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Technical Note

Summary Acoustic design is an important consideration in mechanical services installations of all types and, with this in view, maximum noise levels in buildings are commonly specified by reference to either noise criterion (NC) or noise rating (NR) curves. Although these rating methods have existed for some years, confusion still arises from time to time regarding their use and appropriate measurement procedures. This Note is intended to assist engineers who are not primarily acousticians, but who are nevertheless charged with taking accurate and representative measurements to monitor and certify performance standards. The origin and applicability of rating indices are summarised and practical guidance given on field measurements.

Noise measurements in buildings

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1 Introduction

Research into human hearing has long established that the ear responds unequally to sound pressure level over the audible spectrum which ranges from about 20 Hz to 20 kHz. This can be characterized by equal loudness contours in phons, as shown in Figure 1, which demonstrate that the normal hearing response exhibits a reduced sensitivity over much of the lower part of the frequency range relative to the peak in the 2 to 4 kHz region. It can also be seen that as the sound intensity increases, the contours flatten somewhat over the lower frequencies. Having established a scientific foundation for normal hearing acuity, attention has naturally been focused on developing practical measurement and rating techniques which relate to subjective reaction and which can be undertaken at reasonable cost.

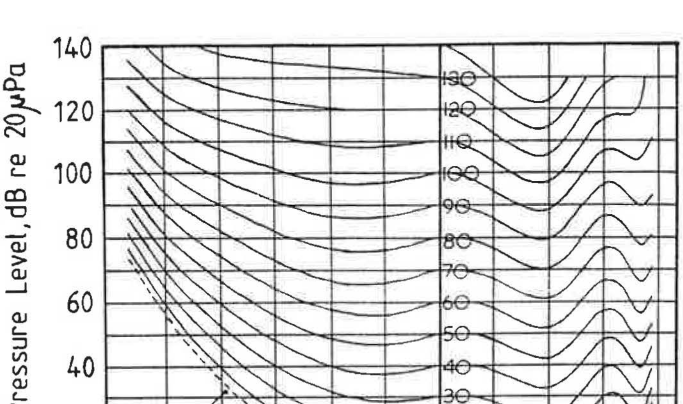

Figure 1 Equal loudness contours for pure tones under free-field conditions, based on *British Standard 3383:1961*

2 Development of rating scales

There are two basic measurement approaches to account for the difference in subjective response across the audible frequency range. The first is to apply a simple frequency weighting which approximates to the human hearing response, and following this theme various weightings have been developed for use under different circumstances. The A weighting has prevailed for use in most circumstances. Although originally intended as an approximation to the equal loudness contours for low noise level applications, as illustrated by the comparison in Figure 2, the dB(A) has been accepted widely for a variety of types and magnitude of noise environment. As a result, the A weighting can usually be found as standard on sound level meters, thus giving a direct reading in dB(A). While having the attractive simplicity of a single figure ranking scale, the dB(A) does not provide any specific information about the noise spectrum. This is found from applying the second measurement approach, that of frequency analysis.

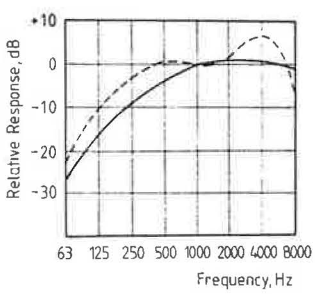

Figure 2 Comparison of the A weighting network (full curve) with the normal hearing response to low intensity sound (broken curve), i.e. inverse of equal loudness contour

Frequency analysis involves splitting the noise spectrum into a number of adjacent frequency bands, which together show the distribution of acoustic energy over the whole frequency range. The choice of bandwidth depends on the detail required and on the purpose of the measurements, but in many cases the resolution provided by octave band analysis is quite adequate. By international agreement, certain values have been chosen as the geometric centre frequencies for octave bands, of which those having the most practical significance are 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. The halving or doubling process of defining the octave centre frequencies continues beyond the examples just given, but these represent the important part of the audible spectrum.

Having carried out a spectrum analysis of this type and plotted the results on a suitable graph, it is still convenient to summarise the findings by an appropriate single figure descriptor. For example, one could compare the measured noise spectrum with the equal loudness contours described above, but since these were derived from pure tones and are of a fairly complex shape, alternative practical measures have been developed.

The basis of both the noise criterion (NC) and noise rating (NR) methods involves comparing the measured octave band spectrum with a family of curves of sound pressure level against frequency, which resemble equal loudness contours. These curves reflect the reduced low-frequency sensitivity of human hearing, and at higher sound pressure levels flatten in shape. In comparing the measured spectrum, the rating value is determined by the highest curve reached and is therefore usually determined by the level in a single frequency band. Although the curves are usually presented graphically in 5 unit steps, as is the case in Figures 3 and 4, it is usual to interpolate between the curves to a resolution of 1 unit.

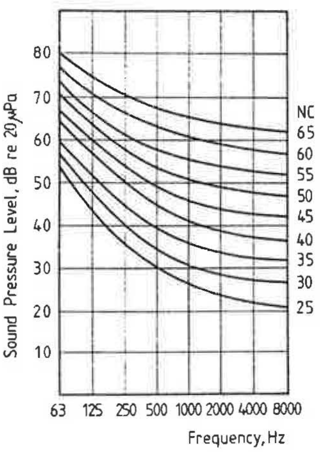

Figure 3 Noise criterion (NC) curves

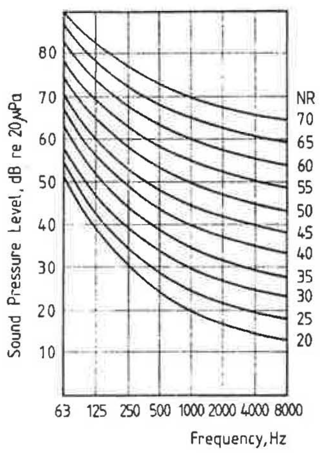

Figure 4 Noise rating (NR) curves, the NR value of each being based on the sound pressure level at 1000 Hz

The NC curves were developed in the United States during the 1950s on the basis of studies into subjective reaction to office noise environments. They were slightly adjusted in the 1960s to bring them into line with the internationally agreed set of preferred frequencies. The NR curves were first proposed in the early 1960s by European researchers who had been involved in an ISO Working Group which was attempting to establish a noise rating system for use in a variety of circumstances including outdoors. The official standing of the NR curves is now rather uncertain; they appeared in an Appendix to an ISO Recommendation for community response to noise but were not included in any issued Standards. The NR curves have nevertheless been widely quoted in European textbooks and have fallen into common use.

The field of noise measurement is blessed with a plethora of noise rating procedures of varying complexity. Despite attempts to improve upon the NC curves and the uncertain official standing of the NR curves, they remain a popular practical approach to the evaluation of noise climates in buildings and are widely used to specify background noise levels to be achieved by mechanical services plant. A guide to such maximum background noise level specifications in typical situations is given in Table 1, which is based on recommendations in Reference 1. Although there is no unique relationship of dB(A) with NC or NR values, the difference depending on the particular noise spectrum, it is often the case that the dB(A) figure is about 6 dB higher as indicated in Table 1.

Table 1 Guide to maximum background noise levels in terms of NR values

Environment	NR value	Approximate dB(A) value
Concert halls, opera halls, studios for sound reproduction, large theatres	20	26
Bedrooms in private homes, small theatres, cathedrals and large churches, television studios, large conference and lecture rooms	25	31
Living rooms in private homes, board rooms, top management offices, conference and lecture rooms, multi-purpose halls, churches, libraries, bedrooms in hotels, etc., banqueting rooms, operating theatres, cinemas, hospital private rooms, large courtrooms	30	36
Public rooms in hotels, ballroooms, hospital open wards, middle management and small offices, small conference and lecture rooms, school classrooms, small courtrooms, museums, libraries, banking halls, small restaurants, cocktail bars, quality shops	35	41
Toilets and washrooms, drawing offices, reception areas, halls, corridors, lobbies, laboratories, recreation rooms, post offices, large restaurants, bars and night clubs, department stores, shops, gymnasia	40	46
Kitchens in hotels, hospitals, etc., laundry rooms, computer rooms, accounting machine rooms, cafeteria, canteens, supermarkets, swimming pools, covered garages in hotels, offices, etc., bowling alleys, landscaped offices	45	51

Table 1 gives specifications in terms of NR values, which can be seen from a comparison of Figures 3 and 4 to be slightly more stringent at the higher frequencies than NC curves of the same numerical value. However, for practical purposes the NR and NC values for a given situation can be regarded as interchangeable. It is also worth noting that while the above data are a guide to maximum values, there are also dangers in having over-quiet conditions which could jeopardise privacy due to the lack of masking noise.

3 Considerations in taking measurements

It is obvious that before noise levels in rooms can be rated, accurate measurments need to be taken; this in turn involves the proper choice and use of equipment.

The basic measurement chain comprises a microphone connected to a measuring amplifier and octave band filter set. These items may all be contained in a hand-held sound level meter, though with some models the filter set would be an accessory. Four standardised grades of sound level meter are available with a range of measurement tolerances, and the manufacturer's handbook should identify the appropriate grade for a given meter. Various factors are specified to qualify for a particular grading, but in broad terms a type 0 meter could be expected to measure accurately to within a fraction of a decibel and is suited to laboratory and calibration tasks; a type 1 or perhaps a type 2 meter would be suited to building acoustics measurement. The tolerance of a type 3 meter would be rather large for this type of measurement. Having selected an appropriate meter it is still necessary for it to be calibrated at regular intervals to ensure accurate readings. This involves sending it to a properly equipped laboratory where its various functions will be measured to verify whether they lie within the specified tolerances.

When on site and before any measurements are taken, it is essential to check that the measuring instrument is working correctly. There is, of course, no substitute for following the manufacturer's instructions in the handbook but the main preliminaries after switching on the meter and allowing any necessary 'warm up' time are to check that the batteries are in a satisfactory condition and to confirm the calibration of the meter by applying a portable sound level calibrator to the microphone. These devices generate a tone of known sound pressure level, generally at 1000 Hz. As this is the frequency where all weightings coincide, it is good practice to check the meter reading after selecting each of the available weightings. For example, a calibrator producing 94 dB at 1000 Hz should give this reading on both 'linear' and 'A' settings. In the same way the function of the filter set can be checked by engaging the 1000 Hz octave band and again taking the meter reading. If the calibrator generates sound at a frequency other than 1000 Hz, the same principle can be applied though it will be necessary to allow for the effect on the meter reading of the A weighting network (e.g. −8.6 dB at 250 Hz relative to the linear reading) and to select the appropriate octave filter. Although this site checking of the calibration is an essential prerequisite to the taking of measurements, it should not be thought of as a substitute for the far more rigorous procedures carried out in a calibration laboratory.

A useful precaution before taking the measurements is to place a foam ball windscreen on the microphone. Indoors, it is unlikely to have to perform its primary function of eliminating wind noise at the microphone but it does serve as very useful protection to the microphone which can be susceptible to impact damage. Providing it is a properly designed windscreen, as supplied by the sound level meter manufacturer, it will have a negligible effect on the measurements in hand.

Various factors related to room acoustics must be borne in mind when taking measurements. The sound field in a room comprises energy which has travelled directly from source to receiver plus that which has been reflected from various room surfaces. These are respectively known as the direct and reverberant components. It is a matter of common experience that direct sound attenuates with distance from the source and that the level of reverberant sound will depend on the acoustic characteristics of the room finishes and contents. In a hard reflective or 'live' room reverberant sound tends to dominate, giving rise to a fairly uniform sound level except very close to the source. In an absorptive or 'dead' room the direct field will predominate over a greater distance from the source. Multiple sources in a room, such as ceiling mounted diffusers, will follow the same rules but of course the individual sound fields will interact. It should also be borne in mind that near the walls of an enclosure or any large reflecting surface the sound pressure level can be significantly higher than in the body of the enclosure. As a general rule, unless required by the specification, microphones should not be placed within one metre of such surfaces. If tonal sounds dominate then standing wave patterns can be produced by interference of direct and reflected energy, giving rise to peaks and troughs in sound pressure throughout the room. Due to their particularly annoying effect, such tones should be eradicated but, if present, enough microphone positions should be used to evaluate the situation.

In addition it is worth remembering that as the object of the exercise is to measure the sound pressure level in the undisturbed sound field; the presence of the operator, the meter and even the microphone can have an effect. It is desirable to either use a tripod to support the sound level meter or at least to hold it at arm's length so as to distance it from the operator. It can also be advantageous to use an extension rod to separate the microphone from the body of the meter. Any microphone will disturb the sound field in which it is placed to some extent, but the 'free field' microphone is designed to compensate for its own presence when the microphone is oriented so that the sound arrives perpendicularly to the microphone diaphragm. The free field microphone is the type usually supplied with sound level meters intended for general sound pressure level measurements. Measurement microphones are usually said to have an omnidirectional response, but if there is a directional component in the sound field and if the room is fairly 'dead' then the microphone should be oriented in accordance with its reference direction which should be defined in the manufacturer's handbook. In the case of the free field microphone described earlier, it should be pointed at the sound source. Other types of microphones are available and any particular requirements relating to directional characteristics should be taken into account. In many practical situations this may not be important but if sound levels at frequencies above about 2000 Hz are significant then this factor should be taken into account due to the possibility of different high frequency responses of microphone types.

The specification for an installation to achieve a given NC or NR rating is usually intended to relate to the areas of a room normally occupied. Unless precise locations are given in the specification, for instance a machine operator's position, in which case it is obvious where to place the microphone, it is reasonable to select a measurement envelope which extends vertically between 1 and 2 metres above ground level and horizontally no closer than 1 metre from the bounding walls. The number of measurement positions selected within this zone would be dependent on the uniformity of the sound field and, perhaps, on how close the results are to the specified level! It is usually worth marking the chosen noise measurement positions on a room plan, which also shows the noise sources in the room, to assist with any subsequent inquiry into the spatial noise pattern. Having set up the sound level meter, the sound pressure levels can be read off in each octave band by selecting the centre frequencies concerned. The gain of the instrument should be chosen to give a reading near the middle of the indicating meter's range, care being taken to avoid extraneous sound influencing the measurement. Services noise is generally fairly constant, so that an average by eye over a few seconds after the meter has settled will be adequate. If there are significant fluctuations then a longer averaging time will be needed, or a meter which offers an L_{eq} measurement facility. If the mechanical services system duty varies according to environmental conditions in the room, then measurements should be taken at the extremes of its operational range in order to identify the fluctuation in noise levels which could occur. As each octave band sound pressure level is measured the result is noted until the complete spectrum has been measured. Although the 'linear' and 'A' settings are not needed for a NC or NR analysis, it is nevertheless worth the extra effort to take these. If, for example, the linear reading is lower than any of the individual octave band levels then this would indicate an error, since it should be the logarithmic sum of the noise in all the octave bandwidths, or a change in the noise climate while the measurements have been in progress.

The measurements are repeated at each of the selected positions and it is now possible to plot the results on the appropriate chart to obtain the NC or NR value. In many cases it would be reasonable to average (logarithmically) the values obtained for each octave band to furnish a representative spectrum. If there are marked spatial variations, then the rating should be determined at each position.

Table 2 Example noise spectrum plotted in Figure 5

Frequency (Hz)	63	125	250	500	1000	2000	4000	8000
Octave band SPL (dB)	61	57	54	53	47	40	35	28

As an example, the noise spectrum in Table 2 has been plotted on Figure 5. The highest level reached relative to the NC curves is at 500 Hz, giving an NC rating of 49.

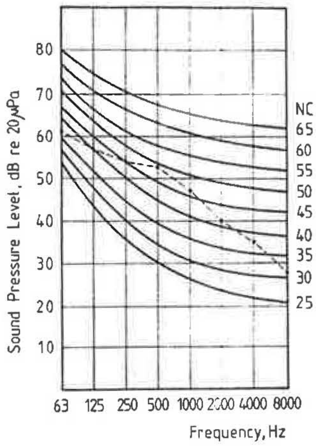

Figure 5 Example noise spectrum plotted on the NC curves, giving a value of NC 49

Reference

1 *CIBSE Guide* Section A1: Environmental Criteria for Design (London: Chartered Institution of Building Services Engineers) (1978)