rate of increase will depend upon the ambient noise level. SEL represents a logarithmic measurement of the total sound energy received, and is therefore a logarithmic measure of the noise dose.

On the other hand, when a sound level meter is switched to the L_{eq} MODE, it is indicating the constant sound level that is equivalent in energy terms to the amount of noise received over the period of measurement. If the noise level being measured is fairly constant, then so will be the L_{eq} whatever the period of measurement.

In the presence of continually fluctuating sound such as noise from road traffic, the passage of each vehicle will increase the total energy received by the sound level meter and so the SEL reading will continue to increase through the period of measurement with the passage of every vehicle. The L_{eq} will be most affected by the noisiest vehicles, since these contribute the most energy. During lulls in the traffic flow or periods of light traffic the L_{eq} reading will fall.

The L_{eq} measurement may be considered to spread out the sound energy evenly over the whole period of measurement. As the peak levels occupy a relatively small fraction of the total period of measurement, the L_{eq} reading, for a period that is long enough to include the passage of several vehicles, will be rather less than the SEL reading for the same period. In fact the period L_{eq} will be lower than the peak sound level due to the noisiest vehicles by an amount that depends upon how often they pass. Since the L_{10} for the traffic noise will correspond most closely to the peak sound levels irrespective of the period of measurement, this means that the L_{eq} over the passage of several vehicles will be less than the L_{10} for that period. The relative magnitudes of the various measurements, over a given period of a fluctuating sound level are shown in Figure 2.

Figure (2) Comparison of noise measurements



3. Neighbourhood Noise Assessment

3.1 Introduction

Although road traffic and aircraft are important and widespread sources of noise nuisance, noise is any unwanted sound and such sounds can emanate equally well from fixed industrial premises, from construction sites or from the actions of neighbours. In general, a noise is liable to provoke complaints whenever its level exceeds the background noise by a certain margin; or when it attains a certain absolute level.

Noise indices (called rating levels) which are based upon the above concept are defined in the International Standard ISO 1996: Acoustics Description and Measurement of Environmental Noise. This standard is in three parts:

part 1- Basic quantities and procedures
part 2- Acquisition of data pertinent to land use
part 3- Application to noise limits

The standard defines basic quantities to be used for the description of noise in community environments and describes basic procedures for the determination of these quantities. The standard does not specify limits for environmental noise but it does describe principles which can be used to specify such limits.

3.2 BS 4142

Many countries have their own national standards which are often based on ISO 1996. For example, in the U.K. BS 4142 which has recently been revised to align it with ISO 1996: Parts 1 to 3. This British Standard describes methods for determining, at the outside of a building:

(a) noise levels from factories, industrial premises or fixed installations and sources of an industrial nature in commercial premises: and
(b) background noise level.

This standard also describes a method for assessing whether the noise referred to in (a) is likely to give rise to complaints from people residing in the building. The method is not applicable for assessing the noise measured inside buildings or for assessing noise in situations where the background noise level is very low, i.e. below an A-weighted sound pressure level of 30 dB.

BS 4142 differs from ISO 1996 in that it is intended to apply solely to noise from factories, industrial premises and other fixed installations whereas ISO 1996 is intended to be applicable to all forms of environmental noise. In both cases corrections for the nature of the noise (pure tone components and impulsive characteristics) are applied and the index produced by the application of these adjustments is called a rating level.

The method of rating in the British Standard depends on comparing the specific noise level, corrected to take account of its character, with the background noise level. The measurements are made out-of-doors in the neighbourhood of buildings housing those likely to be affected. The method enables assessment of the likelihood of complaints, according to the numerical difference between the offending noise level and a measured or estimated background level, and consequently may assist in deciding whether an existing complaint is justified.

Noise levels from a specific noise source are measured in terms of L_{Aeq} If the noise contains a distinguishable, discrete, continuous note (whine, hiss, screech, hum, etc.), or if there are distinct impulses in the noise (bangs, clicks, clatters, or thumps), or if the noise is irregular enough in character to attract attention, 5dB is added to the specific noise level to obtain the rating level. Only a single 5dB correction is made if one or more of the above characteristics is present.

If the noise has none of the characteristics described above which require a correction to be made, the rating level is equal to the specific noise level.

For proposed new or modified noise sources the rating level is based on a forecast of the specific noise level to which a 5 dB correction is added if any of the characteristics described above is expected to be present.

For the measurement of background noise this standard distinguishes three types of situation in which:

(a) a new specific noise source is to be commissioned or a modification is to be made to an existing specific noise source;
(b) there is an existing specific noise source not operating continuously;
(c) an existing specific noise source is operating continuously.

New or modified specific noise source

The background noise should be measured at positions where the specific noise will be assessed and on days of the week and at times of the day when the specific noise source will be operating.

Existing specific noise source not operating continuously

The background noise level should be measured at the same positions as those used for the determination of the specific noise level in the absence of the specific noise on days and at times when the specific noise source would normally be operating, either:

(a) during a temporary shutdown of the specific noise source; or

(b) during a period immediately before or after the specific noise source operates.

Existing specific noise source which operates continuously

If it is not possible to measure the background noise level at the same position as is used for the specific noise level determination and in the absence of the specific noise, the background noise level should be measured at another position where it is presumed to be equivalent.

Assessing the noise for complaint purposes

The background noise level is subtracted from the rating level for the specific noise. A difference of around 10 dB or higher indicates that complaints are likely. A difference of around 5dB is of marginal significance. At a difference below 5dB, the lower the value the less likelihood there is that complaints will occur. A difference of I0 dB is a positive indication that complaints are unlikely.

BS 4142 is intended merely as a guide to the enforcement of noise nuisance provisions in law. It does not lay down permissible levels. Neither does its procedure lead to a result which says whether or not a householder has a right to complain, even though it may be referred to in court .

A serious criticism of the standard stems from the equivalence it suggests between an adjusted level difference of +5 dB(A) and a marginal complaint situation. This has been used to justify the introduction of new industries into industrial areas as long as the new source is not noisier than the existing sources. The successive introduction of new sources fulfilling this condition, however, can result in the noise level in the area steadily creeping up.

3.3 Noise abatement zones

One of the results of the criticisms of the above procedure in the United Kingdom has been the introduction of Noise Abatement Zones (NAZ).

The Noise Abatement Zone specifies emission limits where the noise is measured near to the noise-producing premises rather than at noise-affected facades as required by BS 4142.

It is left to the Local Authority's discretion how many measurement points are specified and their height above ground. The official guidance is limited to the idea that the spacing should be on the basis of equal subtended angles as shown in Figure 3. Some examples of points chosen on this basis are shown in Figure 4.

Figure (3) Selection of measurement points along noise control boundaries

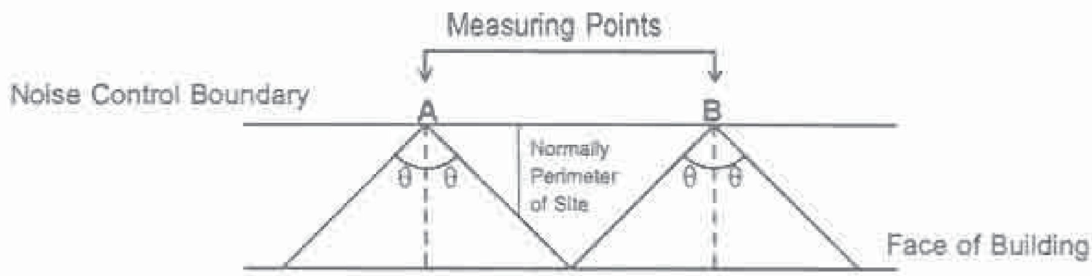
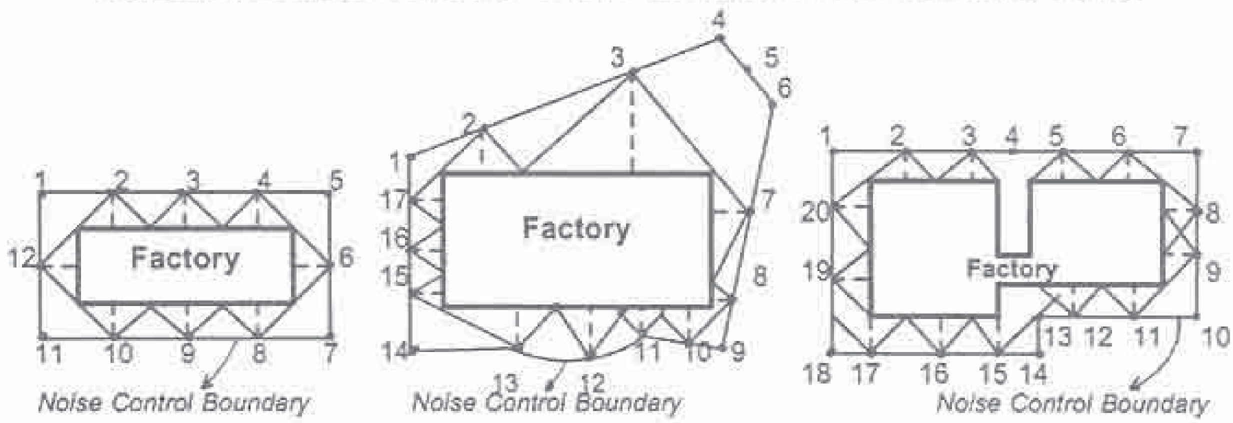


Figure (4) Examples of noise control boundaries and measuring points



Careful specification of the measurement positions is vital to ensure, for example, that they can be found at night if necessary. Meteorological conditions should be taken into account. The noise level to be measured at each measuring position is the equivalent continuous sound level L_{eq} in dB(A) over a stated period of time.

Measurement over 24 hours, or even 8 hours is impracticable from the enforcement point of view, and is probably unnecessary with regard to the noise nuisance. However if a relatively short period of measurement is chosen, say 30 minutes, then it is reasonable to suppose that any subsequent proceedings for contravention can only relate to this period of time, and to the noise level recorded during that period of time. However, whatever measurements and measurement periods are recorded in the register, they must be agreed by both sides.

The position at which noise levels are to be recorded are defined as Noise Control Boundaries. It is simplest of course to take the site boundary of the premises concerned as the Noise Control Boundary. The situation is clearer still if there is a largely residential area containing one large factory premises with no other noise-producing industries and without any areas of land on which noisy activities might be developed. Under these unusual circumstances it is likely that the boundary of the Noise Abatement Zone, the site boundary and the Noise Control Boundary will be coincident. Normally, however, they will differ from each other. It is possible that, where there are several adjacent noise-producing premises within an NAZ, the Noise Control Boundary could lie along a public highway, on top of a high wall or in privately owned land.

Noise Abatement Zones prevent the possibility of creeping noise levels through new factory construction by making any such construction subject to NAZ controls.

3.4 The use of noise indices for setting limits to noise

Many of the noise indices described above have been used to set limits to noise, either as conditions for planning permission for new developments, or, in the case of construction site noise, as consent conditions. Often the limits are set in terms of L_{eq}, sometimes together with a maximum level. As an example a typical Set of conditions for construction site noise could be that the L_{eq} measured over any one hour (L_{Aeq}, 1h) should not exceed 75 dB(A), and the peak level should not exceed 80 dB (A), during the hours from 7 a.m. to 7 p.m. on Mondays to Fridays. Lower levels would almost certainly be set for evenings and night-time, and for weekends. The limits could apply either to noise levels at the site boundary or to the facade of the nearest noise sensitive property. Different limits could be set for different types of property, e.g. residential, school, office etc.

NOISE CONTROL

1. Planning Against Noise Nuisance

1.1 Anticipating the problem

The most cost-effective methods of controlling noise are those that can be employed in anticipating the problem. If possible, thought should be put into the prevention of a potential noise problem at the planning stage.

Most local planning authorities consider the noise-impact of new roads, airports or construction works for which they are responsible. Possible noise disturbance often features prominently in planning inquiries associated with new developments. Anticipation of any of these problems requires the prediction of the way noise levels vary with distance from any given source.

In industry, the purchase of a new machine tool or process plant should be accompanied by some kind of appraisal of the likely change in noise levels resulting from the introduction of the plant both within the factory and outside its walls. Any of the following possibilities should be considered carefully in advance of situations that are likely to give rise to noise problems:

- there might be a quieter procedure or process than that planned;
- noise level requirements could be included in the specifications for new machines and equipment;
- it might be possible to site noise processes and equipment away from noise sensitive areas;
- it might be possible to discontinue operations during noise-sensitive times (e.g. evenings and weekends);
- regular maintenance of machines and any noise-control equipment will restrict noise levels;
- and people could be educated and informed about the purpose and use of noise-control equipment which could be included in the design of the plant.

1.2 Deciding if there is a noise nuisance

The simplest criterion of whether a new noise source is a nuisance is the incidence of complaints once it has started. If this is used as a criterion, it should be noted that the number of complaints might be strongly influenced by the way in which the development is handled.

The construction of an underpass in London aroused a great deal of vociferous local opposition. In this case local people were rudely awoken by sheet-piling, general construction noise and neighbourhood disruption without any prior publicity. The investigating Environmental Health Officer, using a medical analogy, concluded... *that successful suburban surgery cannot be achieved without premedication of the neighbourhood with adequate informatory service, full public relations and a will to respond to all reasonable requests...*

This kind of suggested public relations activity will not necessarily reduce the annoyance that is felt, as a result of the noise nuisance, but it may reduce the predisposition to complain among those likely to do so. Although the number of complaints about a noise is an apparently straightforward indication of whether or not it is a nuisance, the situation is complicated by the fact that only certain types of people will complain when annoyed. This is true particularly about road traffic noise. Many people believe that little or nothing can be done about it even if they know to whom they should complain.

Establishing what level of noise from a particular source represents an annoying level, is, therefore, a task for the social survey. It is important to bear in mind that many non-noise factors are involved in annoyance with any particular noise level. At best, therefore, for widespread noise problems such as those from road or air traffic it is necessary to deal with average annoyance based upon groups of individuals rather than on the highly-subjective annoyance experienced by each individual.

These studies give rise to scales of annoyance against which any given noise level may be judged. In the United Kingdom and elsewhere, social surveys have provided the basis for a blanket standard or fixed limit for noise from a new road, which has the force of legislation behind it. For other types of noise there are guidelines that may be invoked in legal actions or planning against noise nuisance.

1.3 Strategies for noise control

Once noise levels have been measured or predicted and compared with the relevant standard, so that a noise problem is known to exist, there are three strategies that should be considered when a list of possible noise control procedures is being compiled. These strategies are:

1. control at the source(s),
2. control along the path(s) of a sound from source(s) to receiver
3. control at the receiver.

By considering possible noise control measures related to each of these strategies in turn, the best single measure or combination of measures can be identified.

In general, the most effective way of tackling a noise problem is at source. Control of both road and air traffic noise at source is possible by quietening individual vehicles which are subject to legal noise limits.

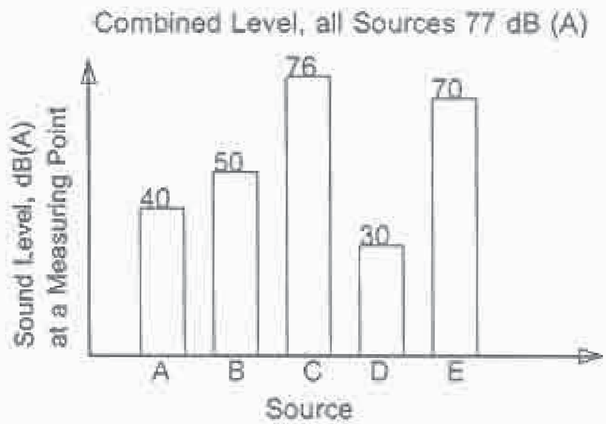
The main concern, usually, is the techniques that are applied between source and receiver and at the receiver. The techniques include specially constructed noise barriers in the case of road traffic noise, take-off and landing restrictions and 'minimum noise' routes in the case of aircraft, and double glazing of noise-affected facades for both road and air traffic noise. Other noise sources, with whose control we shall be concerned include construction sites and industrial premises.

2. The Contrl of Noise at Source

2.1 Choosing which source to control

In a situation containing several noise sources, and where a noise problem has been shown to exist, then each source should be identified, and the most dominant located, so that priorities for noise reduction can be established. Consider, for example, the situation represented in Figure 1. Clearly source C is most important and should be the first priority for noise reduction if possible. But by how much?

Figure (1) Contributions of several noise sources to a noise problem



The answer is provided by observing the impact of various reductions on the combined level. Reduction of noise C by 6 dB(A) will reduce the combined level of all sources from 77 dB(A) to 73dB(A). However, further reduction of the noise from C will then have a relatively small impact. Attention should then be given to both sources C and E, and so on.

On the other hand, it does not always follow that the loudest source should be the first to be tackled. Consider a situation in which there are ten sources each of which produces an SPL of 66 dB(A) at the measuring point and another source producing an SPL of 76 dB(A). The combined level of the ten 66 dB(A) sources is very nearly the same as the level of the highest source. Reduction of the levels of each of the ten 66 dB(A) sources by 3 dB(A) will have more or less the same effect as reducing the 76 dB(A) source level by 6 dB(A). The smaller reductions may be more convenient and less costly than the 6 dB(A) reduction of the 76 dB(A) source.

2.2 Control of noise by design or choice of process

In the design of machines and mechanical systems a great deal can be achieved with regard to reduction of noise. For any particular operation or process complete elimination of the noise-producing forces is impossible, since these forces (such as combustion forces in engines, magnetic forces in motors, impact forces in punching and hammering operations, and cutting forces in many metal working processes) are essential to that operation or process.

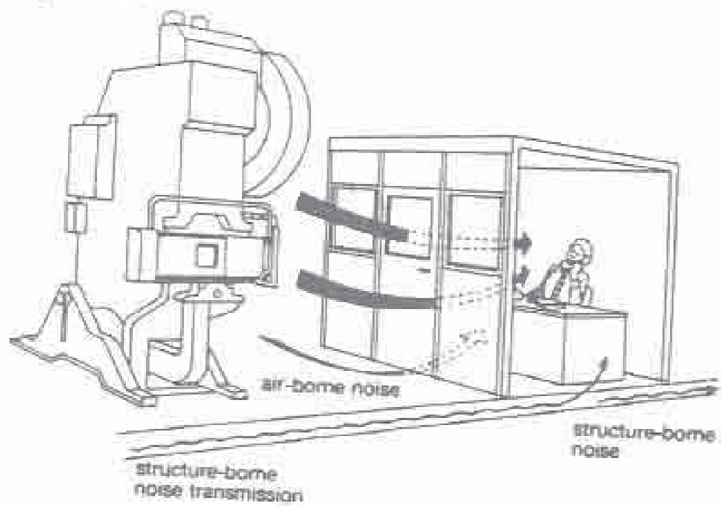
Quiet designs require that impact and rattle between components should be avoided; reciprocating movements should be braked gently; metal components should be exchanged with quieter plastic, nylon or composite components; noisy components or processes should be enclosed; power sources and transmissions which give quiet speed regulation should be chosen; vibration sources within the machine should be isolated; cover panels and inspection hatches should be stiffened and well-damped and machines should be provided with adequate cooling fins which reduce the need for air flows, and therefore the need for fans which are noisy.

Action can be taken to reduce the noise of materials handling. Existing plant can be altered so that impact and shock during manual or mechanical handling is avoided. Processes that produce impulsive forces, such as hammering, punching, and pressing operations, are a very important class of noise producers. The most effective method of control is to replace the impulsive force by a steadily applied force that will achieve the same effect. Examples are the relatively quiet breaking of concrete where a bending action is used rather than percussive methods and the use of steady squeezing forces rather than impulsive hammering to insert rivets into sheet metal work.

2.3 Vibration Isolation

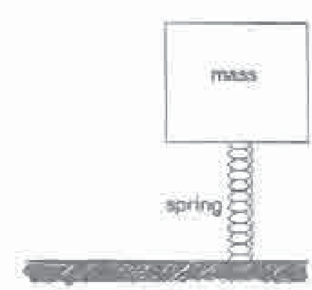
A typical source of noise problems, in addition to those due to sound directly radiated from a machine, is the consequence of vibration transmitted from the machine into the building structure (in which the machine is housed) at the places where the machine is in contact with the building. The building structure then radiates the vibration, induced in this way, as sound. This is an example of noise that is structure-borne (Figure 2).

Figure (2) Structure-borne and air-borne noise



It is possible to reduce such nuisance by introducing some kind of elastic support between the machine and the structure on which it rests. The kinds of support that are used for vibration isolation include steel springs, cork, felt and fibreglass pads and layers of natural or synthetic rubber. The total system of machine, support and foundation can be modelled as a mass on a spring, one end of which is rigidly fixed, as shown in Figure 3.

Figure (3) A simple vibrating system

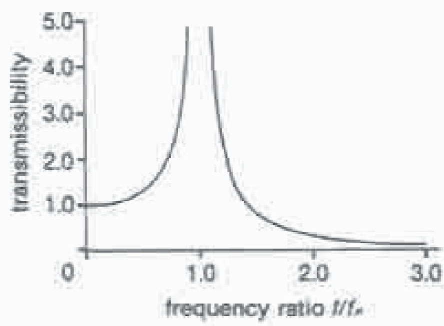


Such a system has a resonant frequency otherwise known as a natural frequency of oscillation. If the mass is first displaced and then released the resonant or natural frequency corresponds to the frequency at which the mass would oscillate being subsequently left to its own devices.

We are interested in the response of the system, not simply to a momentary displacement but to vibrations over a wide frequency range. Where the vibrating frequency is much higher than the resonant frequency the system will not respond very much and this results in the vibration isolation required. However, at or near the resonant frequency the system is likely to go into considerable oscillation. We can imagine that at the resonant frequency there will be a considerable oscillatory force, transmitted to the base of the system.

Instead of referring directly to the transmitted force, it is usual to refer to the ratio of the force transmitted when the elastic support is present to the disturbing force which exists before the support is introduced. This ratio is called the transmissibility of the system. For vibration isolation, the transmissibility should be as low as possible. Theoretical analysis of the simple mass-spring system, assuming that the mass can only move vertically, results in a description of the way transmissibility varies with frequency. This is shown as a graph in Figure 4.

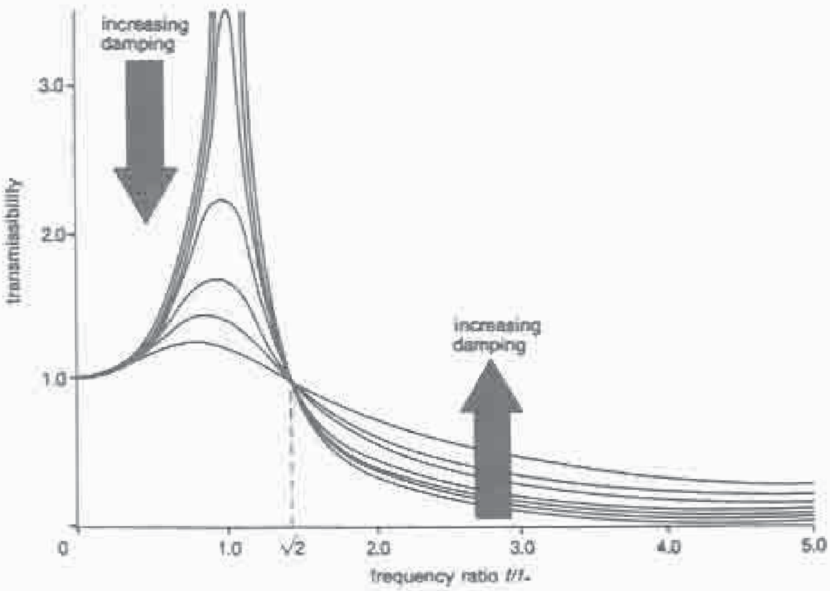
Figure (4) General behaviour of vibration isolation system



Note that the ratio of the frequency to resonant frequency rather than frequency alone is used as the scale for the horizontal axis. Figure 4 displays the features that we have argued from intuition. There is a steep increase in transmissibility near the resonant frequency. It is important to notice however that the transmissibility has lower values above the resonant frequency than below it. From this it is possible to deduce that the elastic support for a vibrating machine should be chosen so that the resonant frequency of the system is well below the lowest frequency at which the machine vibrates.

You should notice also that, as shown in Figure 4, the transmissibility at the resonant frequency becomes extremely large. This is undesirable, especially since many machine vibrations, particularly of rotating machinery, will pass through the resonant frequency while getting up to speed. The problem is met by adding damping to the system. This creates friction and causes energy of vibration to be converted to heat. Some isolating materials such as fibreglass pads and elastomeric mounts made of natural or synthetic rubber have internal damping which serves the purpose. Steel springs on the other hand have little or no damping and dampers must be added, usually through the centres of the coils. The effect of gradually increasing the damping in a simple mass spring system is shown in Figure 5.

Figure (5) Effect of damping on transmissibility



This figure shows that the greater the damping the smaller the amount of resonance that occurs at the resonant frequency. The addition of damping, however, tends to increase the transmissibility in the frequency range, above the resonant frequency, where the support provides vibration isolation. There will be an optimum level of damping, therefore, for a vibration isolator.

Having deduced that the anti-vibration mounting should have a low resonant frequency, the next question to answer is: what characteristics of the mount determine the resonant frequency of the system? This frequency is determined by the mass (m) of machine and by the stiffness (K) of the mount; the higher the mass or the smaller the stiffness, the lower the frequency.

When the full weight of the machine is placed upon the isolating mount, the mount will be squashed. The extent to which it is squashed - the load's displacement usually referred to as the 'static deflection' - will depend on the mount's stiffness; the stiffer the mount, the less will be the displacement.

For a given weight of machine, the resonant frequency of the machine-and-mount system may be raised or lowered by increasing or decreasing the stiffness of the mount respectively.

Of the various types of mounts; helical steel springs may be the least stiff and therefore result in the lowest values of resonant frequency. As mentioned earlier, however, steel springs require the deliberate introduction of damping. Moreover at high frequencies the transmissibility of steel springs does not continue to decrease with increasing frequency, but the springs begin to 'leak' vibration. High frequency vibrations entering the springs do not see their springiness but spiral around the coil to its base. Spring performance may be improved, under these circumstances, by adding damping material in series under the springs as well as that through the springs.

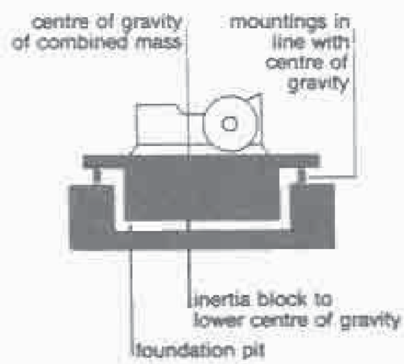
The fact that, with appropriate precautions, vibrating systems consisting of machines mounted on steel springs have low resonant frequencies means that steel springs are useful where machinery vibrating at very low frequencies, say down to 1 Hz, is to be isolated from the load-bearing structure.

Isolation mounts, between 1 and 1.5cm thick, consisting, primarily, of natural rubber or synthetic rubber materials such as neoprene, are used to isolate small electrical and mechanical devices where the lowest frequency of vibration is between 6 and 15 Hz.

Materials such as felt, cork and fibreglass, which produce mounts suitable for isolating frequencies between 12 and 40 Hz, are purchased in sheets and cut and stacked to fit the particular application.

The lower the natural frequency of the system to be isolated, the lower the required stiffness and the larger the corresponding displacement will be. The use of low-stiffness springs alone to control vibration can lead, through the associated large displacements, to rocking motions which are unacceptable. If the load to be isolated is increased deliberately in some way, then stiffer springs can be used. One way of deliberately increasing the load is to use inertia blocks.

Figure (6) An inertia block



These are heavy concrete or steel platforms on which the vibration equipment is mounted. These platforms are then isolated from the load-bearing structure (see Figure 6). The addition of an inertia block in effect increases the mass of the machine and allows stiffer, more stable, isolators to be used to achieve the same resonant frequency. The stability is further improved by the fact that using an inertia block lowers the centre of gravity of the system and the increased inertia results in reduced movement in response to the vibrating forces.

Vibration isolation provides noise reduction primarily at low frequencies, i.e. below 100 Hz. On an A-weighted measurement this will not be large. Nevertheless it might be a significant reduction in terms of effects on people.

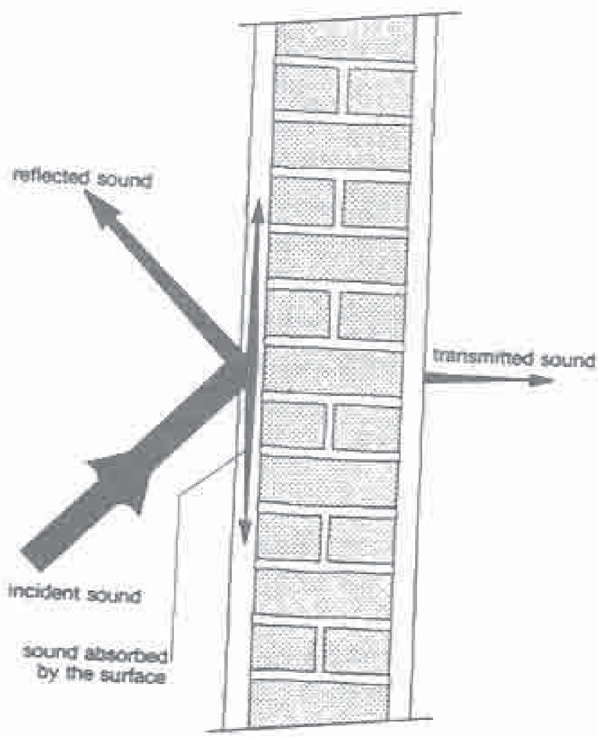
Enclosures

Use of an enclosure to attenuate the noise from a machine, or part of a machine, is an obvious way of solving a noise problem at source. Enclosures are a method of solving noise problems at the receiver also.

To understand the important characteristics of the construction of an enclosure it is necessary to introduce the concept of sound insulation and to distinguish this concept from sound absorption.

When a sound meets a wall, some sound will be reflected, some will be absorbed at the surface and the remainder will pass through the wall and be transmitted. (See figure 7). For an enclosure to be effective it must offer sound insulation so that the amount of sound that is transmitted through the walls and roof must be as small as possible. It is usual to describe the ability of a wall or roof panel to reduce the transmission of sound by the numerical value of the transmission loss that it offers, measured on a decibel scale. This shows how much the sound level would be reduced in its passage through the panel if this were to be the only possible sound path.

Figure (7) Sound reflected, absorbed and transmitted at a wall

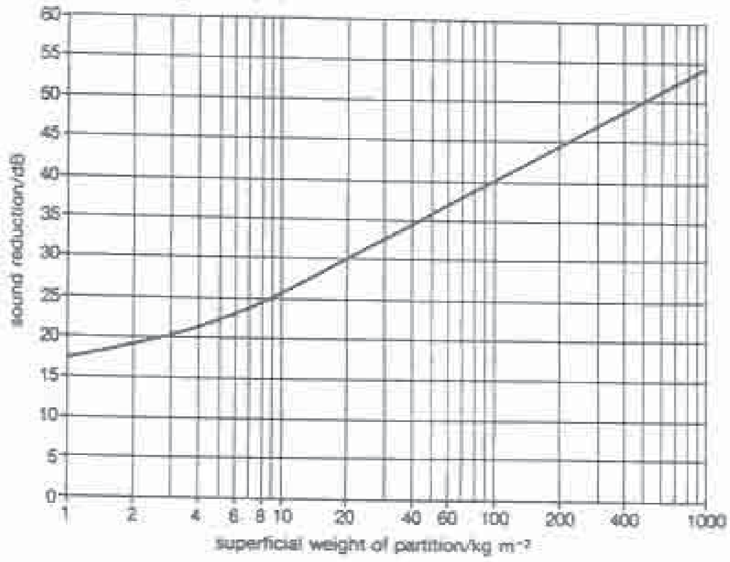


To have a good transmission loss, a wall must be a good sound reflector. The material of the wall must be able to resist the transmission of motion from the air particles which move in association with the passage of the sound wave. The denser the material, the less likely it is to move in response to the incident sound wave.

Consequently, the transmission loss offered by a wall increases with its mass. The relationship between mass and transmission loss is called the mass law and is shown in Figure 8.

Noise control is often complicated by the fact that the direct sound paths are not the only ones. This is one of the reasons why making an enclosure entirely with material, each panel of which would reduce sound passing directly through it by 20 dB(A) will not result in an overall noise reduction of 20 dB(A), where the noise reduction is defined as the difference in sound levels at some measuring position before and after the enclosure is built. Quite frequently the enclosure will have openings for ventilation or to allow passage of material or pipes for water, air and fuel. These openings, however small, will provide an easy path for sound to escape from the enclosure. Pipes and ducts should be isolated from the machine by flexible connectors to stop any vibration being carried along them. The access holes, where they pass through an enclosure, should be as small as possible and air-sealed with flexible mastic-type material. As mentioned already the machine vibrations should be isolated from the floor.

Figure (8) The mass law



Frequency dependence of noise reduction

As stated above, vibration isolation is effective mainly at low frequencies of the order of 100 Hz or less. Both transmission loss and absorption are frequency dependent. Generally they increase with frequency being greatest at frequencies in the range from 500 Hz to 8000 Hz. A combination of vibration isolation of the machine followed by an absorbent-lined machine enclosure, can provide considerable noise reduction over a wide frequency range. Vibration isolation of this enclosure followed by further enclosure can give tremendous reduction.

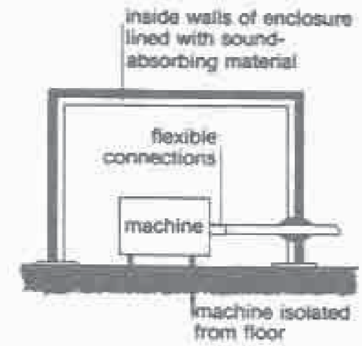
Enclosures are particularly useful for control of machinery noise at source provided that:

(i) they are at least three times as large as the machine they are enclosing;
(ii) they are made with high-transmission loss materials;
(iii) they are lined with sound absorbing materials;
(iv) penetrating pipes and ducts are isolated from the machine and sealed around their access through the enclosure; and
(v) both the machine and the enclosure are isolated from the floor. These features are illustrated in Figure 9.

Noise reduction in dB(A) is defined as the difference in sound levels at a given measuring point before and after application of the noise reduction technique.

The noise reduction of an enclosure depends upon its size, the transmission loss of the material from which it is made and the amount of absorption within it.

Figure (9) Important features of an acoustic enclosure

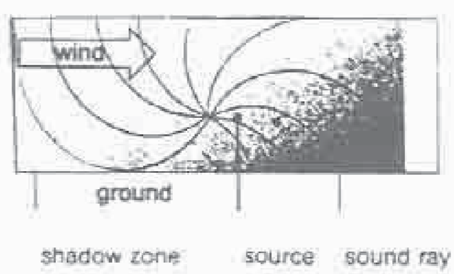


3. Control Between Source and Receiver

3.1 Meteorological effects on outdoor sound propagation

The propagation of sound outdoors is sensitive to atmospheric conditions. Effects due to wind, temperature gradients, air-turbulence and humidity must be considered. The presence of a steady wind - a natural steady air movement - means that the stable position, about which air particles oscillate during the passage of a sound wave, is no longer stationary. It moves at the speed of the wind. Consequently the speed of propagation of the sound has the wind speed superimposed upon it. The wind and sound speed sum if the sound source is upwind of the receiver position, and the windspeed subtracts from sound speed if the source is downwind. Wind speed varies with height, being slowest near to the ground surface and increasing with height as the viscous drag at the surface becomes less significant. Consequently the effect of wind on sound speed increases with height and causes sound rays and wave fronts to curve. Upwind of the source, sound rays bend upwards away from the ground creating a shadow zone near the ground. This means that for listening positions upwind and near to the ground, the sound level will be considerably less than elsewhere. Downwind of the source, the rays bend downwards causing enhancement of the level near to the ground. These situations are shown in Figure 10.

Figure (10) Wind shadow zone



Temperature gradients are important because the velocity of sound depends on temperature. The velocity increases as temperature increases. Under neutral or stable conditions where temperature decreases with height, the sound velocity also decreases with height and the sound rays curve upwards. For a receiver near the ground, therefore, for certain receiver positions, noise levels are less than they would be in an isothermal (constant temperature) atmosphere. Alternatively, under inversion conditions, where temperature increases with height, the sound rays will bend towards the ground. These two situations are shown in Figures 11 and 12.

Figure (11) Temperature shadow zones

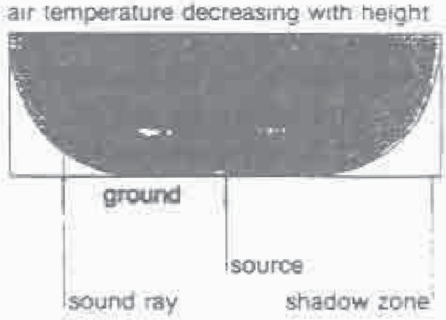
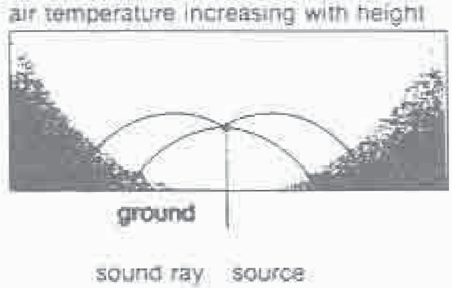


Figure (12) Temperature inversion



The existence of a temperature inversion can greatly increase noise levels. At receiver locations 300 m away from a typical motorway they can be up to I0 dB higher under inversion conditions than for neutral slight upwind conditions.

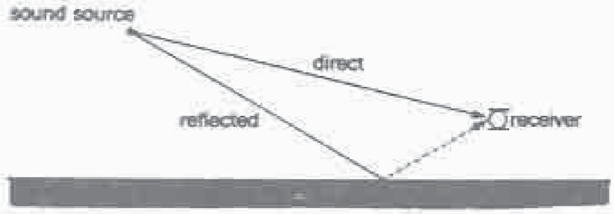
Air itself is a sound absorbing medium, so no airborne sound wave will travel for ever. The presence of moisture, as humidity in the air, effects this absorption in a way that depends on temperature and frequency. The consequent reductions in sound level, however, are still small, being appreciable only for frequencies above 2 kHz. At 100 Hz and 20°c the rate of reduction of sound level is less than 20 dB km^{-1}.

Turbulence can reduce noise levels overall. The noise-reducing effects of turbulence are limited to frequencies above 1000 Hz. However, another effect of turbulence is on the rate at which the noise level fluctuates. This rate may be increased considerably by turbulence particularly at high frequencies.

3.2 Indirect sound paths

Although much of noise control is based upon the sound paths of the type shown in Figure 13, these are not the only paths. Airborne sound results from any vibrating surface. However, the housing of a machine is not necessarily the only vibrating surface. The vibrations of the machine can cause the radiation of noise at places quite remote from the machine itself by causing the structure, on which the machine is mounted, to vibrate. This vibration in turn can be transmitted to adjacent structures which can radiate air-borne sound.

Figure (13) Air-borne sound paths

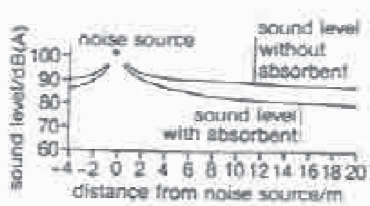


Air-borne sound is detected by its ability to cause vibration in some component of the detector. In the same way as direct mechanical impacts on a surface, air-borne sound is able to cause vibrations in any surface with which it comes into contact. The sound energy can then be carried further as structure-borne sound to re-radiate air-borne sound further. Such indirect paths of sound are known as flanking transmission. These include any areas of low transmission loss, such as open windows creating 'outdoor paths from window to window'. Other air-borne paths lie through connecting duct-work, ventilation grilles, openings under doors, gaps at walls, poor seals at floor edges, back-to-back electrical sockets, false ceilings and open troughs in floor-ceiling structures.

3.3 Absorption and absorbing materials

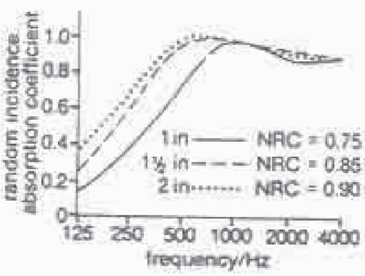
When considering larger spaces, such as factories or machine halls, it is necessary to consider the possible use of absorption as a means of controlling noise between source and receiver. The main effect will be on the reverberant sound and this is demonstrated in Figure 14. The relative importance of the sound that travels directly to the receiver compared with the reverberation, at the point where noise reduction is desired, will determine whether or not the introduction of extra absorption will help. In a space with a low room constant, i.e. consisting mostly of hard, reflecting surfaces, covering the ceiling alone with a moderate thickness of an effective sound absorbing material can reduce the reverberant sound level by between 6 and 8 dB(A) at distances away from the sound source. Covering ceiling and walls with a considerable thickness of an absorbent can reduce reverberant sound by approximately l0 dB in a room with noisy production machinery in one part and relatively quiet work in the other.

Figure (14) Effect of absorbing material on the reverberant level inside a factory



The absorption of a material depends upon frequency. In a porous sound absorber, there is less sound absorption at low frequencies than at high, so the sound absorption coefficient increases with frequency. Where a material is characterised by a single number, called the noise reduction coefficient (NRC), this represents the average of the absorption coefficients in the octave bands centred on 250, 500, 1000 and 2000 Hz. The noise reduction coefficients and the dependence of absorption on frequency corresponding to the various thicknesses of glassfibre quilt are shown in Figure 15.

Figure (15) Variation of absorption coefficient with thickness

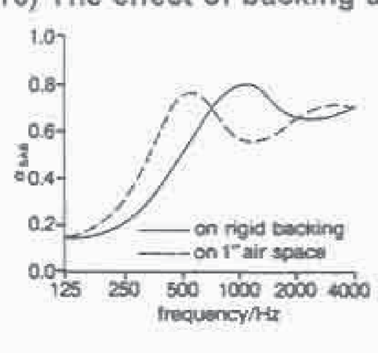


Increasing the thickness of absorbent material increases the frequency range (towards the low frequencies) over which the absorbent is effective. Thin layers of absorbent are effective only at medium to high frequencies.

Many common building materials are porous and so they offer some sound absorption. This means that very few rooms in a dwelling offer no sound absorption. Typically the materials used to create large spaces, such as warehouses and factories, are acoustically hard. Surfaces such as glass, metal and plaster have sound absorption coefficients less than or equal to 0.05 even at high frequencies. The resulting spaces are very reverberant and offer considerable scope for the introduction of absorption. Quite often it is neither convenient nor practicable to cover all surfaces in a factory with absorbing material, particularly those near the floor or ceiling. constraints near the ceiling might be provided by lighting fixtures or overhead cranes. Constraints near the floor might be provided by machine mounts and cleansing or safety requirements. Under these circumstances the effective area of absorbing material can be much increased by employing hanging absorbers of various kinds . These provide good absorption but are relatively expensive. Their efficiency depends upon how densely they can be placed in the room.

The provision of an air gap behind them is another way of increasing the low frequency performance of porous absorbents. Examples are shown in Figure 16.

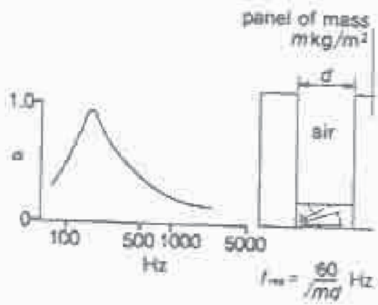
Figure (16) The effect of backing air spaces



Since the performance of porous sound absorbing materials is frequency dependent, the effect of adding them to a reverberant space is also frequency dependent. Even with all the methods of increasing the low frequency performance of porous absorbents that have been outlined, there would remain a problem, for example, in quieting a reverberant room housing a big reciprocating compressor with a peak noise level at 32 Hz. No practicable configuration of porous absorbent is likely to produce much absorption below 125 Hz. An alternative is the panel absorber. These consist of large thin flexible solid panels spaced at some fixed distance from a hard reflecting surface.

A plot of the absorption coefficient of such absorbers against frequency shows a sharp peak, such as that shown in Figure 17. In the same way a drum will emit a definite note when stretched to a given tension. The frequency at which the panel absorber is most effective depends upon its density (quoted in terms of mass per unit area) and the width of the air gap. The useful frequency range for such absorbers is from 40-400 Hz. Apart from the density and the air gap, there are other important requirements for the material of which the panels in a panel absorber are made. There must be enough inherent damping to stop the panel resonating too much and to do the job of dissipating the sound energy. On the other hand the panels must be sufficiently flexible to ensure that they are not too stiff to resonate. Frequent use as panel absorbers is made of plywood panels with grooves cut in the back to reduce their stiffness. A sheet or two of roofing felt also makes a good panel absorber. Frequently a porous absorbent is placed in the air gap behind the panel to broaden the frequency range over which it is effective as an absorber. However, this reduces the panel's effectiveness at the tuned frequency.

Figure (17) Absorption characteristics of panel absorber

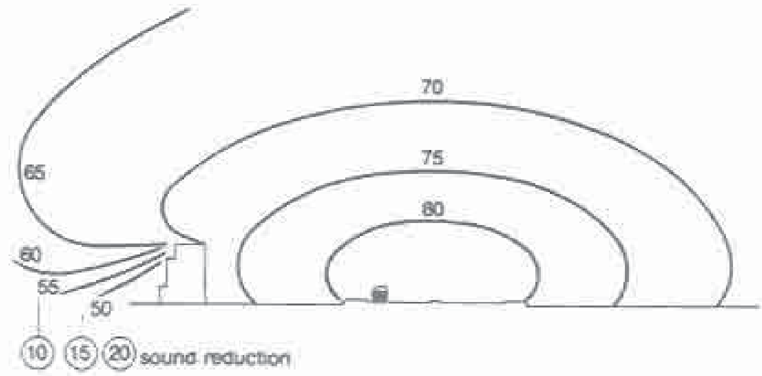


An increase of ten times the original absorption, which corresponds to a noise reduction of I0 dB is often considered a practical limit.

3.4 Barriers

Several noise control methods depend upon putting an obstacle in the way of an airborne sound path. The effectiveness of such an obstacle depends upon how much sound can get through or around the obstacle and how much is reflected or absorbed by it. The obstacle may be wall-like or it might be a building or an earth mound. Land is at a premium in urban areas and it is not possible to route roads so that the nearest buildings are sufficiently far away to allow adequate attenuation of traffic noise. Many major roads and motorways pass within 30 m of the nearest buildings. It would, typically, require an additional 40 m to attenuate the noise level by only 5 dB(A). One solution, which applies really at the planning stage is to build factories or industrial plant, which are less sensitive to noise, close to the roads. These buildings can then act as barriers for residential areas beyond them. When a building is used as a barrier, the noise levels at the side that is remote from the road will be approximately 15-20 dB(A) less than those at the side fully exposed to the noise (Figure 18).

Figure (18) Buildings as a noise barrier



Sound tends to bend over obstacles and this bending phenomenon is called diffraction. It means that a sound 'shadow' is less well defined than the optical shadow cast by the barrier. The attenuation of sound increases, the deeper is the reception point into the shadow. Sound will bend around the ends of a barrier as well as over the top, so the effectiveness of a barrier will depend upon how far the reception point is away from the ends of the barrier as well as the height of the barrier and of the reception point.

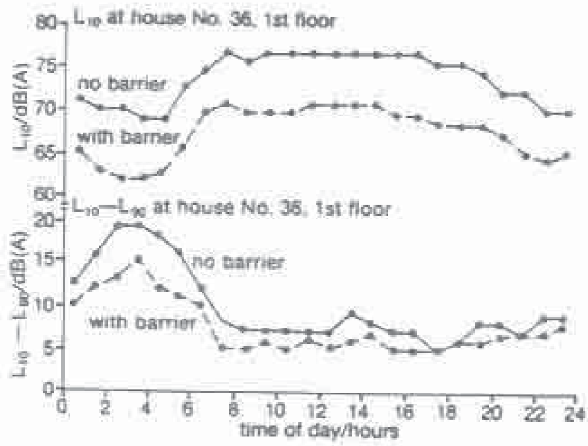
Diffraction is frequency dependent. Longer wavelengths, and hence lower frequencies, are better able to bend around barriers than short wavelengths or high frequencies. In other words high frequency components of noise cast sharper sound shadows at barriers than do low frequency components. The attenuation offered by barriers, therefore, increases with frequency and is lowest at low frequencies.

The effectiveness of a purpose-built noise barrier depends upon how much sound can get through it. Cracks or holes will transmit sound, very easily and so the barrier should be airtight. Furthermore,the material, from which the barrier is made, must be sufficiently dense (a mass per unit area of at least 10 kgm^{-2}) to prevent sound from passing directly through it. This ensures that the primary path from one side of the barrier to the other is by diffraction. There is little point in choosing much higher densities for the barrier material since further attenuation of the direct path will have no further influence on barrier attenuation.

The presence of flanking paths provided by other reflecting surfaces around the barrier will be detrimental to barrier performance. Consequently barriers are more likely to be effective outdoors than indoors.

Noise barriers are used extensively along heavily-trafficked roads in many countries. In the UK they are used along principal motorways and some major trunk. Figure 19 shows the measured effect of an experimental barrier erected alongside a motorway upon the 18-hour L_{10} in dB(A) and upon the noise climate. It is important to note that these results show the difference in sound levels at a reception point before and after construction of a barrier. Automatically, therefore, it takes account of any attenuation due, for example, to the presence of acoustically-soft ground between source and receiver, which is present before the barrier is erected. Although the noise reduction of the 2.7m high barrier was fairly small, purpose-built barriers have produced noise reductions of up to 13 dB(A). However, they constitute a visual intrusion and tree belts or grassed earth banks are more acceptable visually. Unfortunately tree belts have been found to provide little or no attenuation of road traffic noise, except when they are so wide that they take up an unacceptable amount of land. Earth banks are of proven usefulness, but they take up more room than wall-type barriers. An optimum form of barrier may well be a combination of trees or shrubs and purpose-built wall barriers.

Figure (19) Performance of highway noise barrier



The fact that purpose-built barriers have to be good sound reflectors can lead to problems when they are used on both sides of a road. The reverberation between their vertical surfaces leads to a noticeable increase in noise levels for the road vehicle drivers and passengers. A solution with purpose-built barriers is to make their surfaces absorbing, which may also lead to a small improvement in their acoustical performance as barriers. With cuttings or embankments (which essentially act as noise barriers) an alternative is to slope them.

The published procedures for predicting road traffic noise include a facility for assessing the effect of purpose-built barriers. Alternatively there are straightforward formulae for predicting barrier attenuation based on the geometry of the source and receiver positions with respect to the barrier. For reasons of space these are not detailed here.

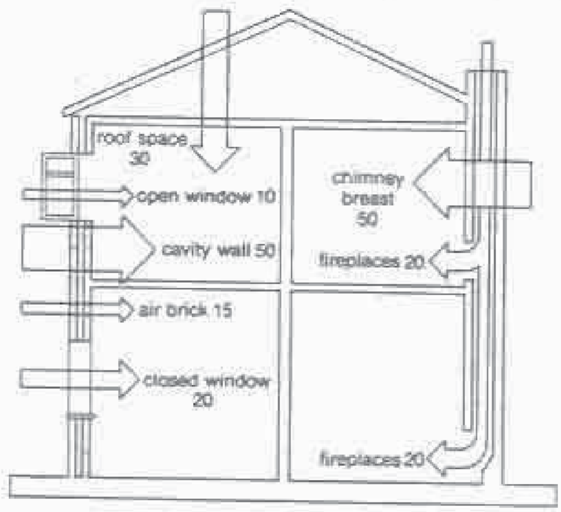
4. Control at the Receiver

4.1 Sound Insulation of dwellings

People are most often disturbed by road traffic noise, aircraft noise or noise from nearby industrial premises, when they are in their own homes. If the disturbance occurs during the evening or night time, then, probably, people are at their most sensitive to noise as well. Figure 20 shows the insulations typical of the elements of a standard U.K. dwelling. It can be seen that if everyone lived in cavity-wall brick structures containing no windows, doors, air-bricks, roof joists or fireplaces, they could count upon average sound insulations of 50 dB(A).

Obviously open windows, air-bricks and chimneys represent weak links, since sound is able to pursue a relatively unhindered airborne path through them. Recall that the physical characteristics needed for a wall to offer good transmission loss are (i) that it should be made from non-porous dense material and (ii) that there should be no flanking paths. Recall also that the sound reduction offered by a wall increases with its mass. This is called the mass law.

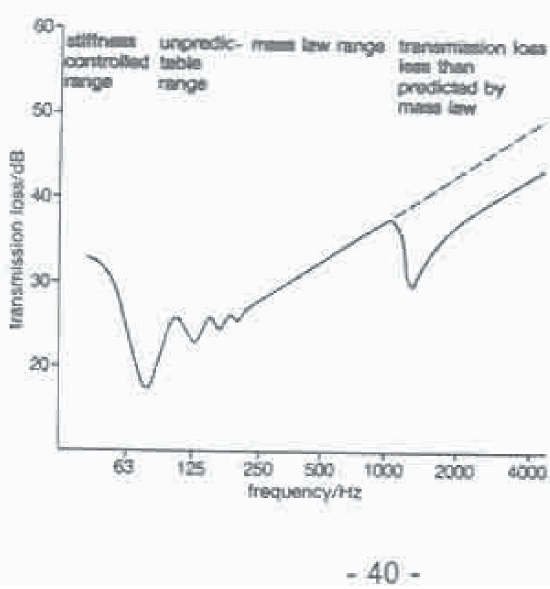
Figure (20) Sound Insulation provided by elements of a house



Each of the single-figure sound reductions shown in Figure 20 for each of the elements represents the average transmission loss over the frequency range of interest. A single figure for the average insulation over the audio-frequency-range is often misleading since transmission loss is frequency dependent.

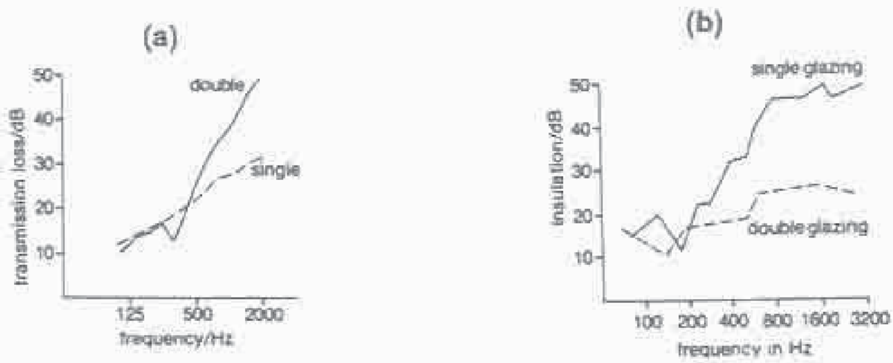
The variation of transmission loss with frequency is rather complicated and the mass law does not hold over the whole frequency range of interest. There are complications related to the stiffness of the wall at low frequencies and to its inherent damping at high frequencies. Such complications can be seen in Figure 21. In the frequency range 250 Hz to 1 kHz where the mass law holds, doubling the frequency increases the transmission loss by about 6dB. The departures from the mass law become increasingly important and extend over a wider frequency range as the mass per unit area of the material decreases. These complications are important in assessing the insulation of many of the lightweight cladding structures used in modern building. Nevertheless the mass law explains why closed windows, doors, or plasterboard partitions offer less insulation than a single-brick wall.

Figure (21) Variation of transmission loss with frequency



A doubling of the mass of a wall, at most, brings 5dB improvement. Adding another wall with an airtight air-gap in between can produce at least l0 dB improvement because the trapped air tends to act as an isolating spring reducing the transmission of vibrations from one side of the double wall to the other, the larger the gap the better the isolation. Inserting absorbing material into the air-gap brings even greater improvement. Figure 22(a) shows the way in which the improvement in transmission loss between single and double walls varies with frequency. Unfortunately, practical cavity constructions are limited in width and contain a number of mechanical connections which detract from the potential acoustical performance.

Figure (22) Cavity construction



The idea of double walls explains the success of acoustic double glazing. (Figure 22b)). This is most effective when:

(i) the gap between the panes is at least l00 mm;
(ii) there is a resilient mounting for at least one pane and
(iii) there is a sound-absorbing lining to the reveal.

The low-frequency performance is improved by increasing the width of the gap. Apart from non-openable acoustic double glazing with solar controls, another standard treatment in insulating a building against road traffic noise is the provision of a ventilator unit with a sound-attenuating inlet duct.

To insulate against aircraft noise additional measures are necessary. These include improvements to the insulation of the roof space by laying lead sheeting, sand or dense mineral wool over the ceiling joists of upper rooms (strengthened if required) and the sealing of flues.

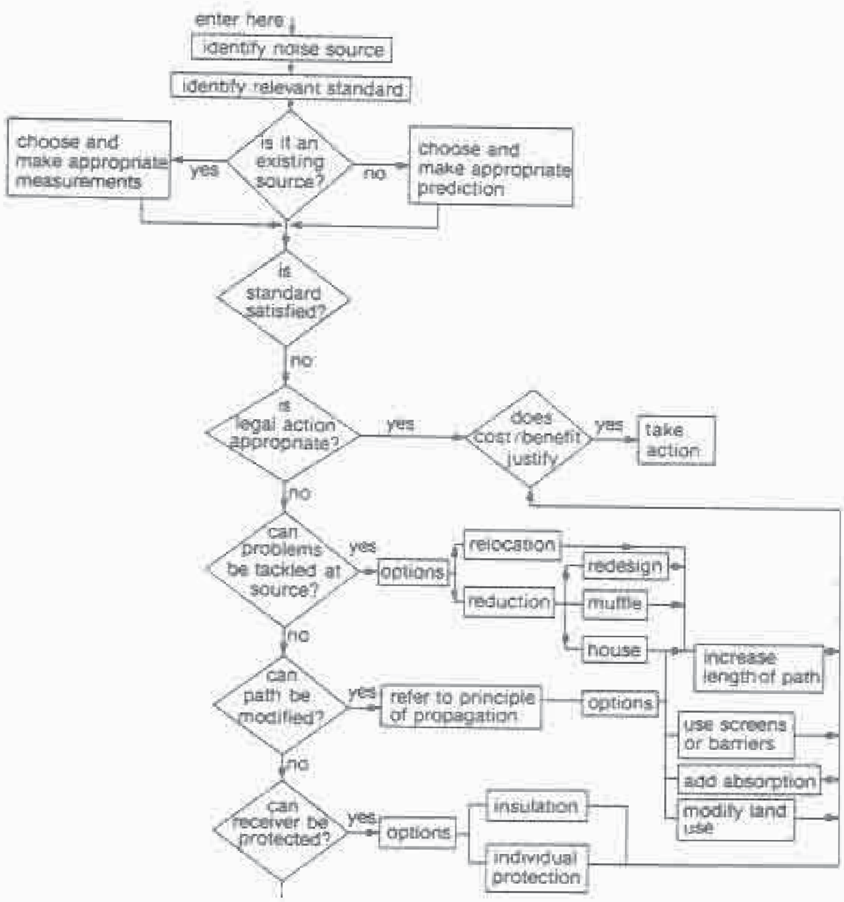
5. General Summary

Possible options and procedures for controlling noise indoors and outdoors are summarised in Figure 23. At the stage where a noise source is being identified, it may be possible to identify several sources and the decision on which to tackle first will depend upon cost and practicability as well as relative source levels. The identification of relevant standards is an important subsequent step.

If the noise source is being anticipated the appropriate procedure for predicting the sound power level or in the case of road traffic, the basic 18-hour L_{10} in dB(A), and the consequent sound pressure level should be employed. The SPL will depend upon location of source. The predicted or measured

SPL can then be judged against the standard and if action is desired the choice must be made between control at source (which is usually most cost-effective), between source and receiver, (the paths of the sound) and at the receiver. Control at source can involve relocation, or redesign of source, or of the noise producing process. Specific noise-reducing devices at source that have been discussed are vibration isolation pads or springs, and absorption has been discussed. Outdoors considerations relating to ground effect, meteorology and barriers have been introduced. At the receiver, the sound insulation of buildings has been discussed.

Figure (23) Noise control methodology



ENVIRONMENTAL HEALTH IMPACTS OF NOISE POLLUTION

Noise is by far the most frequently mentioned disamenity in the home and the most directly felt environmental pollution in the European countries.

An example can be shown from Austria. In table 1 the percentage of homes, where people feel annoyed by noise is given. In table 2 the noise sources causing strong and very strong annoyance are shown.

Table (1) Percentage of homes annoyed by noise in Austria in 1988

Percentage of homes annoyed			
Very Strongly	Strongly	Somewhat	Not
6.7	12.8	18.9	61.6

Table (2) Sources causing strong and very strong annoyance

Source accused to cause annoyance	in dwellings annoyed	
	verly strongly	strongly
traffic	82.3	
road traffic	79.5	73.4
railways	4.2	4.6
air traffic	2.3	2.4
neighbours in the house	6.2	
industry and commerce	9.0	
others	2.5	

The effects of noise were recently laid down in a brochure published by OECD (1) as follows.

(a) Effects on health

(1) Physiological effects

Irritant noises even of moderate intensity are known to be capable of giving rise to psychological discomfort and serious somatic disorders. Noise is therefore a pathogenic factor to class with stress-causing aggressive agents which may contribute to cardiovascular and digestive diseases.

(2) Disturbance of sleep

Research in this field has shown , that exposure to noise during sleep causes

- difficulty in getting to sleep
- waking up during the night
- shortest periods at certain stages of sleep
- lower quality sleep through change of level (from deep sleep to light sleep) not perceived by the sleeper

There is no accustomisation to noise.

(3) Pathological effects

Effects on hearing: Noise with high levels perceived for many years causes hearing damage; mainly for workers in noisy working places, High noise levels in and near main roads may effect also the hearing and cause "socioacousia" in addition to the presbyacousia.

Overall effects: Several studies showed that the rate of medical presciptions is higher in noisy than in quiet areas.

Non-auditory impacts: Repetition of the physiological reactions could bring on a chronic and therefore pathological change in blood pressure in the case of high sound levels. In the Netherlands it was shown that long term exposure to airport noise could increase susceptibility to cardiovascular disease amongst persons pre-disposed to this type of disorder. In Germany a survey showed that there was a greater frequency of hypertension amongst persons exposed to noise than in the "control" population located in quiet areas.

(b) Effects on communication

Noise reduces the intelligibility of conversation, radio, music, television and similar others. This is an important discomfort in dwellings, and is of special interest for schools. Children in noisy areas learn to speak later than in quiet areas. Especially hard of hearing persons can not follow conversation in places with higher background level.

(c) Psychological annoyance.

Surveys conducted in many countries showed the amount of annoyance caused by noise and its correlation to the noise levels.

(d) Effects on behaviour

Noise causes individuals to behave in such a way as to reduce their annoyance. The need to close the windows is one of the most noise sensitive forms of behaviour, furtheron the reduced use of gardens, balconies, the more frequent change of homes and the installation of soundproofing measures.

The physical quantities used to describe noise with respect to its effect on man are the A-weighted sound pressure level L_A in dB (Decibel) and for the (most usual) noises with fluctuating sound pressure level, like traffic noise the A-weighted energy equivalent sound level $L_{A,eq}$,which is defined in ISO 1996-1 (2).

Usually $L_{A,eq}$ is measured separately for day time and night time. Day time and night time are laid down according to the local custom. For example in most European countries daytime is 6 - 18 (or 22), night time 22 - 6 o'clock. Sometimes day time and night time levels are combined within L_{DN} ($L_{day\text{-}night}$) which is calculated (giving the night time level 10 dB higher weight) from:

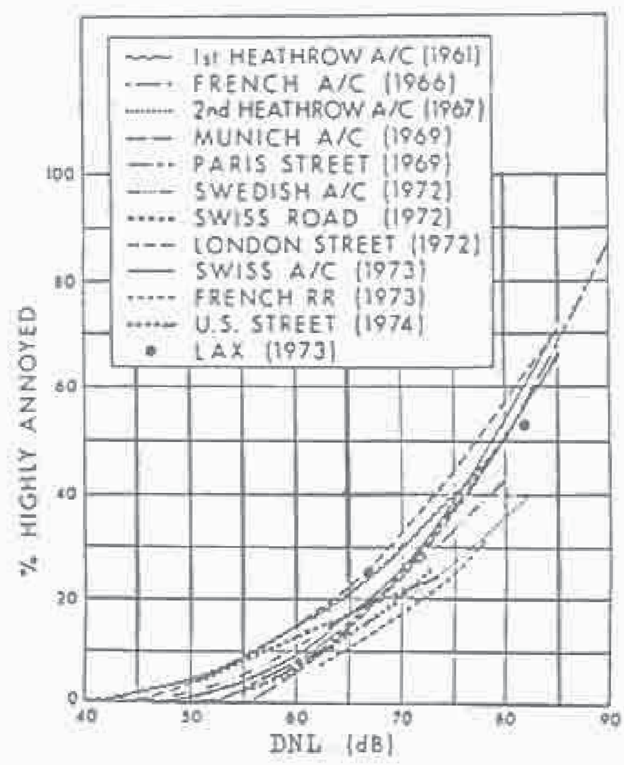
$$L_{DN} = 10 \log (T_{day}\, 10^{L_{Aeq,\,day}/10} + T_{night}\, 10^{(L_{Aeq,\,day} + 10)/10})$$

with

T_{day}: duration of day time in hours
T_{night}: duration of night time in hours
$T_{day} + T_{night} = 24$ hours
$L_{A,eq,day}$: A-weighted energy equivalent level during day time
$L_{A,eq,night}$: A-weighted energy equivalent level during night time

Social surveys carried out in many European countries and in the USA show a high correlation between the A-weighted energy equivalent level and the amount of annoyance felt by people. An example is shown in fig. (3). Several investigations also found a high correlation between A-weighted energy equivalent level at the working place and hearing damage to workers (see ISO 1999 (4)).

Figure (1) Revised Analysis of the Clustering Surveys Using a Rule for Counting the Present Highly Annoyed that leaves out personal Judgement in the Individual Surveys



Since noise was first recognised as a serious environmental pollutant, a number of social surveys have been conducted in order to asses the magnitude of the problem and to develop suitable noise ratings, such that, from a measurement of certain physical characteristics of community noise, one could reliably predict the community's subjective response to the noise. Recently, the author has reviewed the data from social surveys concerning the noise of aircraft, expressway traffic, and railroads. Going back to the original published data, the various survey noise ratings were translated to day-night Average sound level, and an independent judgment was made where choice was possible, As to which respondents should be counted as "highly annoyed" The results of 11 of these surveys show a remarkable consistency. It is proposed that the average of these curves is the best currently available relationship for predicting community annoyance due to transportation noise of all kinds. (Source (3))

Supplementary to the energy equivalent level often the maximum A-weighted sound level $L_{A,max}$ is used to describe a noise situation.

Based on the results of considerable research work conducted in several countries on the impact of noise it appears that (1):

- below 55 dB in $L_{A,eq}$ during the day (at housefront) damage caused by noise is very slight. Sound conditions enable the most noise sensitive activities to be carried out normally;

- between 55 and 60 dB noise impact remains limited, but some disturbance is probably occasioned to the more sensitive individuals in particular older persons;

- between 60 and 65 dB behaviour designed to reduce the annoyance is exhibited, although this is not too constraining. However, the effects on sleep and especially the level of annoyance increase very appreciably;

- above 65 dB constrained behaviour patterns arise, symptomatic of serious damage caused by noise.

In order to keep to the noise levels for comfort indoors ($L_{A,eq}$ 30 - 35 dB at night and 40 - 45 dB in the day time) a maximum external level of 65 dB would be necessary. However, insofar as possible, and particularly for new residential areas the outdoor limit should not be higher than 55 dB. However in most European countries a considerable percentage of the population is exposed to $L_{A,eq}$ > 55 dB and even > 65 dB (about 10-20%).

Prof. G. Jansen, Germany, working since many years in the field of noise on man has proposed the noise level criteria ("Anhaltswerte") as given in table 3.

Economic aspects may be considered besides the adverse effect of noise on the population. The social cost caused by reduced working efficiency, increased illness and medicine consumption can not be calculated easily. More defined the diminuition of the value of houses and land caused by noise can be shown. From an investigation in Austria (6) with a questionnaire answered by about 100 real estate agencies it turned out that the loss of value of houses and land is on average 35% near main roads, 10% near motorways with access and 30% near motorways without access. An inquiry of about 500 persons showed, that people are willing to pay a premium price of + 22% on the average for housing in a quiet location (compared to a house of the same quality in a noisy environment).

Table (3) Noise level criteria proposed by G. Jansen (5)

	$L_{A\,eq}$		$L_{A\,max}$
	outside	inside	inside
change of quality of sleep	-	38	40
threshold physiological changes	-	-	40
threshold communication disturbed	-	45	-
threshold efficiency diminished	-	-	45-70
threshold reactions of general public (0-20% annoyed)	45-55	-	-
threshold vegetative reactions during sleep	-	-	55
99% intelligibility of sentences	-	-	55
threshold of waking up	-	-	60
primary effects (vegetative)	-	-	60
significant reactions of general public (30-70% annoyed, 5-15% complaints)	65	-	-
diminished efficiency probable (compensation possible)	-	-	70-85
significant vegetative reactions	-	-	75
increased diminuition of efficiency (hardly to be compensated)	-	-	85-100
majority of population greatly annoyed	80	-	-
risk of hearing damage	-	85	
upper limit physiological balance			100
considerable and continous diminuition of efficiency	-	-	> 100
extra aural symptoms (illness)	-	-	> 130

References:

(1) Fighting Noise; Strengthening Noise Abatement Policies, Organization for Economic Co-operation and Development (OECD), Paris, 1986

(2) International Standard 1996/1 Acoustics- Description and measurement of environmental noise- Part 1: Basic Quantities and procedure, Geneva, 1982

(3) Th. J. Shultz: Synthesis of social surveys on noise annoyance, Journal of the Acoustical Society of America, 1978

(4) International Standard 1999 Acoustics - determination of occupational noise exposure and estimation of noise- induced hearing impairment, Geneva, 1990

(5) G. Jansen: Zur "erheblichen Belästigung: und :Gefährdung" durc Lärm: Lärmbekämpfung 33, 1986

(6) J. Lang: Lärmbelastung an Starzen. Wirksamkeit und Kosten von lärmschutzmaznahmen. Bundesministerium für Bauten und Technik, Strazenforschung, Heft 150, Wien 1980

PROCEDURES FOR NOISE PREDICTION

Noise prediction is an important tool to control noise with regard to new works like roads, factories, railway lines, airports, recreational facilities and similar others. It is necessary for procedures "checking compliance with the environment" which are now introduced in the design state of larger works in many countries, e.g. in the countries of the European Community.

Noise and the annoyance it may cause, has to be considered when new residential sites are planned near existing noise sources like roads, railway lines, airports, as well as when such noise sources are planned in or near existing residential areas.

Social surveys carried out in many countries (a summary of many social surveys is given in (1) and (2)) indicated, that the physical quantity to describe noise with respect to its annoying effect on man is the energy equivalent A-weighted sound level $L_{A,eq}$. For aircraft noise other descriptors have been established and introduced into legislation; however at present $L_{A,eq}$ is also recommended by the international organisations dealing with air traffic and aircraft noise.

At present the A-weighted equivalent sound level $L_{A,eq}$ is used in nearly all countries[1)] and nearly all prediction methods use this basic quantity.

$L_{A,eq}$ may be considered separately for day time and night time, together with different sound level limits for day time and night time or the quantity L_{DN} ($L_{Day,\ night}$) based on $L_{A,eq}$ may be calculated for 24 hours with 10 dB added to the night time value i.e.

$$L_{DN} = 10 \log (T_D.10^{L_{A,eq,D}/10} + T_N.10^{(L_{A,eq,N}+10)/10})/24$$

$L_{DN} = L_{Day,\ night\ in\ dB}$
$L_{A,eq,D}$ = A-Weigthed energy equivalent level for day time in dB
$L_{A,eq,N}$ = A-Weigthed energy equivalent level for night time in dB
T_D = Duration of day time in hours
T_N = Duration of night time in hours
$T_N + T_D = 24$ hours

Day time and night time may be laid down according to the local living custom. In most European countries day time is defined 6 - 22 o'clork ($T_D = 16$ hours) and night time is defined 22 - 6 o'clo1k ($T_N = 8$ hours).

L_{DN} is mainly used to describe aircraft noise around airports.

For noise prediction 3 basic input data are necessary:
- the number and type of sound sources and the sound emission of these sources
- the description of the site between source and receiver and the physical rules of sound propagation
- the position of the receiver

(1) In the United Kindom L_{10}, the sound level exceeded 10% of the time is used to describe road traffic noise; it is highly correlated with $L_{A,eq}$.

To assess the predicted sound level noise-level limits have to be known with regard to the site (rural, town, industrial area) and time of the day (day, night). The sound emission of a noise source is described by the sound power level:

$$L_W = 10 \log W/W_0$$

L_W = sound power level in dB
W = sound power in watt
W_0 = reference sound power, $W_0 = 10^{-12}$ watt

- It may be given in octave (or in 1/3-octave) bands or A-weighted.
- At the time being sound power level is mainly used to describe the noise output of machines and installations, in Austria also for railways.
- The measurement methods to determine the sound power level are laid down in ISO-Standards (3).
- For road traffic and railway lines usually the sound emission is described by the A-weighted sound pressure level in a certain distance of the axis of the lane or track, mostly 25 m.
- For aircraft it is used to give the A-weighted sound pressure level versus distance in tables or graphs; an example is shown in Annex 1 (the uniform format to give all data on performance and sound level of aircraft has been established by ANCAT (working group on the abatement of nuisances caused by airtransport) in ECAC (European Civil Aviation Conference) and is widely used now.
- The number n of equal sources has to be taken into account with the general term + 10 lg n in dB to be added to the sound power level or sound pressure level describing the sound output of a source.
- The physical rules on sound propagation are covered in several prediction models. The basic data are described in the following:
- The sound pressure level decreases with distance from the source according to:

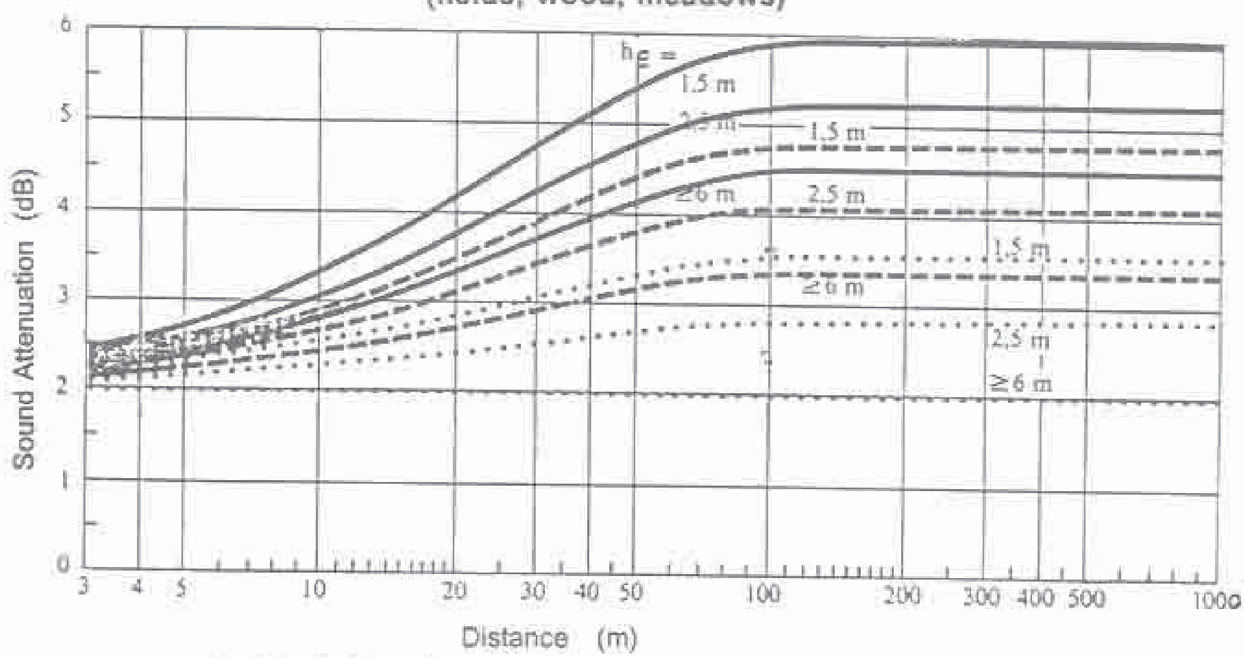
$$L_r = L_w - 10 \log 4\pi r^2/r_0^2$$

L_r = sound pressure level in dB at distance r
L_w = sound power level in the source in dB
r = distance of reciever to source in m
r_0 = reference distance, r_0 = 1 m
or
$L_r = L_{25} - 10 \log r^2/25^2$ for a point source
$L_r = L_{25} - 10 \log r/25$ for a line source like a road
L_{25} = sound pressure level in dB at 25 m distance from the source

In addition, the reflection from the ground has to be taken into account if the source is near a reflecting or absorbing plane. Simply for a source on a reflecting plane this is done by the term $2\pi r^2$ (sound energy is spread to a hemisphere) instead of the term $4\pi r^2$ (sound is spread to a sphere) in the first formula. For absorbing ground more detailed calculations in frequency bands are necessary to take care of a frequency dependant additional sound leve reduction, which varies with the height of source and receiver above the ground. The details of calculation are given in (4).

For the second formula several prediction models contain several procedures to take care of the sound absorption of the ground. An example of the effect of ground absorption for road traffic noise used in the Netherlands is given in fig. 1.

Figure (1) Sound attenuation for road tarffic noise propogating above absorbing ground (fields, wood, meadows)



———— road at level of terrain

– – – – – – road 1 m above terrain

··········· road 6 m above terrain

h_E = heigt of reciever above terrain

Sound absorption in the air is rather small; it depends on frequency and on air temperature and humidity. For usual noise sources like roads, factories a.s.o. in general one can assume that the decrease of the A-weighted sound level due to absorption in air is 0.5 dB per 100 m. The following table shows an example of the sound absorption in air to be used for calculations in octave bands for 15°C and 70% relative humidity (conditions usual in Europe). For other conditions see Annex 2.

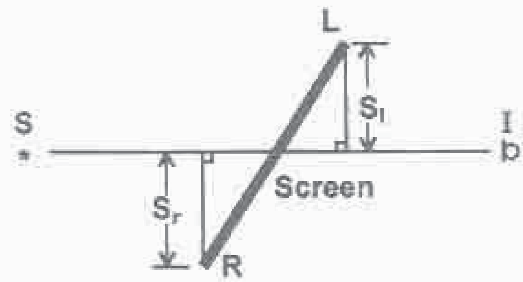
Table (1) Sound attenuation coefficient due to absorption in air

Frequency (Hz)	63	125	250	500	1000	2000	4000	8000
Attenuation Coefficient (dB/m)	0.000	0.000	0.001	0.002	0.004	0.007	0.017	0.056

An additional absorption is caused if the sound passes through dense vegetation of trees and bushes. A group of trees and bushes is considered dense if - along the sound transmission path - it is impossible to see through the vegetation, i.e. if the transmission path is visually blocked. It is also frequency dependent and may be estimated with 1 dB per 5O m, maximum 4 dB for larger distances.

A decrease in sound pressure level is caused by screening obstacles between source and receiver, provided these screening obstacles have a mass of > 10 kg/m², have no slits or openings and their dimensions are large compared to the wavelength λ of the sound (which is depending on frequency f with $\lambda = 34O/f$, λ in m,f in Hz) as shown in the following figure 2.

Figure (2) Minimum dimension of a screen

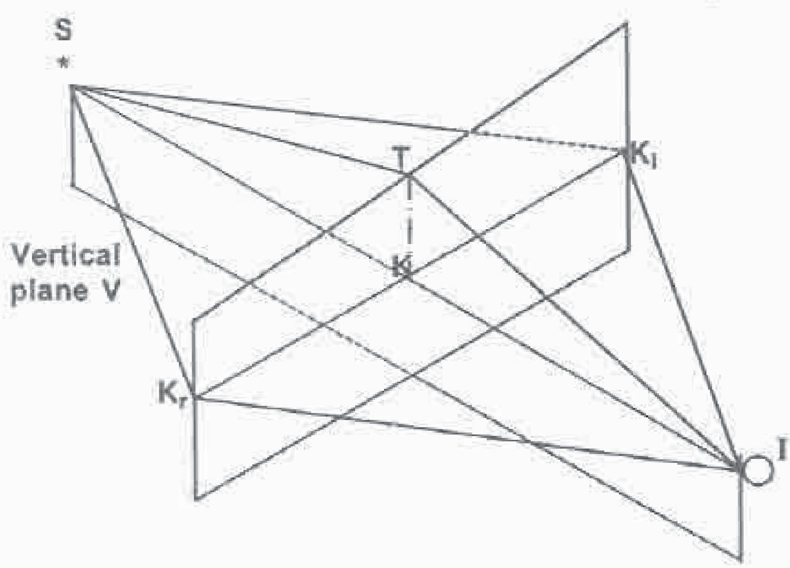


The horizontal dimension perpendicular to the line between the source S and the emissionn point I (receiver) should be greater than the wavelength λ.

$S_r + S_l = \lambda$

The sound level diminuition is frequency dependent and may be calculated from the sound path length above the screen and along the right and the left side edge of the screen as shown in fig.3

Figure (3) Illustration of sound paths with screen



$\delta_v = |ST| + |TI| - |SI|$ in m

$\delta_r = |SK_r| + |K_rI| - |SI|$ in m

$\delta_l = |SK_l| + |K_lI| - |SI|$ in m

For larger distances between source and receiver a curved sound path is assumed, see (4).

From the excess sound path length via the edges of the screen δ_v (top, vertical), δ_r (right side edge), δ_l (left side edge) and the Fresnel-numbers[1)] calculated from these the sound level decrease in octave bands is calculated from:

1) *The Fresnel number depends on the frequency. The constant number 0.0047 takes care of the lower 1/3 octave band within the octave band ($0.0047 = (2/340 \cdot 2^{1/3})$)*

$\Delta L = 10 \log [(1/20N_v + 3) + (1/20N_r + 3) + (1/20N_l + 3)]$

$N_v = 2.\delta_v/\lambda = 0.047.\delta_v.f_c,\ N_r = 2.\delta_r/\lambda = 0.047.\delta_r.f_c,\ N_l = 2.\delta_l/\lambda = 0.047.\delta_l.f_c$

f_c = centre frequency of ocatve band in Hz

if $\Delta L > 0$ then set $\Delta L = 0$, if $\Delta L < -20$ dB then set $\Delta L = -20$ dB

The emission point (position of receiver) has to be chosen according to the local situation. Usually the receiver position at the residential building nearest to the source (which is generally the most exposed) is considered with the exposed window at the maximum height (where generally screening effects and ground absorption effects are smallest).

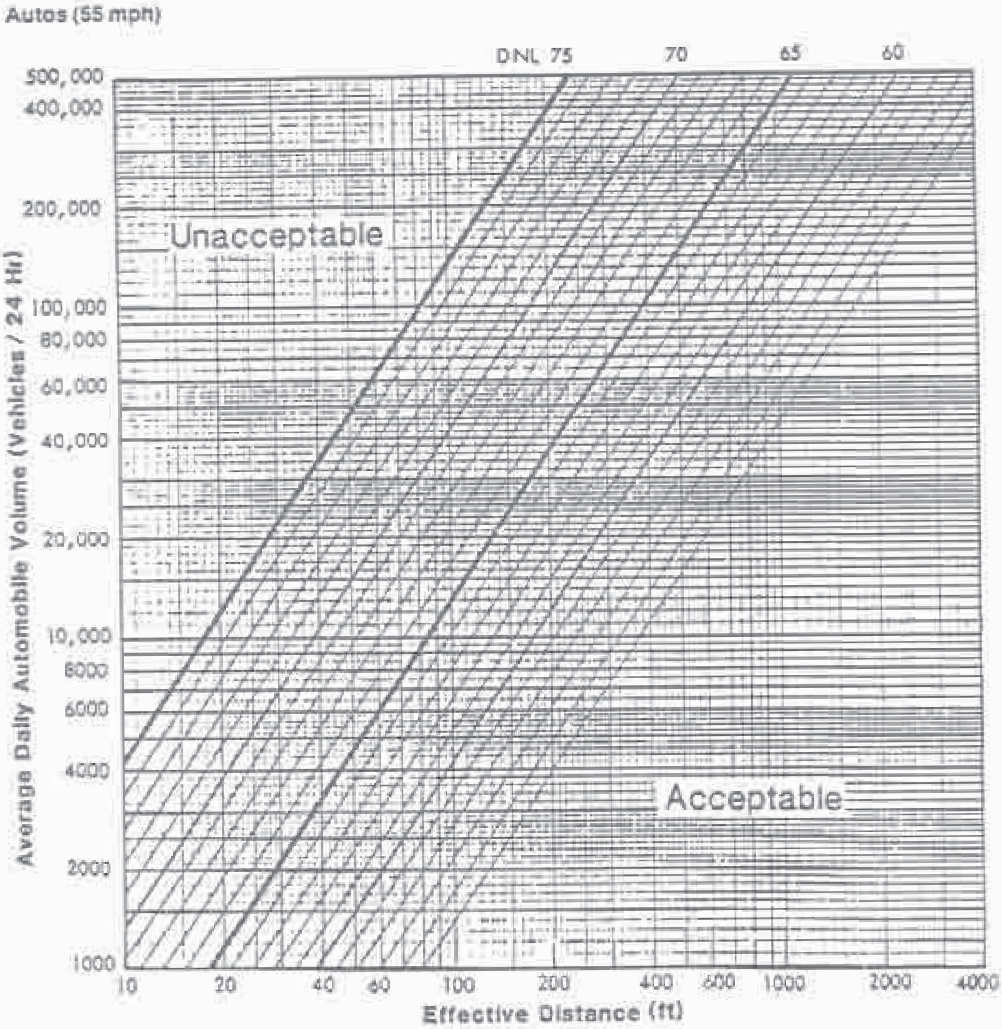
Sound level limits also have been established, An example from Austria is given in table 2. In most of the European countries the limits are more or less the same.

Table (2) Maximum permissible sound level (emission limits) used in Austria (ÖNORM S 5021)

category	area and locations	maximum permissible equivalent sound level $L_{A,eq}$ day	night
	A) BUILDING LANDS		
1	quiet area, spa area, hospital	45	35
2	residential area in suburbs, weekend residential area, rural housing area, schools	50	40
3	urban residential area, area for agricultural and forestry enterprises with flats	55	45
4	city (offices, shops, commerce, administration without noise emission, flats), area for enterprises without noise emission	60	50
5	area for enterprises with little noise emission (distribution, services, administration)	65	55
	B) GRASS LANDS		
1	recreation area, spa area	45	35
2	parks, cemetries	50	40
3	games- and sport fields without noise emission, market gardens and allotments	55	45
4	games- and sport fields without slight noise emission	60	50
5	smaller games- and sports installations with spectator stands	65	55
6	Large games- and sports installations with spectator stands	70	(60)

For road traffic noise and railway noise calculation models have been established in most European countries and the USA. These have been-compiled in the WHO-brochure "Assessment of Noise Impact on the Urban Environment" (5).

Figure (4) Workchart to calculate L_{DN} caused by road traffic according to the noise asessment guidelines in the USA

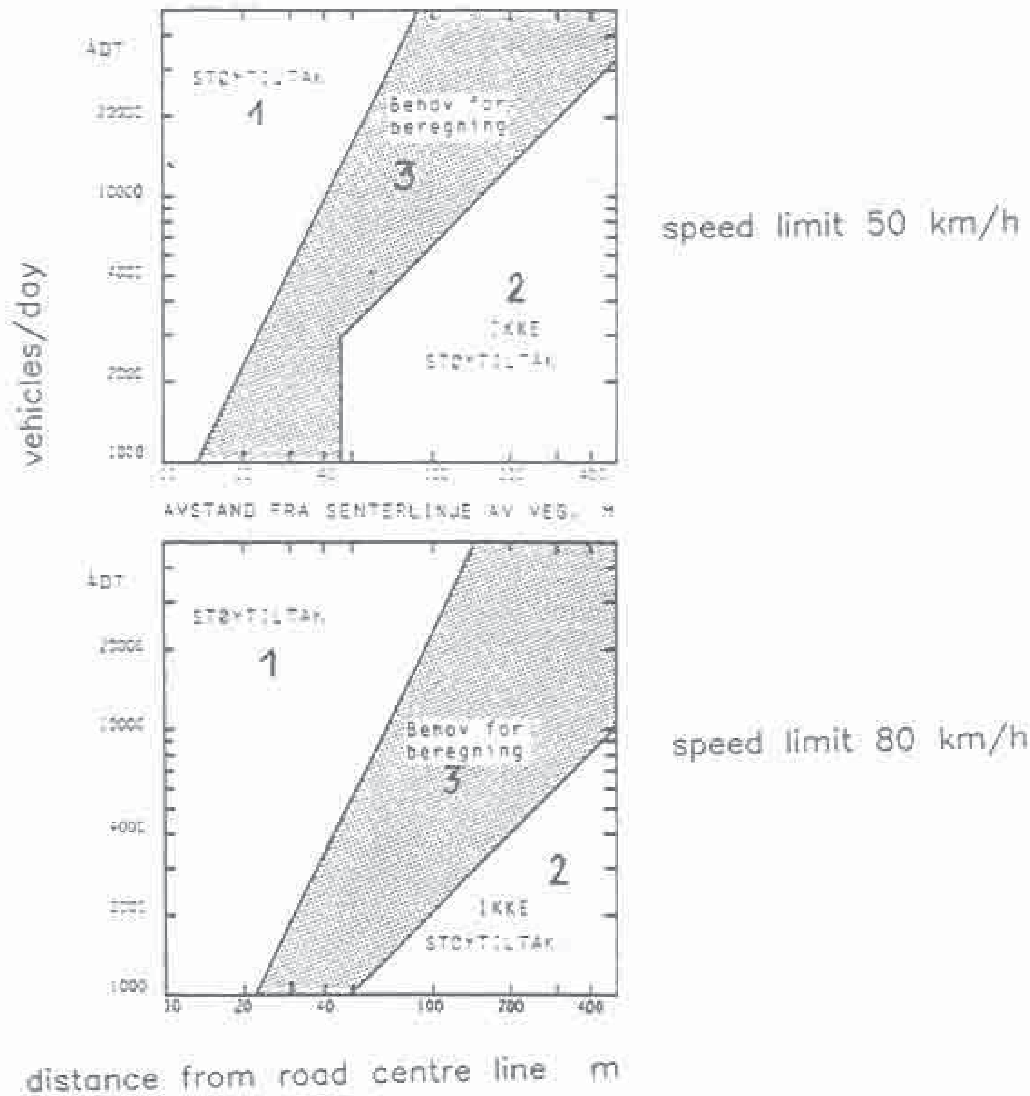


Besides the calculation models in several countries design charts, easily to be used by planners, have been derived from the formulae. An example for road traffic noise as used in USA, based on L_{DN} is shown in figure 4, another from Norway is shown in figure 5 (6).

In both graphs one can read from number of cars and distance road-receiver if the road traffic noise exceeds a certain limit. The Norwegian design chart shows 3 cases: noise clearly beneath limit, noise clearly above limit and area between those two possibilities, where more: detailed calculations have to be carried out.

Data have also been prepared to take care of sound propagation in built up areas showing iso-sound pressure level lines in different types of built up areas: an example is shown in figure 6. An extensive compilation of these data is given in (7).

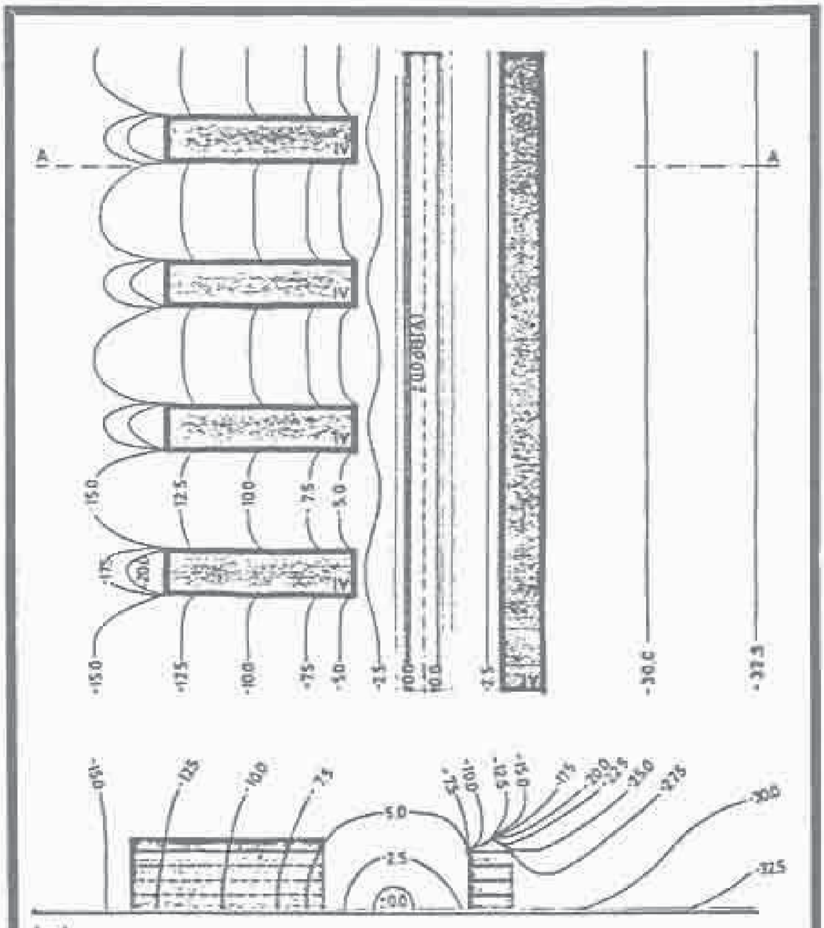
Figure (5) Road Traffic: Simple method
Sound level limit 60 dB(A)



10% heavy vehicles, 0–4% gradient
freely flowing traffic
at least 150° of road not visually blocked

1 measures against noise
2 no measures against noise
3 calculation necessary

Figure (6) Example of iso-sound level lines in built up areas



A-A *the sound level decrease between and behind the houses is shown*

An example of a simple design chart for the noise from railways is shown in figure 7

Calculation models have also been established for aircraft noise. The most complete is the Integrated Noise Model (INM) edited by the US Federal Aviation Authority, which contains the sound emission and performance data of all generally used types of aircraft.

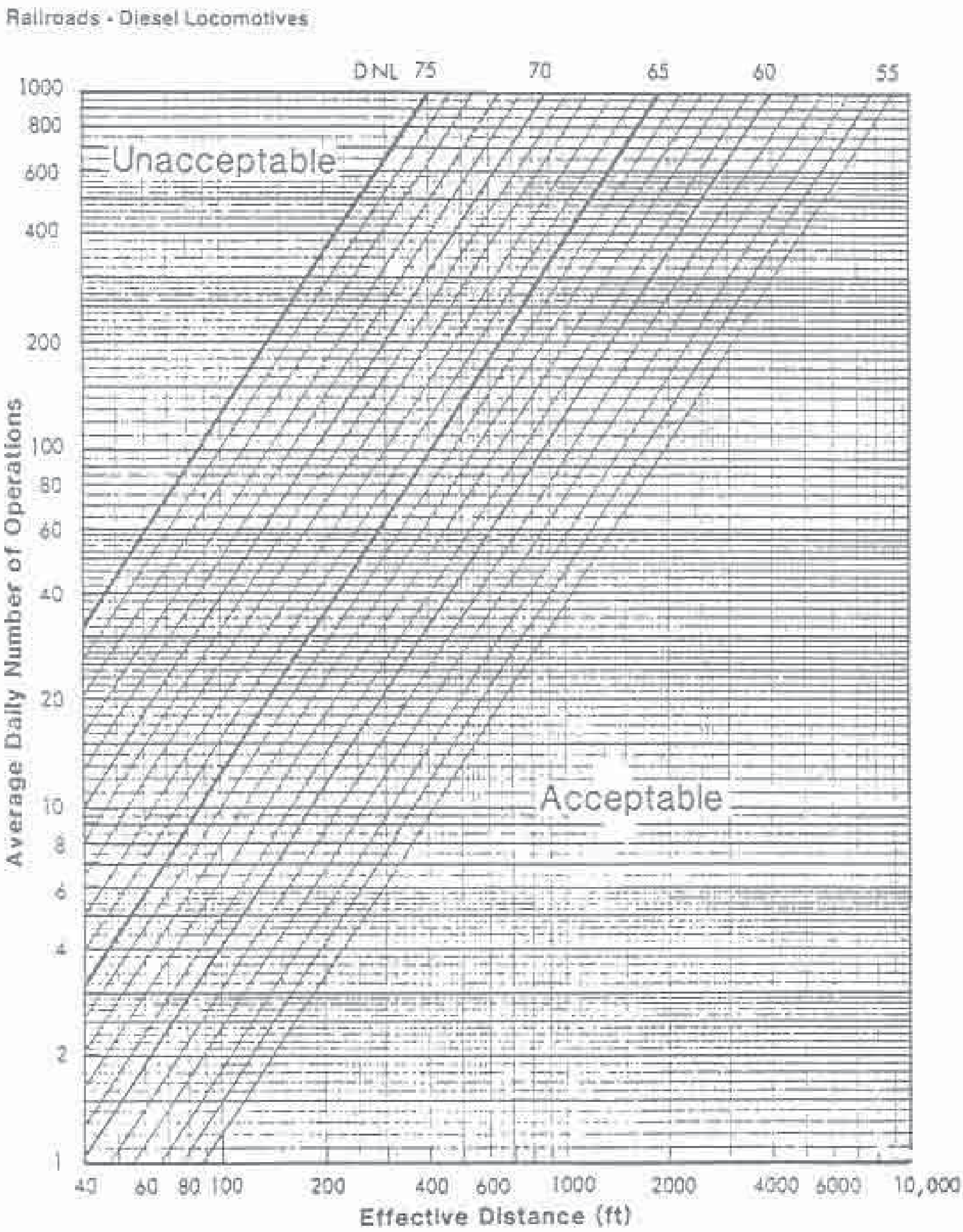
The aircraft noise zones around an airport are calculated in L_{DN}. Usually the zones L_{DN} = 60, 65, 70, 75 dB are drawn.

L_{DN} is calculated from the number of movements of the several types of aircraft on the several flight paths during day time and night time in the 6 most busy months of the year from:

$$L_{DN} = 10 \lg 1/T \sum [\bar{n}_{D,i}\, 10^{L_{AE,i}/10} + \bar{n}_{N,i}\, 10^{(L_{AE,i}/10 + 10/10)}]$$

L_{DN} = $L_{day\text{-}night}$ in dB (A-weigthed)
T = 86400 seconds (24 hours)
$\bar{n}_{D,i}$ = average daily number of movements of a type of aircraft on a flight path during day time
$\bar{n}_{N,i}$ = average daily number of movements of a type of aircraft on a flight path during night time
$L_{AE,i}$ = A-weighted sound event level of a type of aircraft passing by on a flight path

Figure (7) Workchart to calculate L_{DN} caused by trains with diesel locomotives according to the noise assessment guidelines in the USA



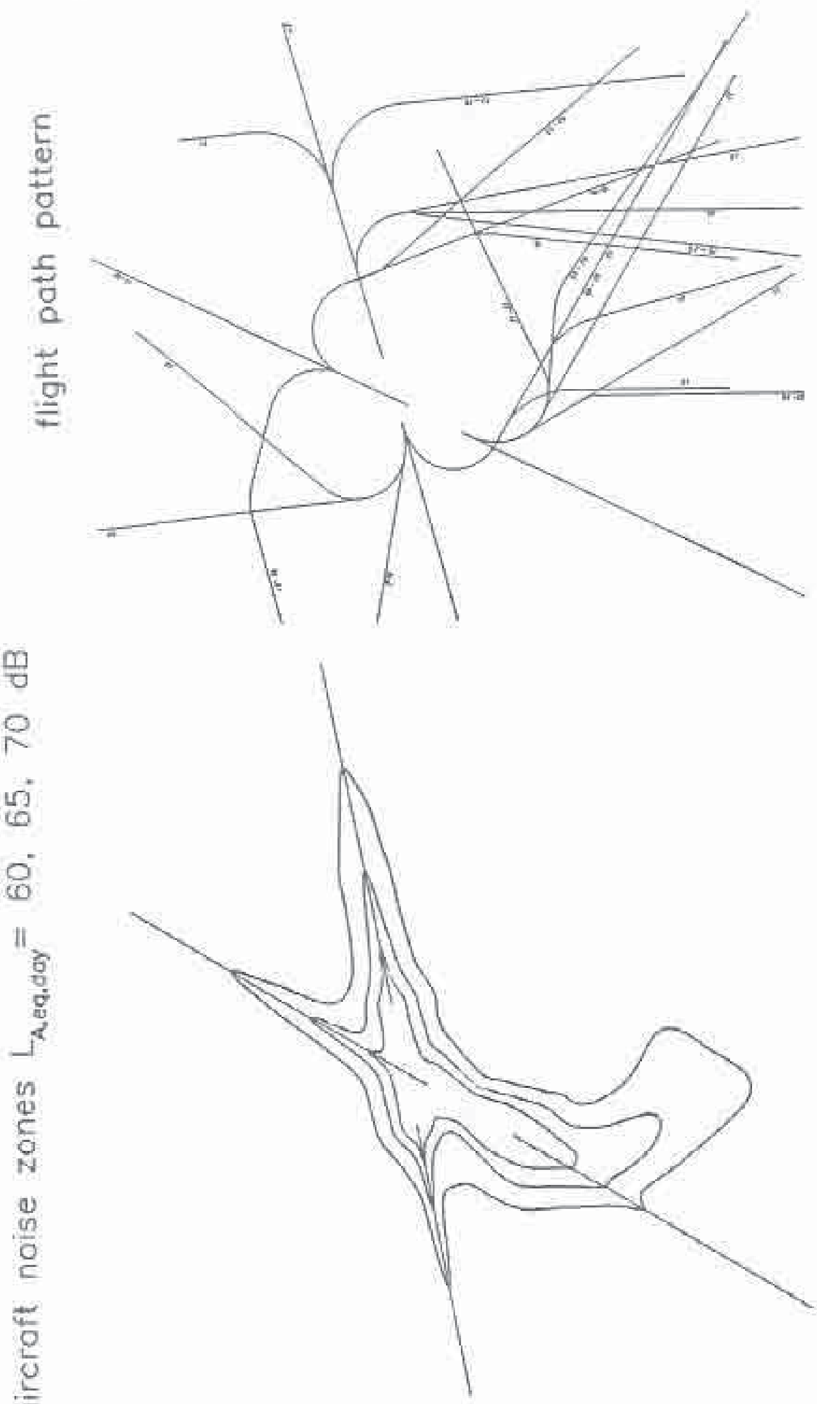
The. summation is done over all tvpes of aircraft on all flight **paths.**

The input data are:

- number of movements of any type of aircraft on any flight path (usually to be gathered by the airport operator)
- data on geometry of flight paths and flight procedures (to be provided by aviation authority)
- sound emission of the different types of aircraft (A-weighted sound event level versus distance aircraft-receiver)

An example of flight path pattern and aircraft noise zones is shown in figure 8 (Vienna airport).

Fig (8) Aircraft Noise Zones Around Vienna Airport 1986



References:

(1) J. M. Fields: A catalog of social surveys of resident reactions to environmental noise (1943-1980).Washington, DC, National Aeronautics and Space Administration, August 1981 (NASA Technical Memorandum 83187)

(2) Th. J. Schultz: Synthesis of social surveys on noise annoyance, Journal of the Acoustical Society of America, 1978

(3) ISO 3740, 3741, 3742, 3743, 3744, 3745, 3746, 3747. International Organization for Standardisation, Geneva

(4) Environmental noise from industrial plants. General prediction method Report no.32 The Danish Acoustical Laboratory Technical University of Denmark, Lyngby, Denmark

(5) J. Lang: Assessment of Noise Impact on the Urban Environment. A Study on Noise Prediction Models. World Health Organization, Regional Office for Europe, Environmental Health Series no.9, Copenhagen, 1986

(6) S. Solberg: stoyhandbok for saksbehdndling i kommunene. Statens forurensningstilsyn, Oslo 1990, (in Norwegian language)

(7) A. Machtemes: Schallschutz im Städtebau. ILS, Band 2.002, Dortmund 1974 (Germany) und A. Machtemes und K. Glück: Schallschutz im Städtebau 2, Schallpegelminderung bei typischen Baukorperformen und -stellunqen. ILS des Landes Nordrhein-Westfalen, Dortmund 1977 (Germany)

Annex 1

MODEL MD-87 AIRPLANES EQUIPPED WITH JT8D-219 ENGINES

NOISE and PERFORMANCE DATA

Airplane:	MD-87
Engine:	JT8D-219
Configuration:	flap angle: 11° slat angle: mid landing gear: up
Engine Thrust:	parameter specified: F_N/δ "corrected" parameter value: 19,000 lbs
Airplane Weight:	125,400 lbs (85% of Maximum Takeoff Gross Weight)
Airspeed:	160 Knots

Slant Distance (m)	80	100	125	160	200	250	315	400	500	630	800
L_{AMAX} (dB)	108.2	106.3	103.9	101.7	99.2	97.2	94.5	92.2	89.4	86.9	83.9
L_{AE} (dB)	109.2	108.1	106.8	105.5	104.1	102.9	101.3	99.9	98.2	96.7	94.8

Slant Distance (m)	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
L_{AMAX} (dB)	81.4	78.2	75.4	71.8	68.6	64.7	61.0	56.7	52.8	47.7
L_{AE} (dB)	92.9	90.6	88.3	85.6	83.2	80.0	77.1	73.7	70.5	66.2

Annex 2

Attenuation coefficients for air absorption

(for pure tones at frequency f) to be used in octave bands centred at f_c

f_c (Hz) / (f) (Hz) / t, RH		63 (50)	125 (100)	250 (200)	500 (400)	1000 (800)	2000 (1600)	4000 (3150)	8000 (6300)
0°c	30%	0.000	0.000	0.001	0.002	0.007	0.024	0.059	0.100
	50%	0.000	0.000	0.001	0.001	0.004	0.014	0.046	0.121
	70%	0.000	0.000	0.001	0.001	0.003	0.010	0.033	0.107
	80%	0.000	0.000	0.001	0.001	0.003	0.008	0.029	0.097
	100%	0.000	0.000	0.001	0.001	0.002	0.007	0.023	0.080
10°c	30%	0.000	0.000	0.001	0.002	0.004	0.014	0.047	0.140
	50%	0.000	0.000	0.001	0.002	0.003	0.008	0.027	0.097
	70%	0.000	0.000	0.001	0.002	0.003	0.007	0.020	0.070
	80%	0.000	0.000	0.001	0.002	0.003	0.006	0.018	0.062
	100%	0.000	0.000	0.001	0.002	0.003	0.006	0.015	0.050
15°c	30%	0.000	0.000	0.001	0.002	0.004	0.011	0.037	0.124
	50%	0.000	0.000	0.001	0.002	0.004	0.008	0.022	0.077
	70%	0.000	0.000	0.001	0.002	0.004	0.007	0.017	0.056
	80%	0.000	0.000	0.001	0.002	0.004	0.007	0.016	0.050
	100%	0.000	0.000	0.001	0.002	0.004	0.007	0.014	0.042
20°c	30%	0.000	0.000	0.001	0.002	0.004	0.009	0.029	0.102
	50%	0.000	0.000	0.001	0.002	0.004	0.008	0.019	0.063
	70%	0.000	0.000	0.001	0.002	0.005	0.008	0.016	0.048
	80%	0.000	0.000	0.001	0.002	0.005	0.008	0.016	0.043
	100%	0.000	0.000	0.001	0.002	0.005	0.008	0.015	0.038
25°c	30%	0.000	0.000	0.001	0.003	0.005	0.009	0.024	0.083
	50%	0.000	0.000	0.001	0.002	0.005	0.009	0.018	0.053
	70%	0.000	0.000	0.001	0.002	0.005	0.010	0.017	0.043
	80%	0.000	0.000	0.001	0.002	0.005	0.010	0.017	0.040
	100%	0.000	0.000	0.000	0.002	0.005	0.010	0.018	0.038

NOISE ABATEMENT
REGULATIONS AND STRATEGIES

Noise is a considerable nuisance to people at the time being and its importance will still grow in the future with growing number of vehicles and machines of all kinds and rapid urbanisation and increasing mobility. Noise abatement regulations and strategies have therefore to be established as soon as possible covering all aspects. In general the following measures have to be considered: - noise source; - sound transmission path; and - receiver, and covering all these aspects in - land use planning and zoning.

1. Measures to limit the noise emission of the source

These are generally the most effective. Regulations with noise level limits for the main noise sources should therefore be introduced.

1.1 Road traffic noise

Limits on the noise emission of vehicles have been introduced in all European countries (following ECE or EEC recommendations) and have been reduced several times in the last decade. It is of utmost importance that these limits together with the relevant measuring methods be also introduced in the countries of the Eastern Mediterranean Region. The limits in use in Austria (following ECE-regulations together with the relevant measuring method) since 1 October I989 are shown in the following table 1.

In the last years besides these limits a special class of "low noise trucks" has been introduced. These trucks follow the state of the art of noise control and are now widely used in Austria and also in Germany and their use is put forward by economic incentives as e.g. exception from night-ban on certain routes, reduction of taxes. The maximum permissible noise levels are also given in table 1 (some additional limits have to be observed for stationary vehicle, motor brakes and similar others.

Table (1) Maximum permissible sound levels of vehicles in Austria

Type of Vehicle		Maximum Permissible A-Weighted Sound Level (dB)
Motor Vehicles		69
Small Two Wheeled Vehicles		74
Other Two Wheeled Vehicles	$< 175\ cm^3$	80
	$> 175, < 500\ cm^3$	81
	$> 500\ cm^3$	83
Cars		77
Trucks		84
Low Noise Trucks	< 150 kW	78
	> 150 kW	82

In addition to the observation of noise level limits for new vehicles (type test) the noise emission of vehicles already in use should be controlled regularly. To enable police to carry out such measurements in the road the "near field measurement method" has been introduced. In regulations on maximum permissible sound emission of motor vehicles therefore in addition to the type test measurements near field measurements **should be introduced.**

Sound level limits for the vehicles limit the noise emission of the engines. However the main noise source in traffic on highways is rolling noise. This may be reduced by quiet road surfaces (porous asphalt "drain asphalt").

Road traffic noise may also be reduced by speed limits, provided these are observed by the drivers, which mainly can only be ensured by supervision by the traffic police. Fig. 1 shows the maximum A-weighted sound level $L_{A,max}$ and the A-weighted sound event level[1)] $L_{A,E}$ of cars and trucks passing by with different speeds on different road surfaces at 10 m distance (1). From this diagram the noise reduction to be achieved by speed limits can be read. For example on concrete roads the reduction of the speed for trucks from 90 to 60 km/h would result in a reduction of the maximum sound level by 5 dB and of the sound event level (equally to the equivalent sound level) by 4 dB and the reduction of the speed for cars from 140 to 100 km/h would result in the same sound level reduction.

In the central parts of cities a speed limit of 30 km/h may be introduced (30 km/h - zones are now installed in many European towns). Measurements have shown, that cars driving with 30 km/h produce 7 dB lower maximum sound levels and 5 dB lower equivalent sound level than cars driving with 50 km/h.

Noise emission of road traffic may further be reduced by night-ban for all vehicles or especially for heavy vehicles.

Traffic management in towns ensuring equal traffic flow serves also for noise reduction.

A considerable amount of noise emission of vehicles is caused by the driver; different driving manners may result in sound level differences up to 10 dB. Well educated drivers are therefore very important in noise control. Adequate regulations and their execution should ensure "low-noise-behaviour" of drivers. Police should be encouraged to take care of disciplined behaviour of drivers.

In some countries car drivers blow their horns extremely often causing a lot of noise with high peak levels. The blowing of horns within cities should be forbidden - at least during night time - and police should execute this regulation.

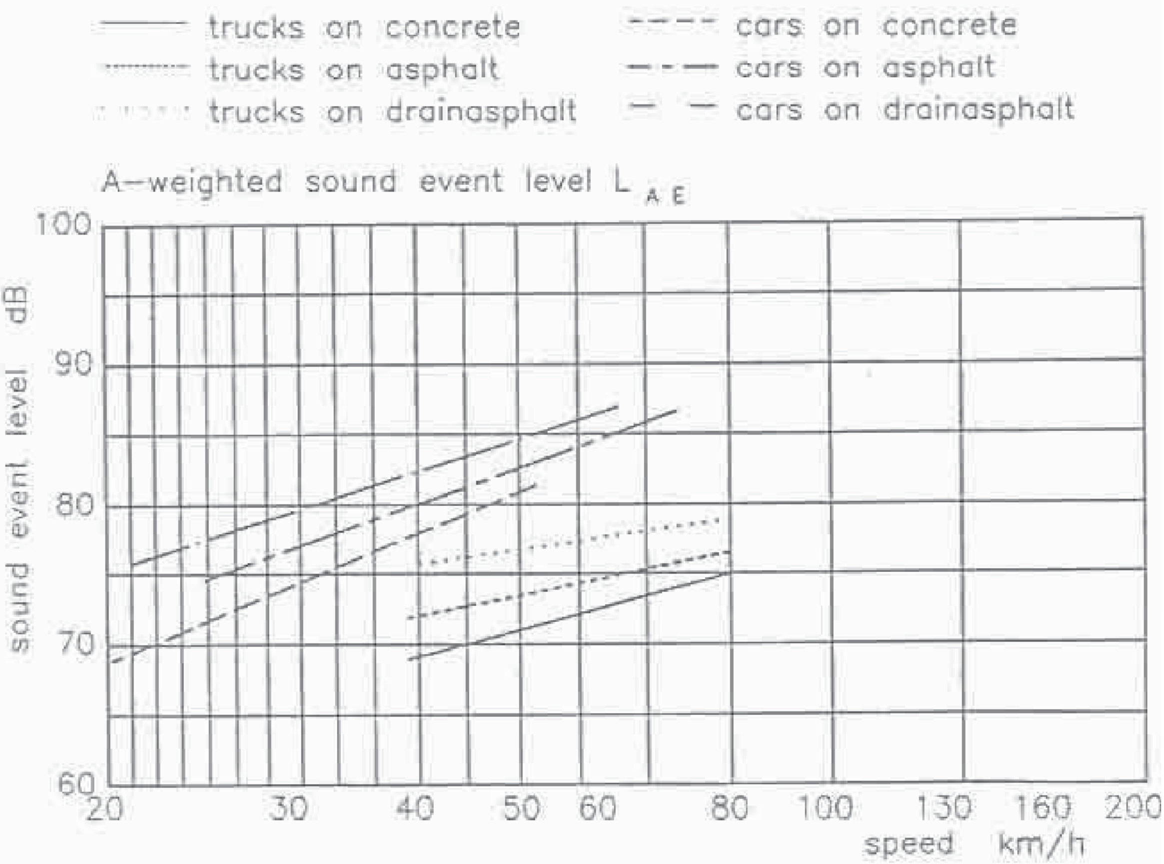
---

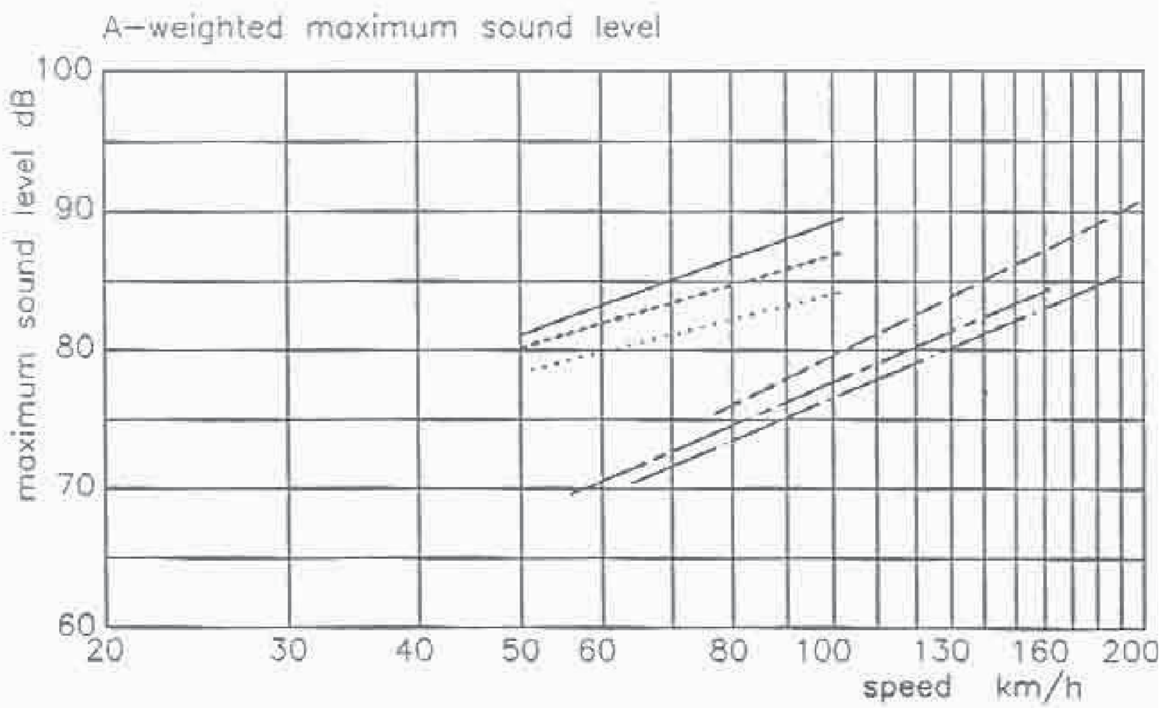
1) *The sound event level $L_{A,E}$ (in ISO 1996/1 called sound exposure level, in ISO 3891 called single-event exposure level) has with 1 second duration the same sound energy as a single sound event with varying sound level with the equivalent sound level $L_{A,eq}$ over a certain duration T:*

$$L_{A,E} = L_{A,eq} + 10 \log T/1 \text{ sec.}$$

From the sound event level of a sound event (e.g. caused by a passing vehicle) the equivalent sound level caused by n such events in the time period T_{ref} (e.g. day time, night time) can be calculated from $L_{A,eq} = L_{A,E} + 10 \log n - 10 \log T_{ref}/1$ sec.

Figure (1) Sound Level Caused by Cars and Trucks Passing by with Different Speeds on Highways with Different Road Surfaces





1.2 Railway noise and noise from trams

The main noise source is the wheel-rail-contact. Noise at the source can be reduced by well maintained rails and wheels (no flats): sound levels vary with maintenance of the rails by more than 10 dB.

1.3 Aircraft noise

The noise emission of aircraft is limited by ICAO Annex 16, chapter 2 and 3, defining maximum permissible sound level limits under certain measuring procedures. While aircrafts of older types do not fulfill the ICAO-requirements ("non certified aircraft"), aircrafts following chapter 3 represent the state of the art of noise control. The sound level versus distance at take off and landing for the different types of aircrafts is shown in fig.2. It should therefore be aimed at, that all aircrafts operating at an airport are chapter 3 or at least chapter 2 aircrafts. For example in Europe non certified aircrafts are not allowed to start anymore and chapter 2 aircrafts may not be registered anew; after 2002 only chapter 3 aircrafts will be allowed to operate[1)]

Similar legislation should be established (if need be with a certain time lag) in the countries of the Eastern Mediterranean Region.

The use of low noise aircraft may also be enforced by setting noise related charges (landing fee not only related to weight and capacity but also to noise emission). These could be installed at all airports. Examples of existing noise charge systems in several countries (France, Japan, Germany, United Kingdom, Netherlands, Switzerland) are given in an OECD-report (2).

1.4 Machines

Noise emission has to be considered as a main property of all types of machines and equipment and has to be taken into account in the decision to buy a certain product. Basic data for this decision are the sound emission declared as A-weighted sound power level.

The introduction of noise labelling is a main tool to reduce noise emission of products by the market. For example in Austria it is prescribed by law, that for any machine offered the A-weighted sound power level has to he stated (if it exceeds 80 dB). Within the countries of the European Community sound power levels have to be stated for several groups of machines e.g. lawn mowers, construction machines, house hold equipment. For a great number of other groups of machines sound power level data have been compiled, e.g. in Germany by VDI (3) and show the state of the art with respect to noise control.

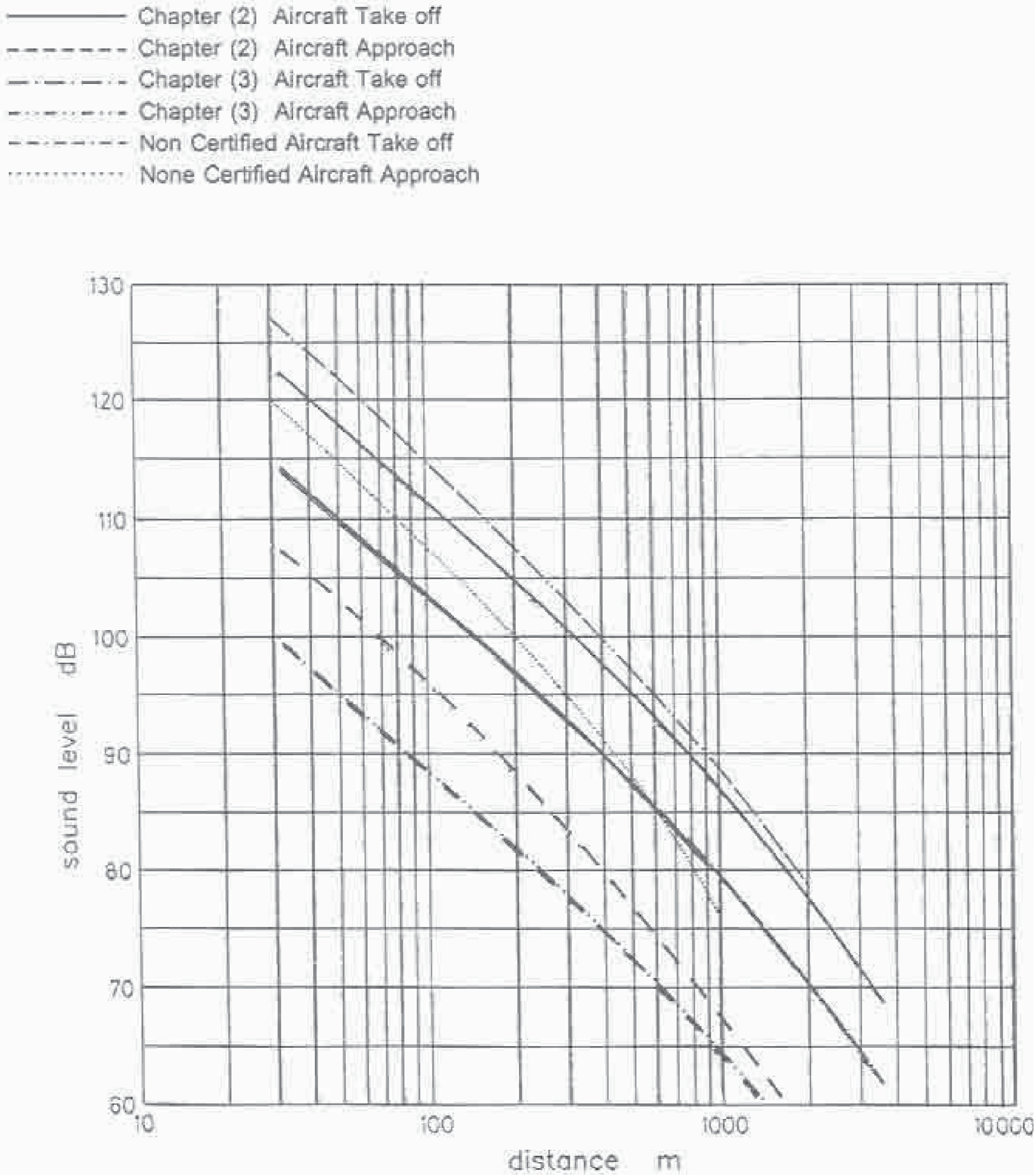
A second step would be the introduction of sound power level limits for certain groups of machines (e.g. construction machines, house-hold appliances). These limits, which should follow the state of the art, may be set:

- by law
- in recommendations (guidelines)
- by consumers.

---

1) *Aircraft complying with ICAO chapter 3, Annex 16 have also the advantage of being the best performers in terms of fuel conservation and maintenance costs.*

Figure (2) Maximum A-Weighted Sound Level of Air Craft



Measuring methods for sound power levels have been laid down by the International Organization for Standardization (ISO) and regulations on sound emission labelling could be based on these (4).

2. Noise control within the sound transmission path

This may be used in certain cases. For example alongside highways or main roads with heavy traffic noise barriers may be installed to protect dwellings near the road.

In several European countries relevant regulations have been established. These regulations have to define:

- calculation schemes for the equivalent sound level of the road traffic (or measuring methods) and for the effect of a barrier
- sound level limits ($L_{A,eq,day}$ and $L_{A,eq,night}$ or L_{DN}) which have to be fulfilled by installing the barriers
- budget provision
- responsible authority.

For example in Austria noise barriers alongside federal roads or sound proof windows for dwellings alongside federal roads (and also a number of regional roads) have to be installed, so that $L_{A,eq}$ = 65/55 dB is not exceeded day/night in front of dwellings.

Sound levels are decreasing with distance; large distances between noise source and receiver may therefore be used to control noise. This is mainly prescribed in land use planning and zoning with respect to noise.

3. Noise control at the receivers site

It is mainly used for existing situations and has to be considered for new buildings in noisy areas. Residential buildings near main roads with heavy traffic or railway lines may be provided with sound proof windows. For new buildings standards or building codes should describe the position of houses and the groundplan of houses with respect to noise sources and also the required sound insulation of the facades. An example of the noise level limits for certain types of buildings according to their use as laid down in the Austrian standard on sound insulation in buildings is given in table 2.

Table (2) Maximum sound level in front of buildings

Type of Building	Maximum A-Weighted Equivalent Sound Level (dB)	
	Day	Night
Hospitals, spa	45	35
Residential Buildings in Suburbs and in Rural Areas, Schools	50	40
Residential Buildings in Towns and in Agricultural Areas	55	45
Residential Buildings in City Centres, Areas with Industries and workshops without noise emission	60	50
Commercial Buildings	65	55*)

*) if relevant

An example of the minimum required sound insulation of facades depending on the sound level in front of the building is shown in table 3 according to the Austrian standard.

Table (3) Minimum Required Sound Insulation for Facades According to Austrian Standards (ÖNORM B 8115/2)

Building	Minimum Required Weighted Sound Reduction Index R_w (dB)*) at Sound Level in Front of Building $L_{A,eq}$ in (dB)					
	Day < 50 Night < 40	51-55 41-45	56-60 46-50	61-65 51-55	66-70 56-60	71-75 61-65
Hospital, spa	33	38	43	47	52	–
Residential Building, School, Hotel	33	33	38	38	43	48
Office Building	33	33	33	33	38	43

*) According to ISO 717 part 1

4. Town and country planning

This, with noise related zones, is a main tool for noise control. Planners have to be given the necessary tools as:

- calculation methods to predict the noise impact caused by road traffic, railtraffic, airports, industries and similar others.
- noise level limits for various zones depending on the type of buildings in these zones[1)]
- noise maps or noise cadastres showing the existing noise situation so that:
  - construction of noise sensitive buildings in noisy areas
  - installations and buildings emitting noise in quiet areas may be avoided.

Table 4 and 5 show the data laid down in guidelines in Austria for emission limit values for the different zones and for the emission of different types of buildings and installations.

It is recommended, that noise level measurements ($L_{A,eq}$ daytime and nighttime) should be carried out in the big cities and new projects and zoning be based on these data.

Noise zones around airports should be calculated based on a prognosis of number of movements for about 2000-2010, Usually the zones L_{DN} = 60, 65, 70, 75 dB are calculated and land use based on these zones. An example for a proposal of a relevant regulation in Austria is given in table 6. Input data and calculation schemes have been established in several countries; one of the most complete is the INM (integrated noise model) in the USA.

---

1) In general such limits are derived from results of social surveys with inquiries on annoyance caused by noise correlated to sound level measurements.

Table (4) Maximum Permissible Sound Level (Emission Limits) Used in Austria (ÖRONM S 5021)

category	area and locations	maximum permissible equivalent sound level $L_{A,eq}$	
		day	night
	A) BUILDING LANDS		
1	quiet area, spa area, hospital	45	35
2	residential area in suburbs, weekend residential area, rural housing area, schools	50	40
3	urban residential area, area for agricultural and forestry enterprises with flats	55	45
4	city (offices, shops, commerce, administration without noise emission, flats), area for enterprises without noise emission	60	50
5	area for enterprises with little noise emission (distribution, services, administration)	65	55
	B) GRASS LANDS		
1	recreation area, spa area	45	35
2	parks, cemetries	50	40
3	games- and sport fields without noise emission, market gardens and allotments	55	45
4	games- and sport fields without slight noise emission	60	50
5	smaller games- and sports installations with spectator stands	65	55
6	Large games- and sports installations with spectator stands	70	(60)

Table (5) Planning Values [1] for Emissions from Locations[2]

Category According to ONORM S 5021	Locations for A Building Land	B Grass Lands	Equivalent Sound Level [1] LA,eq (dB) by day Building land & grass land	by night building land	grass land	Remarks
1	Recreation Areas (except sports installations), hospitals, spa institutes, old people homes, spa hotels in general	Areas for spa & Recreational purposes, spa parks, park installations without children's playgrounds, cemeteries in rural areas	45	35	4)	Access for estate care and rescue vehichles to be considered separately
2	Residential quarters in solely residential areas with low building density (e.g. with open layout, row homes) schools without open-air facilities, mona-steries in general, boarding houses, old peoples homes garage installations[5]	Agricultural and forestry utilisation, parks, larger cemeteries games & sports fields without any important noise emission (e.g. golf courts, cross-country ski-runs)	50	40	4)	Also in traffic abated zones without children's playgrounds or residential access installations
3	Agricultural premises, residential premises with greater building density, schools with open air games & sports grounds, hotels, garage installations	Market gardens, allotmant gardens Indoor-baths without open air installations	55	45	4)	Residential areas in general, including playgrounds
4	Residential areas with high building density, service & administrative premises Professional trades and industrial goods-production and service premises with slight noise emission, catering enterprises, garage installations[5] shopping centres	Games- and sports installations with slight noise emission (e.g. tennis courts, smaller children's play-grounds), Holiday homes, juvenlles, Ski lifts (motive elements)	60	50	4)	
5	Work premises for distri-bution, professional trades, and industrial goods production and service premises, exhibition premises, filling stations, storage yards, barracks in general, drive-in cinemas	Smaller games- and sports with specator's stands, larger children's playgrounds, smaller open-air baths, riding sports grounds without larger spectaor's stands, sewage treatment plants, transformer installations[6]	65	4)	4)	
6	Professional trades- and industrial goods production and service premises. Catering premises with garden, dancing and music discotheques	Larger games- and sports-grounds with specator's stands (e.g. football grounds with spectators, stands, larger open baths etc.) premises for popular entertainment, skating rinks[6], gravel works	70	4)	4)	
7	Premises with specially High noise emission	Quarries, shooting ranges[6] motor sports grounds, model aircraft flying grounds	> 70	4)	4)	

1) near the borders of an estate
2) all examples are held to be exemplifications according to the allocation categories valid in the Austrian provinces, some locations may be found both on building land and grass lands
3) with the noise caused by the access and departure venues
4) observe topical night operations
5) according to topical noise emission, dependent on output and type of construction
6) Approximate values for emission of recreational and tourist installations

Table (6) Aircraft Noise Zones and Land Use

<table>
<tr><th>L_{DN}/L_{Amax} (dB)</th><th colspan="2">New Buildings</th><th colspan="2">Existing Buildings</th></tr>
<tr><td>> 75/105</td><td rowspan="3">No New Residential Zones Permitted</td><td>Buildings for agricultural and military purpose airport</td><td rowspan="2">Residential Buildings Fitted with required sound insulation</td><td rowspan="4">Buildings used for noise, sensetive functions (schools, hospitals, nursing homes) fitted with required sound insulation</td></tr>
<tr><td>> 65/-</td><td>Residential buildings only in existing residential zone and commercial buildings with required sound insulation</td></tr>
<tr><td>> 60/-</td><td>Residential buildings only in existing residential zone</td><td rowspan="2"></td></tr>
<tr><td>> 55/-</td><td colspan="2">Buildings used for noise sensitive functions only in case of overriding need and with required sound insulation</td></tr>
</table>

5. Examination of compliance with the environment

This (including noise) should be carried out for all kinds of new works and installations in the planning stage. Laws on this examination have been established in several European countries and also in the European community.

6. Education and awareness-promotion

Noise abatement policies can only be established and executed, if

- basic knowledge and background material is available

- people and authorities are aware of noise as an environmental danger and the necessity to avoid and control noise.

It is therefore necessary to

- include noise control in school curricula

- establish scientific institutes in universities and similar institutions, working on acoustics and noise control.

- give persons working in these institutes the possibility for studies in other countries and exchange of information at international conferences (e.g. Inter-noise)

- organize dissemination on knowledge in noise control

- organize information for the public

- gather all persons working in the field of acoustics and noise control in an advisory group to promote information, establish uniform methods of noise measurement and assessment and prepare legislative steps[1].

7. Strategies of noise abatement in different countries

In 1987 Organization for Economic and Co-operation and development (OECD) Environment Committee launched a project on noise abatement policies in member countries. The aim of the project was to solicit information on the effective implementation of such policies in solicited countries. The report "*Fighting the noise in the 1990s*" published by OECD, Paris, 1991, describes what has been done in six countries and an analyses and assessment of policies applied is given.

8. Recommended Actions

In summary the following actions are recommended:

1. **Limit noise emission of sources**
   - define sound level limits for road vehicles
   - execute these limits for new vehicles and vehicles in use
   - set and control limits for speed of vehicles in noise sensitive areas and times (night)
   - promote low-noise-vehicles (buses, trucks) by incentives
   - set and execute regulations prohibiting blowing of car horns
   - use low noise road surfaces
   - ensure maintenance of rails and vehicles for all railbound vehicles
   - promote low-noise-aircraft by setting noise related charges (landing fee related to noise emission of aircraft)
   - introduce noise labelling for machines, e.g. construction machines
   - set sound level limits for several classes of machines

2. **Town and country planning**
   - establish calculation rules to predict noise impact
   - establish noise maps or noise cadastres showing the existing noise situation
   - set sound level limits for various zones
   - calculate aircraft noise zones around airports as basis for planning

3. **Introduce examination of compliance with the environment including noise for all kinds of new works and installations**

4. **Establish noise control programmes for existing dwellings alongside existing highways, busy main roads and railway lines**

5. **Establish sound insulation requirements for facades of residential and other noise sensitive buildings**

---

1) *e.g. in Austria and Germany an "Arbeitsrinq fur Lärmbekämpfung" is working. Similar organizations work in several other countries; all are represented in Association International contre le Bruit.*

6. **Introduce noise control in school curricula and public information**

7. **Establish and promote scientific institutes to work in the field of acoustics and noise control**

8. **Promote advisory group on noise control.**

References:

(1) J. Lang: Gerauschemission von Lastkraftwagen und Personenkraftwagen auf Autobahnen unter tatsacheichen Einsatzbedingungen. ost.Zeitschrift f.Verkehrswissenschaft Heft 2/1990 Wien, Austria

(2) Fighting Noise: Strengthening Noise Abatement Policies. OECD Paris 1986

(3) VDI-Richtlinien "Emissionskennwerte technischer Schallquellen" Verein Deutscher Ingenieure, Dusseldorf, Germany

(4) ISO 3740, 3741, 3742, 3743, 3744, 3745, 3746, 3747. International Organization for Standardization, Geneva

International Standard ISO 1996/1

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Acoustics — Description and measurement of environmental noise — Part 1 : Basic quantities and procedures

Acoustique — Caractérisation et mesurage du bruit de l'environnement — Partie 1 : Grandeurs et méthodes fondamentales

First edition — 1982-09-15

UDC 534.61 Ref. No. ISO 1996/1-1982 (E)

Descriptors : acoustics, acoustic measurement, noise (sound), sound pressure, quantities, units of measurement.

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 1996/1 was developed by Technical Committee ISO/TC 43, *Acoustics*, and was circulated to the member bodies in November 1980.

It has been approved by the member bodies of the following countries :

Australia	Germany, F. R.	New Zealand
Austria	Greece	Norway
Belgium	Hungary	Romania
Canada	India	South Africa, Rep. of
China	Ireland	Spain
Czechoslovakia	Israel	Sweden
Denmark	Italy	Switzerland
Finland	Japan	United Kingdom
France	Netherlands	USSR

The member body of the following country expressed disapproval of the document on technical grounds :

USA

This International Standard cancels and replaces ISO Recommendation R 1996-1971, of which it constitutes a technical revision.

Acoustics — Description and measurement of environmental noise — Part 1 : Basic quantities and procedures

0 Introduction

This International Standard is the first in a series of documents replacing ISO Recommendation R 1996, *Acoustics — Assessment of noise with respect to community response*. The present list of parts of ISO 1996 is as follows :

Part 1 : Basic quantities and procedures;

Part 2 : Acquisition of data pertinent to land use;

Part 3 : Application to noise limits.

Extensive research concerning the way in which human beings are affected by noise from a single kind of source such as rail or road vehicles, aircraft or industrial plants, has led to a variety of measures for assessment of different kinds of noise, many of which are in common use. Conversion from one measure to another is often beset with serious uncertainty.

If an acoustical environment were always dominated by a single kind of noise, the confusion caused by the existence of different measures would not be so severe. But often environmental noise is a composite of the sounds from many sources, and the distribution of the different kinds of noise is likely to change from moment to moment. The methods and procedures described in this International Standard are intended to be applicable to sounds from all sources, individually and in combination, which contribute to the total noise at a site. At the present stage of technology this requirement seems to be best met by adopting the equivalent continuous A-weighted sound pressure level as a basic quantity. Results shall always be expressed in terms of this quantity even if supplemented by corrections or other descriptors that, in certain cases, may be deemed appropriate.

The aim of the ISO 1996 series is to provide authorities with material for the description of noise in community environments. Based on the principles described in this International Standard, acceptable limits of noise can be specified and compliance with these limits can be controlled.

This International Standard does not specify limits for environmental noise.

1 Scope and field of application

This part of ISO 1996 defines the basic quantities to be used for the description of noise in community environments and describes basic procedures for the determination of these quantities.

This International Standard forms the basis for further parts in the ISO 1996 series.

2 References

ISO 1999, *Acoustics — Determination of occupational noise exposure and estimation of noise-induced hearing impairment.*[1]

ISO 3891, *Acoustics — Procedure for describing aircraft noise heard on the ground.*

IEC Publication 651, *Sound level meters.*

IEC Publication ... , *Integrating-averaging sound level meters.*[2]

3 Definitions

For the purpose of this International Standard and other parts in the series the following definitions apply :

3.1 A-weighted sound pressure, in pascals : The root mean square sound pressure determined by use of frequency-weighting network "A" (see IEC Publication 651).

3.2 sound pressure level, in decibels : The sound pressure level is given by the formula

$$L_p = 10 \lg \left(\frac{p}{p_0}\right)^2$$

where

p is the root mean square sound pressure, in pascals;

p_0 is the reference sound pressure (20 µPa).

1) At present at the stage of draft. (Revision of ISO 1999-1975.)

2) At present at the stage of draft.

3.3 A-weighted sound pressure level, in decibels : Sound pressure level of A-weighted sound pressure is given by the formula

$$L_{pA} = 10 \lg \left(\frac{p_A}{p_0} \right)^2$$

3.4 percentile level : The A-weighted sound pressure level obtained by using time-weighting "F" (see IEC Publication 651) that is exceeded for N % of the time interval considered. Symbol : $L_{AN,T}$; for example $L_{A95,1h}$ is the A-weighted level exceeded for 95 % of 1 h.

NOTE — Percentile levels as determined over a certain time interval cannot generally be extrapolated to other time intervals.

3.5 equivalent continuous A-weighted sound pressure level, in decibels : Value of the A-weighted sound pressure level of a continuous, steady sound that, within a specified time interval T, has the same mean square sound pressure as a sound under consideration whose level varies with time. It is given by the formula

$$L_{Aeq,T} = 10 \lg \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_0^2} \, dt \right]$$

where

$L_{Aeq,T}$ is the equivalent continuous A-weighted sound pressure level, in decibels, determined over a time interval T starting at t_1 and ending at t_2;

p_0 is the reference sound pressure (20 µPa);

$p_A(t)$ is the instantaneous A-weighted sound pressure of the sound signal.

NOTES

1 Equivalent continuous A-weighted sound pressure level during time interval T is also called time interval average sound level, $L_{A,T}$, in decibels, with the averaging time interval usually indicated in the format, for example, one-hour average sound level, $L_{A,1h}$.

2 Equivalent continuous A-weighted sound pressure level is also used for assessment of occupational noise exposure (see ISO 1999).

3.6 sound exposure level, in decibels : The sound exposure level of a discrete noise event is given by the formula

$$L_{AE} = 10 \lg \frac{1}{t_0} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_0^2} \, dt$$

where

$p_A(t)$ is the instantaneous A-weighted sound pressure;

$t_2 - t_1$ is a stated time interval long enough to encompass all significant sound of a stated event;

p_0 is the reference sound pressure (20 µPa);

t_0 is the reference duration (1 s).

NOTE — L_{AE} is given in ISO 3891 as L_{AX} (single-event exposure level).

3.7 measurement time interval : That time interval over which the squared A-weighted sound pressure is integrated and averaged.

3.8 reference time interval : The time interval to which an equivalent continuous A-weighted sound pressure level can be referred. It may be specified in national or international standards or by local authorities to cover typical human activities and variations in the operation of sound sources.

3.9 long-term time interval : A specified time interval for which the results of the noise measurement are representative. The long term time interval consists of a series of reference time intervals and is determined for the purpose of describing the environmental noise and is generally designated by competent authorities.

3.10 long term average sound level : The average over the long term time interval of the equivalent continuous A-weighted sound pressure levels for a series of reference time intervals comprised within the long term time interval. Averaging is to be carried out as described in ISO 1996/2.

3.11 rating level : The equivalent continuous A-weighted sound pressure level during a specified time interval, plus specified adjustments for tonal character and impulsiveness of the sound.

3.12 long term average rating level : The average over the long term time interval of the rating levels for a series of reference time intervals. Averaging is to be carried out as described in ISO 1996/2.

3.13 categories of noise :

3.13.1 ambient noise : Totally encompassing sound in a given situation at a given time usually being composed of sound from many sources near and far.

3.13.2 specific noise : A component of the ambient noise which can be specifically identified by acoustical means and may be associated with a specific source.

NOTE — The ambient noise remaining at a given position in a given situation when one or more specified noises are suppressed is sometimes called the residual noise.

3.13.3 initial noise : The ambient noise prevailing in an area before any modification of the existing situation.

3.14 symbols : Symbols for sound levels are given in the table.

Table — Symbols for sound levels

Quantity	Symbol	Unit	Remarks
Sound pressure level	L_p	dB	
A-weighted sound pressure level	L_{pA}	dB	
Percentile level	$L_{AN,T}$	dB	Level exceeded for N % of time interval T
Sound exposure level	L_{AE}	dB	For noise events
Equivalent continuous A-weighted sound pressure level	$L_{Aeq,T}$	dB	Time interval shall be stated
Long term average sound level	$L_{Aeq,LT}$	dB	Time interval shall be stated
Rating level	$L_{Ar,T}$	dB	Time interval shall be stated
Long term average rating level	$L_{Ar,LT}$	dB	Time interval shall be stated

4 Instrumentation

4.1 General

The instrumentation system shall be designed to determine equivalent continuous A-weighted sound pressure level, either directly or indirectly, and either in direct accordance with the definition in 3.5 or by some approximative process. The instrumentation shall comply with the specifications for sound level meters preferably of type 1 but at least of type 2 as given in IEC Publication 651. Integrating averaging sound level meters shall be of category P as specified in IEC Publication ... Alternative instrumentation, if used, shall provide equivalent performance in respect of frequency and time weightings and tolerances.

The instrumentation may comprise

a) integrating-averaging sound level meter set to frequency-weighting "A";

b) sound exposure level meter for measurements of sound exposure level of discrete events;

c) sound level meter set to frequency-weighting "A" and time-weighting "S";

d) data logger for sampling the running value of A-weighted sound pressure level using time-weighting "F";

e) statistical distribution analyser for sampling the running value as in d).

The instrumentation described in d) and e) could also be used to obtain values of percentile levels.

NOTES

1 Instrumentation of types a) and b) is preferred and will generally be used for noise of impulsive, fluctuating or cyclic character. Special care should be taken to ensure that the dynamic range is large enough and that the inherent electrical noise and overload capacity of these instruments are suitable for the applications.

2 When using instrumentation described in e) the class interval should be chosen in relation to the overall range of sound pressure levels but should not exceed 5 dB.

Ways of determining the equivalent continuous A-weighted sound pressure level using the various kinds of equipment are described in 5.4.

4.2 Calibration

All equipment shall be calibrated and the configuration for calibration shall be in accordance with the manufacturer's instructions.

A comprehensive recalibration at certain time intervals (for example, annually) may be prescribed by authorities responsible for the use of the measurement results.

A field check shall be made by the user at least before and after each series of measurements, preferably including an acoustic check of the microphone.

5 Measurements

5.1 General

The results of the measurements described in this International Standard may be used for the purposes described in detail in the relevant International Standards. It is important that pertinent details of the measurement instrumentation, measurement procedure and conditions prevailing during the measurements are carefully recorded and kept for reference purposes. Reference to the pertinent International Standards shall also be given.

NOTES

1 When the measured signals are recorded on magnetic tape for control and reference purposes it should be borne in mind that even with studio-quality (non-digital) recorders the dynamic range may fall short of that necessary when instrumentation of the types mentioned in 4.1 a) and b) is used.

2 In some circumstances the frequency-weighting network "A" is inadequate for filtering out high level infrasound which occurs near some industrial locations and some forms of transport as well as near buildings due to wind turbulence. This may cause overload and, if not detected, distortion produced at higher frequencies may be inaccurately attributed to audible sound.

5.2 Measurement positions

The choice of the actual measurement positions depends on the purpose of the measurements as specified in the pertinent International Standard.

5.2.1 Outdoor measurements

When it is desired to minimize the influence of reflections then measurements should, whenever possible, be carried out at least 3,5 m from any reflecting structure other than the ground. When not otherwise specified, the preferred measurement height is 1,2 to 1,5 m above the ground. Other measurement heights may be specified in pertinent standards.

5.2.2 Outdoor measurements near buildings

These measurements shall be carried out at places where the noise to which a building is exposed is of interest. If not otherwise specified, the preferred measurement positions are 1 to 2 m from the façade and 1,2 to 1,5 m above each floor level of interest.

5.2.3 Measurements inside buildings

These measurements shall be carried out in enclosures where the noise is of interest. If not otherwise specified, the preferred measurement positions are at least 1 m from the walls or other major reflecting surfaces, 1,2 to 1,5 m above the floor and about 1,5 m from windows.

5.3 Meteorological effects

Sound levels are affected by meteorological conditions, especially when the transmission distance is large. Where levels are likely to be affected by meteorological conditions they should be measured in one of the two ways described below.

5.3.1 Measurements averaged over a range of meteorological conditions

The measurement time intervals are chosen in such a way that the long term average sound level is determined over the range of meteorological conditions found at the measurement position(s).

5.3.2 Measurements made under specific meteorological conditions

The measurement time intervals are chosen so that measurements are taken only under carefully specified meteorological conditions. Normally, the conditions chosen are those which result in the most stable sound propagation, that is, with a significant positive wind component from source to measurement position(s).

NOTE — In some cases it may be possible to determine a sound pressure level equivalent to that obtained under the conditions of 5.3.1 by applying a correction to the values obtained by using the method of 5.3.2.

5.4 Recommended procedures for the determination of equivalent continuous A-weighted sound pressure level

5.4.1 General recommended procedures

The environmental noise descriptors defined in this International Standard may be used for a variety of purposes; the wide range of circumstances makes it extremely difficult to specify in detail procedures for any particular case. Procedures for certain specific cases will be described in the relevant International Standards. Four cases can be distinguished for which different instrumentation is best suited, see 4.1. These cases are described in 5.4.2 to 5.4.5.

NOTE — The use of integrating-averaging instrumentation described in 4.1 a) and b) will yield correct results for all types of noise. For the simpler cases of 5.4.3 and 5.4.4 the sound level meter may be used; for the cases of 5.4.2 and 5.4.5 approximate results may be obtained by sampling methods using the equipment described in 4.1 d) and e).

5.4.2 Fluctuating noise

For general use, and especially if the noise is fluctuating, the preferred instrument is the integrating-averaging sound level meter or the sound exposure level meter in which case the associated measurement time intervals shall be recorded. Alternatively, sampling or statistical distribution analysis can be used.

5.4.2.1 Sampling of the sound pressure level at a sampling rate $1/\Delta t$, over the time interval $t_2 - t_1$

The A-weighted equivalent continuous sound pressure level, $L_{\mathrm{Aeq},T}$, is derived using the formula

$$L_{\mathrm{Aeq},T} = 10 \lg \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1\, L_{pAi}} \right]$$

where

N is the total number of samples $\left(N = \dfrac{t_2 - t_1}{\Delta t} \right)$;

L_{pAi} is the sampled values of the pressure level, in decibels;

Δt is the time interval between two adjacent samples taken by the instrument.

The sampling period may greatly influence the accuracy of the result if not conveniently matched to the approximate time constant of the integration giving the sound pressure level. A sampling period less than the time constant of the complete instrumentation will generally give a good approximation to the results obtained with a true integration.

5.4.2.2 Use of statistical distribution by observing the readings of the A-weighted sound pressure level at intervals of time by a sampling technique

Class intervals for the sound pressure levels should be chosen according to the character of the noise; in most cases an interval of 5 dB will be appropriate.

The A-weighted equivalent continuous sound pressure level, $L_{\mathrm{Aeq},T}$, is derived using the formula

$$L_{\mathrm{Aeq},T} = 10 \lg \left[\frac{1}{100} \sum_{i=1}^{n} f_i\, 10^{0,1\, L_i} \right]$$

where

n is the number of classes;

f_i is that percentage of the time interval for which the A-weighted sound pressure level is within the limits of class i;

L_i is the A-weighted sound pressure level corresponding to the class-midpoint of class i, in decibels.

5.4.3 Steady noise

If the noise is steady over the period of interest the measurements may be carried out with a sound level meter complying with IEC Publication 651, type 1 or 2. The frequency-weighting network "A" and the time-weighting "S" should be used.

The reading is taken as the average meter deflection. If the meter reading fluctuates over a range of more than 5 dB, then the noise cannot be considered steady.

5.4.4 Steady noise with stepwise variations of level

If the noise is steady but occurs at a number of clearly distinguishable values of sound pressure levels, then the separate levels can be measured as for steady noise and the durations associated with each level can be determined, thus permitting the calculation of the equivalent continuous A-weighted sound pressure level, in decibels, by the formula

$$L_{\text{Aeq},T} = 10 \lg \left[\frac{1}{T} \sum T_i \, 10^{0,1 \, L_{pAi}} \right]$$

where

$T = \sum T_i$ is the total time interval;

L_{pAi} is the A-weighted sound pressure level prevailing during the time interval T_i.

5.4.5 Separate noise events

When a noise environment is the result of a number of identifiable noise events, the equivalent continuous A-weighted sound pressure level, in decibels, may be calculated from the sound exposure levels of the individual events occurring within a time period T:

$$L_{\text{Aeq},T} = 10 \lg \left[\frac{t_0}{T} \sum_{i=1}^{n} 10^{0,1 \, L_{\text{AE}i}} \right]$$

where

$L_{\text{AE}i}$ is the sound exposure level of the i'th event in a series of n events in time period T, in seconds;

$t_0 = 1$ s.

If the noise consists of a succession of similar discrete events (that is, having equal values of sound exposure level) it may be measured by any of the methods given in 5.4.2 over an integer number of complete cycles of the noise.

Alternatively, the sound exposure level of a cycle of the noise, L_{AE}, may first be measured by means of a sound exposure level meter, see 4.1 b), and the reading then converted to equivalent continuous A-weighted sound pressure level, in decibels, by the formula

$$L_{\text{Aeq},T} = L_{\text{AE}} + 10 \lg n - 10 \lg \left(\frac{T}{t_0} \right)$$

where

n is the number of cycles occurring in the time interval T;

$t_0 = 1$ s.

5.5 Adjustments

The measurements described in this International Standard are designed to give a reliable physical description of the environmental noise. For assessment of human reactions to noise it is sometimes necessary to make adjustments to the measured values in order to arrive at a more meaningful basis for the assessment. When such adjustments are made to a value of equivalent continuous A-weighted sound pressure level it is termed rating level, $L_{\text{Ar},T}$.

6 Information to be recorded

In addition to the results of the acoustic measurements the information in 6.1 shall be recorded and kept for reference purposes. The information in 6.2 and 6.3 should also be recorded, if relevant.

6.1 Measurement technique

a) Type of instrumentation, measurement procedure and any calculation employed.

b) Description of the time aspect of the measurements, i.e., the reference and measurement time intervals, including details of sampling, if used.

c) Positions of measurements.

6.2 Conditions prevailing during measurements

a) Atmospheric conditions : direction and speed of wind; rain; temperature at ground level and other levels; atmospheric pressure; relative humidity.

b) Nature and state of the ground between noise source(s) and measurement position(s).

c) Variability of emission of noise sources.

6.3 Qualitative data

Data such as the following may be significant for the interpretation of the results :

a) Possibility of locating the origin of the noise.

b) Possibility of identification of the sound source.

c) Nature of the sound source.

d) Character of the sound.

e) Connotation of the sound.

INTERNATIONAL STANDARD

ISO 1996-2

First edition
1987-04-15

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Acoustics — Description and measurement of environmental noise —

Part 2 : Acquisition of data pertinent to land use

Acoustique — Caractérisation et mesurage du bruit de l'environnement —

Partie 2 : Saisie des données pertinentes pour l'utilisation des sols

Reference number
ISO 1996-2 : 1987 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 1996-2 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

ISO 1996-2 together with ISO 1996-1 : 1982 and ISO 1996-3 : 1987 cancel and replace ISO Recommendation R 1996 : 1971, of which they constitute a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Printed in Switzerland

Acoustics — Description and measurement of environmental noise —

Part 2 : Acquisition of data pertinent to land use

0 Introduction

0.1 ISO 1996 comprises the following three parts :

Part 1 : Basic quantities and procedures.

Part 2 : Acquisition of data pertinent to land use.

Part 3 : Application to noise limits.

0.2 This part of ISO 1996 describes methods to be used for measuring and describing environmental noise relevant to general land use.

The use of different measuring methods, such as continuous integration, sampling techniques and measurements under selected meteorological conditions, is considered. Calculation methods or scale model investigations may also be used.

This part of ISO 1996 does not deal in detail with calculation methods. If, however, such methods are used to obtain data pertinent to land use, it is important that the noise be described in a way that is consistent with the requirements of this part of ISO 1996.

The purpose of this part of ISO 1996 is to provide methods for the acquisition of data for describing environmental noise. Using these data as a basis, authorities may establish a system for selecting the appropriate land use, as far as levels of noise are concerned, for a specified area, or the sources of noise — existing or planned — which are acceptable with respect to land use, existing or planned.

This part of ISO 1996 does not give guidance on the estimation of the overall uncertainty of the results, but this should be considered in each specific case, if possible.

It does not specify noise limits.

1 Scope and field of application

This part of ISO 1996 describes methods for the acquisition of data which provide descriptors that enable

a) a description of the environmental noise in a specified area of land to be made in a uniform way;

b) the compatibility of any land use activity or projected activity to be assessed with respect to existing or predicted noise.

2 References

ISO 1996-1, *Acoustics — Description and measurement of environmental noise — Part 1 : Basic quantities and procedures.* [1]

IEC Publication 651, *Sound level meters.*

IEC Publication 804, *Integrating-averaging sound level meters.*

3 Definitions

For the purposes of this part of ISO 1996, the definitions given in ISO 1996-1 together with the following definitions apply.

3.1 land use : An existing or intended use of a delineated area of land.

3.2 noise zone : Region where the long-term average rating level lies between two specified levels such as, for example between 65 and 70 dB. The noise zone number for this example is 65-70 dB.

3.3 receiver : Person or group of persons who are or who are expected to be exposed to environmental noise.

4 Acquisition of data

For the purpose of acquisition of data relevant to land use, the following basic information is required :

a) geographical description of the area under consideration;

1) Cross-references to specific clauses, sub-clauses, etc. in ISO 1996-1 apply to the first edition published in 1982.

b) description of the main characteristics of the sources of noise pertinent to this area;

c) description of the situation of the receiver, such as location, occupation, use and features of the immediate surroundings.

NOTE — If possible, information on prevailing meteorological conditions in the area under consideration should be given, preferably as statistical information on wind speed and direction, on precipitation and temperature (including the occurrence of temperature inversions) for a typical time interval, such as a year or any other suitable time interval.

4.1 Acoustical data

4.1.1 General

Basic acoustical data are equivalent continuous A-weighted sound pressure levels determined over the reference time intervals and rating levels for the same reference time intervals with additional information on the characteristics of the noise, if required.

4.1.2 Rating level

The rating level shall be determined over reference time intervals related to the characteristics of the source(s) and receiver(s).

The rating level, $(L_{\mathrm{Ar},T})_i$, for each reference time interval, is given by the formula

$$(L_{\mathrm{Ar},T})_i = (L_{\mathrm{Aeq},T})_i + K_{1i} + K_{2i}$$

where

$(L_{\mathrm{Aeq},T})_i$ is the equivalent continuous A-weighted sound pressure level during the ith reference time interval;

K_{1i} is a tone adjustment applicable to the ith reference time interval;

K_{2i} is an impulse adjustment applicable to the ith reference time interval.

NOTE — If the tone or impulse characteristics are present for only a part of the reference time interval, the values of K_1 and K_2 may be adjusted to take account of the duration.

4.1.3 Tone adjustment, K_1

If tonal components are essential characteristics of the sound within a specified time interval, an adjustment may be applied, for that time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated.

NOTE — In some practical cases, a prominent tonal component may be detected in one-third octave spectra if the level of a one-third octave band exceeds the level of the adjacent bands by 5 dB or more, but a narrow-band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal. If tonal components are clearly audible and their presence can be detected by a one-third octave analysis, the adjustment may be 5 to 6 dB. If the components are only just detectable by the observer and demonstrated by narrow-band analysis, an adjustment of 2 to 3 dB may be appropriate.

4.1.4 Impulse adjustment, K_2

If impulse is an essential characteristic of the sound within a specified time interval, an adjustment may be applied, for this time interval, to the measured equivalent continuous A-weighted sound pressure level. The value of this adjustment shall be stated.

NOTES

1 A method of describing the impulse characteristic of the sound within the specified time interval is to measure the difference between the A-weighted sound pressure level, determined with time-weighting characteristic I averaged over the same time interval, and $L_{\mathrm{Aeq},T}$. The sound pressure levels should be determined simultaneously. The character of the noise may be further illustrated by determining the peak level and the number of impulses during a specified time interval.

2 For large-amplitude noise, such as the noise generated by sonic booms, mining or quarry blasts, measurements with C-weighting are used in some countries to determine the rating level.

4.2 Meteorological adjustment

To extrapolate from a value of the equivalent continuous A-weighted sound pressure level measured under selected meteorological conditions to a long-term value, a meteorological adjustment may be used (see 5.3 in ISO 1996-1).

4.3 Long-term average sound level

The long-term average sound level, $L_{\mathrm{Aeq},LT}$, in decibels, for a given reference time interval, is given by the following formula :

$$L_{\mathrm{Aeq},LT} = 10 \lg \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1\,(L_{\mathrm{Aeq},T})_i} \right]$$

where

N is the number of samples of the reference time interval;

$(L_{\mathrm{Aeq},T})_i$ is the equivalent continuous A-weighted sound pressure level in the ith sample, in decibels.

4.4 Long-term average rating level

The long-term average rating level, $L_{\mathrm{Ar},LT}$, in decibels, for a given reference time interval, is given by the following formula :

$$L_{\mathrm{Ar},LT} = 10 \lg \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1\,(L_{\mathrm{Ar},T})_i} \right]$$

where

N is the number of samples of the reference time interval;

$(L_{\mathrm{Ar},T})_i$ is the rating level in the ith sample, in decibels.

4.5 Percentile level

In some cases, it may be desirable to describe a noise situation by the use of both the equivalent continuous A-weighted sound pressure level and the distribution of A-weighted sound pressure levels. For this purpose, percentile levels such as L_{95}, L_{50} and L_5 may be determined.

5 Determination of long-term average sound level and long-term average rating level

5.1 General

In general, these quantities are determined from measurements and/or calculations. The results shall be representative of the sound pressure level at a specified location. The measurement technique used, for example the instrumentation, the number of microphone positions, the number and duration of measurement time intervals, depends on the nature of the sound sources and the receivers, and on the significance of the results for land use.

Results that include contributions from exceptional sounds that are not typical for the noise received at a specified location shall be stated separately, if necessary.

5.2 Instrumentation

See clause 4 in ISO 1996-1.

The instrument used shall comply with the specifications for sound level meters, preferably of type 1, but at least of type 2, given in IEC Publication 651. Integrating-averaging sound level meters shall be as specified in IEC Publication 804.

If a recording device (e.g. a tape recorder, digital recorder, etc.) is used, its effect on the accuracy of the measurements shall be taken into account.

5.3 Location and number of measurement positions

5.3.1 General

The measurement of equivalent continuous A-weighted sound pressure levels shall be carried out at those outdoor locations that are appropriate for the acoustical description of the environment under consideration. The measurement positions shall be indicated on a map.

The location and number of measurement positions will depend on the required spatial resolution for the environment under consideration.

The measurement positions may be

a) chosen at approximately equally spaced positions over the area under consideration (e.g. at the intersections of grid lines on the map) — contours of equal levels of noise can be drawn by interpolation between the points;

b) representative of the average level of a specified zone or area (e.g. taking into account local shielding effects, topographical features, etc.);

c) at locations which characterize the noise which results from emissions by various sources that can be identified in the area under consideration; this allows noise to be determined at other locations in the area by means of calculations based on the propagation of sound.

5.3.2 Microphone position

The height of the microphone shall be chosen according to the actual or expected height of the receiver. In potentially built-up areas, the preferred measurement height shall be 3 to 11 m. In all other cases, see 5.2.1 in ISO 1996-1.

NOTE — By choosing the greater measurement height, the influence of ground effects and low barriers is reduced and the reproducibility is improved, but the measured level will generally be higher than that measured close to the ground.

In the case of outdoor measurements near buildings, measurements shall be carried out at locations where the noise to which a building is exposed is of interest. Unless otherwise specified, the preferred measurement positions are 1 to 2 m from the façade, and 1,2 to 1,5 m above each floor level of interest.

If it is desired to minimize the influence of reflections, measurements should, whenever possible, be made at least 3,5 m away from any reflecting structure or 0,5 m in front of an open window.

NOTE — If measurements are made 1 to 2 m in front of the facade of a building and the noise spectrum is of broad-band type with no dominating narrow band or pure tone, an approximation to the incident sound pressure level may be obtained by subtracting 3 dB from the measured value. If measurements are made in the plane of the facade at least 3,5 m from the edge of the facade, no corrections need be made. To characterize the effects of the walls of a proposed building, the addition of 3 dB to the free-field values may be useful in order to determine the sound pressure level near the walls.

The heights of the microphones shall be stated in the test report.

The microphone should be orientated to be most uniformly sensitive to the incident sound.

5.3.3 Location of grid points in an area

The density of grid points in an area depends on the spatial resolution required for the study concerned and the spatial variation of sound pressure levels of the noise. This variation is strongest in the vicinity of sources and large obstacles. The density of grid points should, therefore, be higher in these places. In general, the difference in sound pressure levels between adjacent grid points should not be greater than 5 dB. If significantly higher differences are encountered, intermediate grid points shall be used.

5.3.4 Location(s) representative of an area

If spatial variations of the sound pressure level are small, or only a small area is under consideration, location(s) may be selected such that measurements will be representative for the whole area. A preliminary survey may be useful to identify such locations).

5.3.5 Locations used for the description of sources

If it is desired to evaluate the contributions of various sound sources individually or as a class, measurement positions should usually be chosen in the vicinity of each of the sources in order to reduce the influence of the others.

The sound pressure level of the noise at the other positions can be estimated by interpolation and extrapolation, taking due account of attenuation as a result of the geometrical spreading of the sound, atmospheric absorption, ground effects, screening effects, etc.

NOTE — The number of measurement positions can be reduced when interpolation is possible by means of a suitable propagation model which permits the calculation of sound pressure levels at intermediate positions.

5.4 Selection of time intervals

5.4.1 Reference time interval

For the selection of appropriate reference and measurement time intervals, it may be necessary to investigate the noise situation over relatively long time periods during which survey measurements may be taken.

Reference time intervals shall be specified to cover typical human activities and variations in the operation of the source, e.g. density of traffic and working hours for industrial plants.

In relation to human activities, one reference time interval may be chosen for the day and another for the night. Reference time intervals for evenings, for weekends and for holidays may also be established.

When different human activities take place in a single reference time interval, an adjustment to the levels, as a function of the time at which these activities take place, may be introduced when determining the rating level for that reference time interval. Any such adjustments and the time intervals to which they were applied shall be recorded in the test report.

5.4.2 Long-term time interval

For the purpose of land use, it is the responsibility of the cognizant authority also to specify the long-term time interval. The choice of the long-term time interval is related to the noise control objective, the nature and activity of the receiver, the operation of the sources and variations in propagation conditions.

NOTE — The long-term time interval should be chosen so that long-term variations in noise emission are covered. It will frequently be of the order of several months. If the noise situation considered is restricted to a well defined part of the year, for example summertime with special activities, the long-term time interval may be restricted to that part of the year.

5.4.3 Measurement time intervals

5.4.3.1 Measurement time intervals shall be chosen so that all significant variations of noise emission and transmission are covered. Furthermore, the choice of the measurement time intervals shall be such that the long-term average sound level or rating level is determined with the desired accuracy.

5.4.3.2 If the noise displays a clear periodicity, the measurement time intervals shall cover at least one period. If continuous measurements over this period cannot be made, measurement time intervals shall be chosen so that each represents a part of the cycle and so that, together, they represent the complete cycle.

If the sound pressure level varies stepwise, the measurement time intervals shall be selected so that each represents a period within which the noise level may be considered to be approximately steady.

If the noise varies at random, measurement time intervals shall be chosen so as to give sufficient independent samples to give a significant estimation of the long-term average sound level.

If the noise is of the fly-over or pass-by type (i.e. the noise varies during the fly-over and is absent during a considerable portion of the reference time interval), measurement time intervals shall be chosen so that the sound exposure level, L_{AE}, of the fly-over or pass-by can be determined.

5.4.3.3 To facilitate the comparison of results, it may be convenient to carry out measurements under selected meteorological conditions which are reproducible and correspond to quite stable sound propagation conditions. In particular, when there is one dominant source, it may be convenient to choose meteorological conditions which correspond to enhanced propagation from the source to the receiver and/or to the specified area and to adopt measurement time intervals corresponding to the following conditions :

- wind direction within an angle of ± 45° of the direction connecting the centre of the dominant sound source and the centre of the specified area, with the wind blowing from the source to the receiver;
- wind speed between 1 and 5 m/s, measured at a height of 3 to 11 m above the ground;
- no strong temperature inversions near the ground;
- no heavy precipitation.

NOTES

1 It should always be ascertained that the wind noise at the microphone does not interfere with the measurements.

2 There will be systematic differences between the results of measurements under selected meteorological conditions and those obtained under random meteorological conditions. Compensation can be made for these systematic differences by the use of a meteorological adjustment of the rating level.

5.5 Acquisition of acoustical data

5.5.1 General

The acoustical data are acquired during the measurement time interval. Two methods can be used to acquire the data (see 5.5.2 and 5.5.3).

5.5.2 Continuous integration

In this method, the measurement time interval covers the whole reference time interval except for time intervals where the measurement conditions could lead to erroneous results, e.g. in periods of strong wind, heavy rain, or contributions of non-typical noise.

NOTE — This method gives the maximum accuracy, but the gain in accuracy compared with that obtained with sampling techniques cannot always be justified in relation to the increase in the overall measurement efforts.

5.5.3 Sampling techniques

The long-term values of the equivalent continuous A-weighted sound pressure level and the rating level are calculated from samples of measurement time intervals within the reference time interval.

In this case, the total measurement time interval will only be a fraction of the reference time interval and will consist of a number of distinct time intervals separated by intervals where no measurement is performed.

5.6 Long-term average sound level and long-term average rating level

From the results obtained according to 5.2 to 5.5, the long-term average sound level can be calculated as specified in 4.3 and the long-term average rating level can be calculated as specified in 4.4.

6 Prediction of noise levels

In many cases, the purpose of describing environmental noise is to predict the noise arising from planned, but non-existent, installations, such as industrial plants, and facilities for road, air and rail traffic.

In such situations, the problems should be approached through the use of suitable methods of calculation or by scale model investigations.

As universally agreed prediction models do not exist, the method adopted should be carefully described in each case.

NOTE — When available, prediction models accepted by relevant authorities should be used.

7 Noise zones, representation of results

In addition to reporting the results of measurements of existing environmental noise and the results of calculations of noise from projected activities, a presentation in terms of noise zones may be useful. It is recommended that contours indicating boundaries between zones in multiples of 5 dB be used. Reference to zones should be made by quoting the upper and lower noise limits, in decibels.

If the different zones are identified on a map of the area under consideration by means of colours or hatching, it is recommended that the combination of colours (or hatching) and classes specified in table 1 be used.

NOTE — In some cases, it may be sufficient to use a zone width of 10 dB. In such cases, colours (or hatching) as specified in table 2 should be used.

Table 1

Noise zone dB	Colour	Hatching
Below 35	Light green	Small points, low density
35 to 40	Green	Medium points, medium density
40 to 45	Dark green	Big points, high density
45 to 50	Yellow	Vertical lines, low density
50 to 55	Ochre	Vertical lines, medium density
55 to 60	Orange	Vertical lines, high density
60 to 65	Cinnabar	Cross-hatching, low density
65 to 70	Carmine	Cross-hatching, medium density
70 to 75	Lilac red	Cross-hatching, high density
75 to 80	Blue	Broad vertical stripes
80 to 85	Dark blue	Completely black

Table 2

Noise zone dB	Colour	Hatching
Below 45	Green	Medium points, medium density
45 to 55	Yellow	Vertical lines, low density
55 to 65	Orange	Vertical lines, high density
65 to 75	Red	Cross-hatching, medium density
75 to 85	Blue	Broad vertical stripes

The details and scale of the map depend on

— the size, structure and use of the area considered;

— the object of planning (large-scale decision on location for new sources and new receivers, change in land use, final decision on the location for new receivers);

— stage of the planning procedure.

The noise map shall be established on an official map, of a given scale, displaying relevant details of buildings, traffic installations, industrial areas, agricultural areas, vegetation and contours of height above sea level.

The mapping shall be performed either by displaying the areas of equal noise zones or by drawing their contours or by a combination of area contours.

The map should show the locations where data were measured (O) or calculated (X).

8 Information to be recorded

8.1 Measurement technique

The following information shall be recorded :

a) the type of instrumentation, measurement procedure and any calculation used;

b) a description of the time aspect of the measurements, i.e. the reference and measurement time intervals, including details of sampling, if used;

c) measurement positions.

8.2 Conditions prevailing during measurements

The following information shall be recorded :

a) meteorological conditions described by two sets of data :

1) qualitative data, such as rainy, drizzly, dry, wet, cloudy, sunny, etc.,

2) quantitative data, such as

— the direction and speed of the wind, measured in such a way that the data are representative of the sound propagation from the source to the receiver during the measurement time interval; unless otherwise specified, these measurements should be made outdoors in the open country at a height between 3 and 11 m above the ground,

— thermal gradient, if required, measured between 1 and 11 m above the ground,

— relative humidity;

b) the nature and state of the ground between noise source(s) and measurement position(s);

c) the variability of emission of noise sources.

8.3 Qualitative data

The following information shall be recorded :

a) the purpose of the measurements and/or calculations;

b) a description of the sound source(s);

c) a description of the receiver(s);

d) the characteristics of the sound;

e) the connotation of the sound;

f) for an area or zone :

— the noise zones and the noise map, if required,

— where applicable, interpolation or extrapolation to other positions, including a description of the sound propagation model used;

g) geographical parameters of the area or location;

h) the land use (existing and planned).

8.4 Quantitative data

The following information shall be recorded :

a) the equivalent continuous A-weighted sound pressu levels for each reference time interval;

b) the rating levels for each reference time interval;

c) the long-term average sound level and, if possible, an estimate of the variability, preferably the standard deviation of the measurements over the reference time intervals for the stated conditions together with the number of measurements, the formula and the quantity used;

d) the long-term average rating level and, if possible, an estimate of the variability, preferably the standard deviation over the reference time intervals for the stated conditions together with the number of measurements, the formula and the quantity used.

9 Information to be reported

The test report shall contain relevant data from clause 8 together with a reference to this part of ISO 1996 (i.e. ISO 1996-2).

A report on prediction of levels should also include the following information :

a) a description of the sound propagation model used or facilities for measurements on scale models;

b) locations and features characterizing the noise emitted by the source, e.g. traffic intensity and characteristics, sound power level, frequency spectrum;

c) the sound attenuation and reflections by the walls of buildings and barriers;

d) the sound absorption in the air;

e) conditions of sound propagation (absorption by the ground, trees or shrubs, buildings, etc.);

f) meteorological conditions adopted;

g) location(s) of receiver(s);

h) position(s) and sound power level(s) of the source(s) considered.

UDC 534.61

Descriptors : acoustics, acoustic measurements, noise (sound).

Price based on 7 pages

INTERNATIONAL STANDARD

ISO 1996-3

First edition
1987-12-15

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Acoustics — Description and measurement of environmental noise —

Part 3 :
Application to noise limits

Acoustique — Caractérisation et mesurage du bruit de l'environnement —

Partie 3 : Application aux limites de bruit

Reference number
ISO 1996-3 : 1987 (E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 1996-3 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

ISO 1996-3 together with ISO 1996-1 : 1982 and ISO 1996-2 : 1987 cancel and replace ISO Recommendation R 1996 : 1971, of which they constitute a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Acoustics — Description and measurement of environmental noise —

Part 3 : Application to noise limits

0 Introduction

0.1 ISO 1996 comprises the following three parts :

Part 1 : Basic quantities and procedures.

Part 2 : Acquisition of data pertinent to land use.

Part 3 : Application to noise limits.

0.2 This part of ISO 1996 lays down guidelines for the ways in which noise limits should be specified and describes procedures to be used for checking compliance with such limits. It is assumed that noise limits are established by local authorities according to these guidelines and are embodied in noise limit regulations to which reference is made.

For certain types of sources of noise, more detailed procedures may be used, for example those specified in ISO 3891 for aircraft noise. ISO 3891 is consistent with the requirements of ISO 1996.

This part of ISO 1996 does not specify noise limits.

Reference should be made to ISO 1999 for situations where noise may cause hearing impairment.

1 Scope and field of application

This part of ISO 1996 lays down guidelines for the specification of noise limits and describes methods for the acquisition of data that enable specific noise situations to be checked for compliance with specified noise limits.

2 References

ISO 1996-1, *Acoustics — Description and measurement of environmental noise — Part 1 : Basic quantities and procedures.*

ISO 1996-2, *Acoustics — Description and measurement of environmental noise — Part 2 : Acquisition of data pertinent to land use.*

IEC Publication 651, *Sound level meters.*

IEC Publication 804, *Integrating-averaging sound level meters.*

3 Definitions

For the purposes of this part of ISO 1996, the definitions given in ISO 1996-1 apply.

4 Specification of noise limit requirements

4.1 General

Noise limits are specified in terms of equivalent continuous A-weighted sound pressure levels or rating levels during time intervals and at locations appropriate to specific noise sources and conditions.

Noise limits may be set by national or local authorities on the basis of general considerations of compatibility with human activities and land use, taking into account the results of survey measurements, if available. Such limits may depend on many factors such as the time of day, the activities to be protected, the type of noise source, and climatic, social and economic factors.

Noise limit regulations have to comprise a number of basic elements which, in combination, define uniquely the circumstances under which compliance with the regulations can be verified. These elements are as follows :

a) noise descriptor;

b) relevant time intervals;

c) the sources and their conditions of operation, where appropriate;

d) locations where the noise limits have to be verified;

e) meteorological conditions, where appropriate;

f) criteria for assessment of compliance with the limits.

These elements are described in more detail in 4.2.

NOTE — For control and enforcement purposes, it may be appropriate to specify limits for emission by individual sources or group(s) of sources.

4.2 Specification of noise limits

4.2.1 Noise descriptors

The preferred noise descriptor for the specification of noise limits is the equivalent continuous A-weighted sound pressure level or rating level during given reference time interval(s). If noise limits are specified in terms of rating levels, the procedures to be used for determining the levels shall be specified. Limits that apply to noise events may be specified in terms of sound exposure level.

If additional limits are specified in terms of other descriptors, the procedures for determining such values shall be specified.

NOTES

1 For large-amplitude noise, such as the noise generated by sonic booms, mining or quarry blasts, measurements with C-weighting are used in some countries to determine the rating level.

2 If it proves impossible to find locations where the noise from a source can be measured in isolation, limits may be specified in terms of the sound power level of the source. Methods for determining this quantity should then be specified (for example in accordance with ISO 3744 or ISO 3746).

4.2.2 Relevant time intervals

The reference time intervals shall be chosen to take into account typical human activities and variations in the operation of the noise source.

Noise levels from the source(s) under consideration may vary strongly at the locations selected. It may then be necessary to carry out measurements, during a number of reference time intervals, to establish a representative long-term average sound level or long-term rating level. The number of samples of the reference time interval required will depend on the range of variation.

The long-term interval shall be chosen to take into account variations in source emission and sound propagation. For situations where variations of the received sound pressure levels are mainly determined by meteorological conditions, or where emitted noise varies in a complex manner, this time interval may be from one week to one year.

4.2.3 Sound sources and their operating conditions

The source(s) to which the noise limits apply shall be specified, together with their conditions of operation.

NOTE — Special noise limits may be specified for periods during which the source is known to emit unusual types or levels of noise, e.g. when the source is undergoing maintenance.

4.2.4 Locations

The locations where the noise limits have to be met shall be clearly specified. They shall be appropriate for the measurement of the noise emitted by the source(s) under consideration. The height of the microphone above the ground shall be specified (see ISO 1996-1 and ISO 1996-2).

If these locations are subsequently found to be unsuitable for measurement of the noise emitted by the source under consideration, additional positions shall be specified where such measurements can be made (check points). Noise limits at the check points shall be derived from the levels specified at the initial locations.

NOTE — When specifying limits, the importance of certain transmission paths should be considered. This may be of special importance for establishing limits for indoor receiver positions (e.g. transmission through open or closed doors and windows).

4.2.5 Meteorological conditions

4.2.5.1 General

For outdoor transmission, changes in meteorological conditions may influence the received noise level if the distance between the source and the receiver is about 30 m or more. In such cases, the noise limits shall be based on an average value for either all relevant meteorological conditions or for specified meteorological conditions only.

Since, for identical patterns of noise, the long-term average level will be different for the two cases, the noise limits should be fixed accordingly.

Reference may be made to one of the two cases outlined in 4.2.5.2 and 4.2.5.3.

4.2.5.2 Averaging of levels for all meteorological conditions

In this case, the noise limits refer to noise levels averaged for all relevant meteorological conditions.

The measurements shall be made at times such that the results will be representative for the range of meteorological conditions for the site under consideration. The long-term average level may be calculated from the individual results, if required after weighting each result with a factor representing the fraction of the long-term time interval during which the corresponding meteorological conditions prevailed.

NOTES

1 Under certain meteorological conditions, it may be difficult to determine the specific noise of the source under consideration if there is insufficient difference between the levels of this specific noise and the residual noise.

2 This technique has the advantage that it takes into account both variations due to meteorological conditions and variations in the source emission.

4.2.5.3 Determination of levels in specified meteorological conditions

In this case, the noise limits refer to noise levels in specified meteorological conditions. The meteorological conditions in which measurements are to be carried out shall be specified.

NOTES

1 The conditions specified will usually be those for which the noise levels at the locations where the noise limits have to be complied with are the highest. In this case, the specified wind direction should form an angle of less than 45° with the direction from the source to these locations.

Measurements during strong temperature inversions near the ground should, however, be avoided.

2 Care should be taken to ensure that the specified meteorological conditions cover all relevant source operating conditions.

4.2.6 Criteria for assessing compliance with limits

In order to assess compliance with a noise limit, it will, in general, be necessary to consider the average of a number of measurements and their statistical distribution. Noise limit regulations should indicate how this information should be used for assessing compliance with the limits.

5 Checking compliance with limits

5.1 Instrumentation

The instrumentation and its calibration shall comply with the requirements given in ISO 1996-1.

5.2 Location of measurement positions

Measurements for verification of compliance with noise limits shall be carried out at the positions and at the elevations specified in the noise limit regulations.

5.3 Measurement time intervals and meteorological conditions

Measurements shall be made over the time intervals and in the meteorological conditions specified in the relevant noise limit regulations.

6 Presentation of results

The results shall be recorded in a report of the investigation of compliance with noise limits, which shall include at least the following information:

a) the relevant section of the noise limit regulations in question;

b) the date and time of measurements;

c) the location of measurement positions;

d) the instrumentation used, details of its calibration and the types of analyses carried out;

e) meteorological conditions during the measurements (wind direction, wind speed, relative humidity, temperature, recent precipitation);

f) operating and loading conditions of the sound source(s) under consideration;

g) results of all acoustic measurements or calculations of the noise from the main source under consideration;

h) noise due to other sources, if significant;

i) any calculation methods used in evaluating the measurements;

j) results and interpretation from an acoustical point of view;

k) any other information required by the noise limit regulations.

7 Bibliography

ISO 1999, *Acoustics — Assessment of occupational noise exposure for hearing conservation purposes.*

ISO 3744, *Acoustics — Determination of sound power levels of noise sources — Engineering methods for free-field conditions over a reflecting plane.*

ISO 3746, *Acoustics — Determination of sound power levels of noise sources — Survey method.*

ISO 3891, *Acoustics — Procedure for describing aircraft noise heard on the ground.*

UDC 534.61

Descriptors : acoustics, acoustic measurements, noise (sound).

Price based on 3 pages

International Standard ISO 2204

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Acoustics — Guide to International Standards on the measurement of airborne acoustical noise and evaluation of its effects on human beings

Acoustique — Guide pour la rédaction des Normes internationales sur le mesurage du bruit aérien et l'évaluation de ses effets sur l'homme

Second edition — 1979-11-01

UDC 534.6 : 613.164

Ref. No. ISO 2204-1979 (E)

Descriptors : acoustics, acoustic measurement, noise (sound), airborne sound, classification, humans, physiological effects

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 2204 was developed by Technical Committee ISO/TC 43, *Acoustics*.

This second edition was submitted directly to the ISO Council, in accordance with clause 5.10.1 of the Directives for the technical work of ISO. It cancels and replaces the first edition (i.e. ISO 2204-1973), which had been approved by the member bodies of the following countries :

Austria	Ireland	South Africa, Rep. of
Belgium	Israel	Sweden
Canada	Japan	Switzerland
Czechoslovakia	Netherlands	Turkey
Denmark	New Zealand	United Kingdom
France	Norway	USA
Germany, F. R.	Poland	USSR
Hungary	Romania	

No member body had expressed disapproval of the document.

Printed in Switzerland

Acoustics — Guide to International Standards on the measurement of airborne acoustical noise and evaluation of its effects on human beings

0 Introduction

The problems associated with the measurement of noise and evaluation of its effects are of increasing importance to the community, not only to specialists in acoustics, but also to a large number of individuals with more limited experience in this field.

Although noise-measuring equipment in common use is relatively simple to operate, a programme of noise measurements and the evaluation of the results obtained should be carefully planned. The correct methods, scales and units should be chosen and a number of precautions should be observed in order that consistent results may be obtained.

This International Standard outlines some of the basic problems associated with the measurement of noise and evaluation of its effects on human beings and presents a summary of the methods in common use and of the methods specified in other International Standards.

1 Scope and field of application

This International Standard describes the general procedures for the measurement of noise and evaluation of its effects on human beings.

It is intended as an introduction to the more specialized instructions contained in standards describing methods for acoustic measurements and evaluations, specific test codes and interpretation procedures published by national and international standardization bodies.

2 Classification of noise problems

2.1 Most noise problems may be classified as follows :

2.1.1 Problems associated with the determination of the amount and character of noise emitted by one or more noise sources, or with the prediction of the performance of one or more noise sources under specified conditions.

For problems of this group, the purpose of the noise measurements is to determine some physical quantity, usually the sound pressure level at a certain point or the sound power level of the source(s). The character of the noise may be described by the frequency spectrum and dependence on time of these levels and by the character of the sound field.

2.1.2 Problems associated with the evaluation and prediction of the different effects of noise on human beings.

For problems of this group, the purpose of the noise measurements is to obtain a quantity that relates the magnitude of the sound stimulus to the effects of the noise on a human being, be it an individual or a smaller or larger part of a group.

2.2 Broadly speaking, the problems of 2.1.1 are mainly concerned with the generation and transmission of noise, whereas the problems of 2.1.2 are mainly concerned with the reception of noise. It is emphasized that these two categories are not mutually exclusive, because a particular noise problem is usually related to both categories. For example, the purpose of many noise abatement projects is to reduce the noise emitted by a source to a level at which the influence on human beings of the noise received is tolerable.

3 Classification of different types of noise

The character of a noise may be described by its frequency spectrum, the variations of level with time, and the character of the sound field. Many noises have a continuous spectrum, i.e. the sound energy is rather evenly distributed over a large part of the audible frequency range. In some cases, discrete tones are clearly audible in the noise.

The noises most frequently encountered in practice may be classified according to the following characteristic features :

3.1 Frequency spectrum

3.1.1 Continuous spectrum

3.1.2 Spectrum with audible discrete tones

3.2 Dependence on time

3.2.1 steady noise : A noise with negligibly small fluctuations of level within the period of observation.

3.2.2 non-steady noise : A noise whose level shifts significantly during the period of observation.

4.2 Noise problems of 2.1.2

The general problem is to determine the effects of noise on people. These effects cannot be measured directly with currently available physical instruments, but the methods mentioned in 4.1.3 can be used to collect information from which approximate measures of noise on human beings can be obtained as described in clause 5.

5 Evaluation of the effects of noise on human beings

5.1 Quantities to be determined

Among the quantities describing the effect of noise on human beings are

a) the loudness level (L_N) of the noise;

b) the perceived noise level (L_{PN}) of the noise;

c) the risk of damage to the hearing mechanism caused by the noise;

d) the degree of annoyance and interference with human activities (for example, speech communications, work, rest or sleep) caused by the noise.

5.2 Methods of determination of the effects

Quantities characterizing the psychophysical effects cannot be measured directly with currently available instrumentation.

The best solution would be to present the noise to a sufficiently large and representatively selected group of persons placed in exactly the same physical, psychological and social situation as the people on whom the influence of the noise should be predicted. By observing the responses of the members of this group, it would be possible to extract information on the effects of the noise in question. This is, however, a very cumbersome and time-consuming method which can only be used in very special situations where information of a fundamental nature is required.

These subjective measurements may, however, be replaced by objective measurements when it is possible to relate some physical properties of the noise to a scale for rating subjective effects. This would generally only be possible if a thorough knowledge of the influence of many physiological, psychological and social factors on the effect of noise on human beings were at hand. It is, however, emphasized that present knowledge of the effect on human beings is very limited. "Conversion methods" relating physical properties of noise to subjective effects are available only in special cases. Some of the conversion methods commonly used are described below. The basis information is obtained by objective measurements as described in 4.1.3 and 4.1.4.

Generally, results obtained by the survey method are of limited value for the evaluation of the effects of noise on human beings. In many cases, a knowledge of the spectral distribution of the noise energy is required, i.e. the engineering or precision method should be used. In other cases, the supplementary information required on the noise situation (distribution of levels of fluctuating noise, duration and repetition rate for intermittent and impulsive noise, character of background noise etc.) is only obtainable by the precision method.

5.3 Methods for relating physical properties of noise to an approximate measure of subjective effects

The conversion may be carried out by computation or by an electric network with specified characteristics included in the measuring instruments or by a combination of these methods. As a rule, the results are only valid in a limited range of situations for which the procedure is created. Even within this range they are generally of an approximate nature only.

5.3.1 Loudness level and loudness

The loudness level (L_N) in phons of a sound signal is defined as the sound pressure level (re 20 µPa) of a standard pure tone of 1 kHz which is judged by a normal observer under standardized listening conditions as being equally loud[27].

The loudness (N) in sones is a numerical designation of the strength of a sound which is proportional to its subjective magnitude as estimated by normal observers. One sone is the loudness of a sound whose loudness level is 40 phons[4].

Methods for approximate calculation of loudness level and loudness of steady noise are given in ISO 532[4].

The data required for the calculation are the band pressure levels of the noise measured in 1/3 or 1/1 octave bands.

NOTE — The best agreement between the results obtained by calculation and those obtained by direct subjective measurements according to the definitions is obtained for steady noise signals having spectra without prominent narrow peaks. In some cases, discrepancies of several phons may be found between calculated values of loudness level and values measured according to the definition.

Data obtained by sound level measurements, especially with A-weighting network, have been found useful for rank-ordering of noises with respect to loudness level as long as the noises are of a similar character. It is emphasized that the values so measured are not those of loudness level, but of A-weighted sound level expressed in decibels.

5.3.2 Perceived noise level and noisiness

The perceived noise level (L_{PN}) of a sound signal in decibels is defined as the sound pressure level (re 20 µPa) of an octave band of frontally presented noise centred on 1 000 Hz subjectively judged to have the same perceived noisiness as the signal under test.

The noisiness in noys is a numerical designation proportional to the subjective magnitude of the nuisance of a noise. One noy is the perceived noisiness of a noise whose perceived noise level is 40 dB.

The method for the calculation of perceived noise level is given in ISO 3891[16]. The method is developed to describe aircraft noise.

The data required for calculation of perceived noise level are the 1/3 octave band pressure levels of the noise. When it is required to allow for the presence of audible discrete tones the procedure is modified[16] and the result is called tone-corrected perceived noise level (L_{TPN}). If, further, it is desired to take into account the duration of the overflight a procedure is used which, in effect, sums the values of L_{TPN} obtained at 0,5 s intervals; the result is called effective perceived noise level (L_{EPN}). A simple direct method for approximate measurement of perceived noise level uses the D-weighting network[25] in the measuring chain and the formula $L_{PN} = L_D + 7$ where L_D is the D-weighted sound level. This procedure does not provide for discrete tone correction.

In most cases, A-weighted sound level may be used for the rank-ordering of noises with similar characteristics with respect to perceived noise level.

5.3.3 Annoyance caused by noise

The problem of rating noise with respect to annoyance on the basis of physical measurements is so complicated that present-day knowledge allows only a very approximate solution. Some aspects of the problem are considered in ISO/R 1996[6], which provides a basis for the establishment of permissible limits for noises in various situations by the relevant regulatory authorities.

The method described is valid for estimation of community response to noise both outside and inside residential premises, offices, business stores, restaurants and workshops, etc.

According to ISO/R 1996[6], steady noise without audible discrete tones is rated by the sound level A. For steady noise with audible discrete tones, fluctuating, intermittent noise and certain sorts of impulsive noises, the level of steady noise (without audible discrete tones) which is assumed to cause the same community response as the noise under test is calculated and used for the rating.

Where corrective measures are required, it may be necessary to perform the rating of the noise by means of a set of noise rating curves (see ISO/R 1996[6]) on the basis of measurements of band pressure levels.

5.3.4 Interference with speech communication

Interference with speech communication caused by the noise may be estimated by calculating a factor called the articulation index. From this index, the speech intelligibility in the presence of the noise may be derived. The band pressure level of the noise as well as other information is required for the calculation. The detailed calculation procedure is described in the acoustical literature. The procedure is complicated and the best agreement between calculated and subjectively measured values is obtained for steady noise signals with broad band spectra.

A simpler method based on measurements of band pressure levels in the octaves centred on 500, 1 000, 2 000 and 4 000 Hz is also used. The average of these band pressure levels is called the *Speech Interference Level* (SIL) as defined in ISO TR 3352[12].

5.4 Assessment of occupational noise for hearing conservation purposes

The susceptibility to damage of the hearing mechanism caused by noise exposure varies considerably between individuals and cannot be predicted in each case. Therefore, when permissible limits for noise-exposure are set, they should be selected and interpreted conservatively. The problem is considered in ISO 1999[7], which gives a procedure for the evaluation of the risk of hearing impairment from noise-exposure to persons at work. Information on the sound level A and duration of the noise and the exposure during a typical working week is used to calculate the level of a steady noise considered to be equally hazardous to hearing.

5.5 General remarks on evaluation procedures

It is clear from this brief résumé that the complicated nature of the physiological, psychological and physical processes makes it impossible for a single, simple method to be applicable to all types of noise problems.

Under some conditions, the survey method will yield data of great value in assessing the effect of a noise stimulus on human beings.

The engineering and precisions methods are, however, of far wider applicability. From the data obtained by using these methods, it is possible to calculate with reasonable accuracy some quantities that are related to the psychophysical effect of the noise on human beings.

This International Standard summarizes a number of the better-established usages concerning the measurements of noise and evaluation of its effects on human beings. It does not claim to cover all cases nor to include certain procedures which are under the jurisdiction of other authorities. Although the methods described here are incomplete in some respects, they will be found useful in many practical cases where action such as setting noise limits is required.

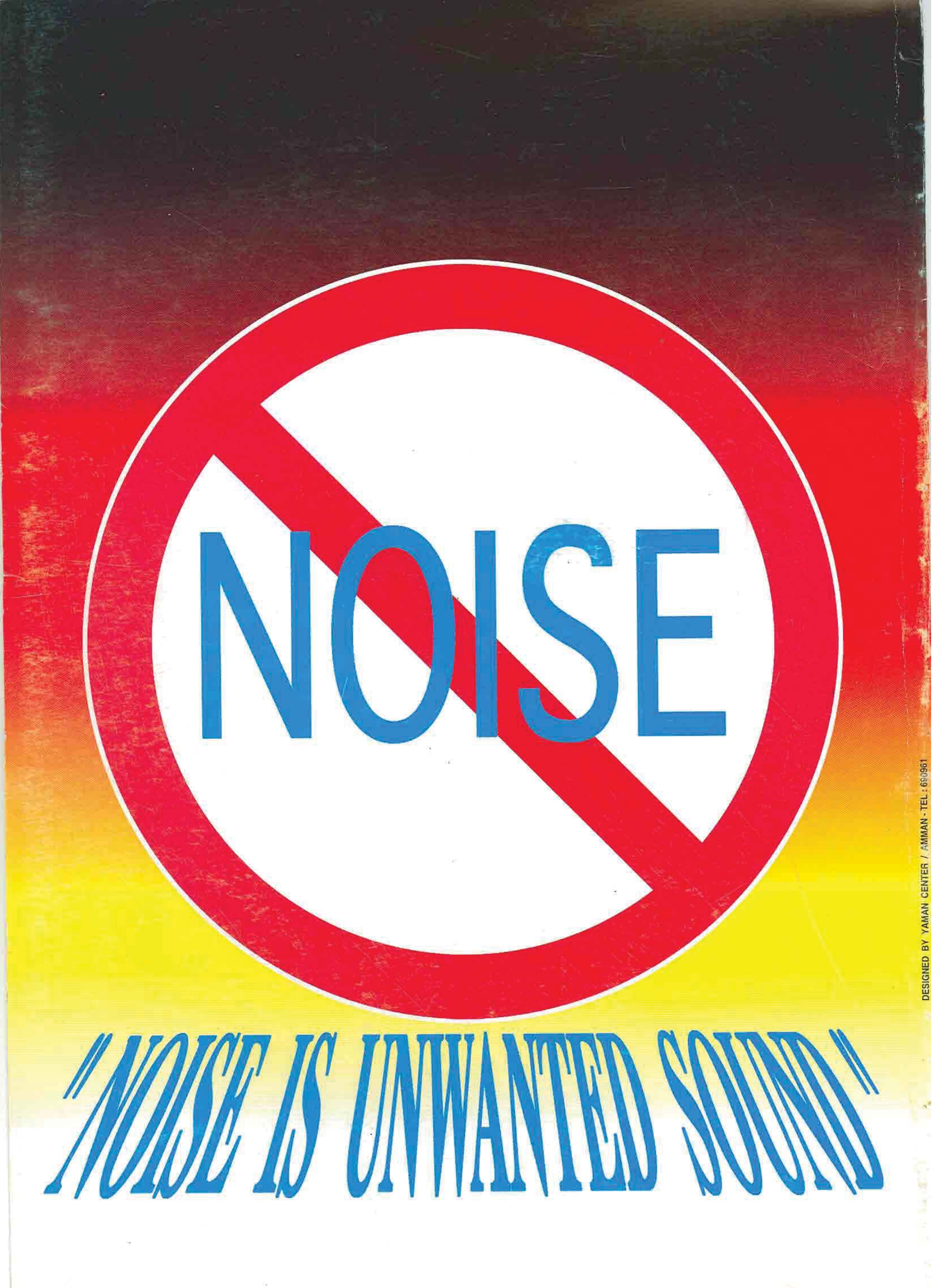
It is necessary that current and future research lead to refinements of these methods. To avoid unnecessary proliferation and duplication, it is strongly recommended that emphasis both in research and practice be placed on the methods described in this International Standard.

Alphabetical index

S

T

W


NOISE
"NOISE IS UNWANTED SOUND"
DESIGNED BY YAMAN CENTER / AMMAN - TEL : 690961