ECOACCESS GUIDELINE FOR THE ASSESSMENT OF LOW FREQUENCY NOISE

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Abstract

As a result of the escalation in low frequency noise sources appearing in new industrial development and the incidence of low frequency noise complaints experienced by residents in Queensland, a low frequency noise guideline has been developed by the Environmental Protection Agency. The Guideline is applicable to low frequency noise emitted from industrial premises, commercial premises and mining operations (not blasting), and is intended for planning purposes as well as for the evaluation of existing problems. The intent of the established criteria is to accurately assess annoyance and discomfort to persons at noise sensitive premises caused by low frequency noise with a frequency range from 10 Hz to 200 Hz. The technical paper will describe the main elements of this guideline including: use of the G-weighting function to determine annoyance due to infrasound in the frequency range from 1 Hz to 20Hz and low frequency noise criterion adopted for initial screening inside home environments in terms of Linear, A-weighted and one-third octave band sound pressure levels in the range 20 to 200 Hz. Initially auditory perception is established by comparing one-third octave band frequency sound with the ISO median hearing threshold levels (HTLs) for the best 10% of the aged population (55-60 years old) followed by separate noise criteria applied to establish annoyance from tonal and non-tonal noise.

Two examples of the application of the guideline to infrasonic noise and non-tonal noise from industrial equipment are given in the paper.

Introduction

There has for many years been a high incidence of low frequency noise complaints reported to the state government environmental protection agency from residents living in Queensland. There also appears to be an escalation in low frequency noise sources appearing in new industrial development in Queensland. As a consequence, a low frequency noise guideline has been developed by the Environmental Protection Agency. The Guideline is applicable to low frequency noise emitted from industrial premises, commercial premises and mining operations (not blasting), and is intended for planning purposes as well as for the evaluation of existing problems.

The intent of the established criteria is to accurately assess annoyance and discomfort to persons at noise sensitive premises caused by low frequency noise with a frequency range from 10 Hz to 200 Hz.

Infrasound

Low frequency noise spans part of the infrasonic and audible ranges and may be considered to range from about 10 Hz to 200 Hz [1]. Sound in the frequency range below 20 Hz is defined as infrasound. Infrasound can be heard (or felt) provided it is loud enough. Infrasound is usually not perceived as a tonal sound but rather as a pulsating sensation, pressure on the ears or chest, or other less specific phenomena. The loudness and annoyance due to infrasound increases extremely rapidly with increasing level above the threshold of hearing.

The G-weighting function is used to determine annoyance due to infrasound. The G-weighting for the determination of weighted sound pressure levels of sound or noise, whose spectrum lies partly or wholly within the frequency range from 1 Hz to 20 Hz, has been standardized in ISO 7196, (1995) [2]. G-weighted sound pressure levels are denoted L_{pG} and are measured or estimated in dB(G).

The average hearing threshold for single tones is usually about 95 to 100 dB(G), and tones with a 20 dB higher level are expected to be sensed as very loud. G-weighted levels below 85-90 dB(G) are not normally significant for human perception and are not annoying.

The recommended limit value for infrasound inside dwellings during the day, evening and night and inside classrooms and offices is 85 dB(G). For occupied rooms in commercial enterprises the limit is 90 dB(G). (Jakobsen 2001) [3].

The noise is measured over a 10-minute period and a 5 dB penalty is added for impulsive noise e.g. single blows from a press or drop forge hammer. An approximate determination of the G-weighted sound pressure level may be made by analysis of the signal using one-third octave bands and application of the weighting values given in Table A1, Appendix A. An example of the determination of the annoyance due to infrasonic noise is given in Table B1 Appendix B.

Low frequency noise above 20 Hz

Items such as boilers, pumps, transformers, cooling fans, compressors, oil and gas burners, foundries, washing machines, electrical installations, diesel engines, asynchronous motors, ventilation and air-conditioning equipment, wind turbulence and large chimney resonances are sources of high level, low frequency noise having frequency content less than 200 Hz. Generally, low level/low frequency noises become annoying when the masking effect of higher frequencies is absent. This loss of high frequency components may occur as a result of transmission through the fabric of a building, or in propagation over long distances. It may even be perceived by a resident who suffers from age-induced, high frequency hearing loss.

A problem arises in determining the location of the source and/or the relative importance of the various transmission paths of low frequency sound sources as the radiation pattern is usually omni-directional. The location of low frequency noise indoors is complicated by a number of factors such as: room dimensions being normally within the wavelength range of interest (1.36 to 17m) which may give rise to standing waves; airborne noise causing windows and other building elements to rattle; and difficulty in distinguishing between airborne and structure borne noise.

The main elements of an assessment include: The low frequency noise criterion adopted for initial screening inside home environments in terms of Linear, A-weighted and one-third octave band sound pressure levels in the range 20 to 200 Hz; the comparison of one-third octave band low frequency sound levels with the values for L_{HS} of the ISO median hearing threshold level for the best 10% of the aged population (55-60 years old) to initially establish auditory perception. The initial assessment is intended for use in cases where an individual complains about low frequency noise and a decision needs to be made as to whether the particular noise is audible. This assessment does not verify whether the noise is annoying or not. A sound that is audible is not necessarily unacceptable.

Initial assessment

Where a noise immission occurs exhibiting an unbalanced frequency spectra, the overall sound pressure level inside residences should not exceed 50 dB(Linear) to avoid complaints of low frequency annoyance. If the dB(Linear) measurement exceeds the dB(A) measurement by more than 15 dB, a one-third octave band measurement in the frequency range 20 to 200 Hz should be carried out.

Audibility assessment

The following checks are made to establish whether noise contains dominant low-frequency components:

1. Determine broad band L_{Aeq} and L_{LINeq} levels inside each affected room for a representative measuring time interval, typically 10 minutes.
2. Determine if $L_{LINeq} - L_{Aeq} > 15$ dB. If it does, measure the noise in 1/3rd octave band levels, in terms of L_{LINeq} for frequencies from 5 Hz to 200 Hz.
3. Compare these levels with the L_{HS} values of the median hearing threshold level for the best 10% of the older population (55-60 years old) given in Table 1 to determine the degree of low frequency noise audibility.
4. Check for the existence of an amplitude-modulating component, where the noise level changes cyclically at a particular 1/3rd octave band frequency. The added perception of loudness caused by this attribute can be accounted for by subtracting a 5 dB penalty from the L_{HS} value in Table 1.

   For example, the L_{HS} level for 50 Hz could be reduced from 39 dB to a corrected 34 dB. This could be the case for poorly designed HVAC systems that generate large turbulent fluctuations at low frequencies and can cause fan surging with concomitant noise level surging of 10 dB or more.

Table 1 Median hearing threshold levels (L_{HS}) exceeded by 10% of an aged population (55-60 years old)

1/3 Octave Centre Frequency (Hz)	L_{HS} (dB)
8.0	96
10.0	92
12.5	88
16.0	84
20.0	75
25.0	62
31.5	55
40	46
50	39
63	33
80	27
100	22
125	18
160	14
200	10

Source: ISO/CD 1996-1

Annoyance due to tonal noise

If the sound pressure level in a particular 1/3rd octave band is 5 dB or more above the levels in the two neighbouring bands, the noise is said to be tonal. There can be one or more tonal components in the spectrum.

For tonal noise, the level in the frequency band/s with the tone/s is compared to the hearing threshold level (L_{HS}) in the corresponding bands (Table 1). It is then found how much (the exceedence) the tonal value is above the threshold level. The levels in the other frequency bands are not taken into account.

Acceptable criteria for tonal noise

The limit values for exceedence of the threshold table values by the equivalent level of the tone/s are as given in Table 2.

Table 2. Limit values for exceedence for annoyance due to tonal noise

Period	1/3 Octave Frequency Band			
	8 Hz to 63 Hz	80 Hz	100 Hz	>100 Hz and < 200 Hz
Day	5	10	15	17
Evening/night	0	5	10	12

Source: Gottlob [4]

If these limit values are not exceeded, the noise is considered to be non-annoying.

Annoyance due to non-tonal noise

To establish annoyance for non-tonal noise in the frequency range 10 Hz to 160 Hz, A-weighting network corrections (Table 3) are applied to the 1/3rd octave band spectra measured indoors and the resulting A-weighted values are summed to yield the A-weighted noise level in the frequency range 10 Hz to 160 Hz. The resulting level is called $L_{pA,LF}$.

Table 3. The A-weighting network corrections

1/3 Octave Centre Frequency (Hz)	A-weighting correction (dB)
8.0	-77.8
10.0	-70.4
12.5	-63.4
16.0	-56.7
20.0	-50.5
25.0	-44.7
31.5	-39.4
40	-34.6
50	-30.2
63	-26.2
80	-22.5
100	-19.1
125	-16.1
160	-13.4
200	-10.9

Source: AS 1259.1-1990 [5]

Acceptable criteria for non-tonal noise

The value of $L_{pA,LF}$ is compared with recommended limits (Table 4) to assess its acceptability for the specific application. If the relevant tabled limit is not exceeded, the noise is considered to be acceptable.

Table 4. Recommended limits for non-tonal low frequency noise ($L_{pA,LF}$)

Type of space (Note 1)	$L_{pA,LF}$ dB (Note 2) (Note 3)
Dwelling, evening and night	20
Dwelling, day	25
Classroom, office etc	30
Rooms with commercial enterprises	35

Source: Jacobsen, 2001[3]

Note 1. Evening and Night defined as period 6pm until 7am, Day period 7am until 6pm.

Note 2. Averaged over 10 minutes.

Note 3. If the noise has an impulsive character (e.g. drop forge, disco music), the limits are reduced by 5 dB.

Measurement locations

Normally, measurement of environmental noise takes place outdoors. This is not advisable with low frequency noise due to the disturbance caused by even light winds and because an outdoor measurement will not take into account re-radiated, structure-borne noise. In addition internal measurements are advisable due to uncertainties in the sound transmission loss of the building envelope and resonance within rooms which can occur at low frequencies. Furthermore, it is a frequent observation that low frequency noise is considered more annoying indoors.

The noise should normally be measured at 3 points at least in each room. One point is chosen near a corner, 0.5 to 1m from the adjoining walls and 1 to 1.5m above the floor. The other points are chosen to represent typical habitation in the room, at least 0.5m from walls and large pieces of furniture and 1 to 1.5m above the floor. Often the occupants can identify points where the noise level is highest, and it is important to measure at these points.

Points near the center of the room must be avoided, as the noise level is often lowest there. In small rooms (less than about 20m^2 floor area) the noise can be measured at two points in different corners, 0.5 to 1m from the adjoining walls and 1 to 1.5m above the floor.

The operating conditions for the noise source must be representative of the situation that is the subject of the complaint, and the background noise should be as low as possible. Windows and doors should be closed; if it is claimed that the low frequency noise is more intrusive with open windows, a supplementary measurement can be made with windows open.

If possible, the internal background noise level should be measured with the noise source inoperative. This will also assist in identifying which source is responsible for any particular part of the noise.

All domestic electric and gas appliances within the premises should be switched off during measurements to establish whether they might be the source of annoyance.

Where it has been possible to measure the internal background noise level, 1/3rd octave band spectra shall be corrected for background noise.

The measured spectra (corrected for background noise, if appropriate) are added to the G or A-weighting network corrections to derive the overall weighted levels.

The energy average of the G and the A-weighted noise levels from all the measurement points in the same room are calculated and compared individually to the recommended noise limits.

Conclusions

Measurements carried out by the author of noise from industrial plant and equipment over a period of 25 years have clearly demonstrated that the use of broad band dB(A) often does not reflect the 'true' annoyance when low frequency components are present. There is a clear indication that even low sound pressure levels at low frequencies may cause unpleasant effects on human beings. The interdependence of spectra, fluctuations and complainant characteristics (individual 'annoyance rating') are required to develop an improved assessment method that incorporates existing methods.

It is acknowledged that knowledge on this topic is not complete, there is ongoing research into the effects of low frequency noise and many questions cannot be fully answered.

With some improvement in the knowledge of hearing thresholds in the low frequency region and the publishing of assessment methods for low frequency noise by some countries (Denmark, Germany, Sweden, Poland, the Netherlands and USA), it seems timely for an assessment method to be developed for Australia. This could be achieved either through consultation by the environmental protection agencies to develop a consistent approach or even publishing as an Australian Standard.

This proposed guideline has had some peer review through government agencies and acoustical practitioners and appears to give some indication of perception and annoyance when applied to real life situations.

This type of work has the potential to improve the quality of life of complainants, reduce the level of complaints of noise and also reduce the demands on environmental, social and health services. It can reduce the extent to which low frequency noise complaints are unresolved by agencies and avoid commitment to use of scarce resources and inappropriate costly noise mitigation solutions.

References

[1] Leventhall, G. A Review of Published Research on Low Frequency Noise and its Effects. Report for DEFRA, May 2003.

[2] ISO 7196:1995, Acoustics – Frequency weighting characteristic for infrasound measurements.

[3] Jacobsen, J. Danish guidelines on environmental low frequency noise, infrasound and vibration. Journal Low Frequency Noise, Vibration and Active Control 20, pp141–148, 2001.

[4] ISO 1996-1:2003: Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures.

[5] Gottlob, D.P.A. German Standard for Rating Low Frequency Noise Immissions, Internoise 98, Christchurch New Zealand, 16-18 November 1998.

[6] AS 1259.1-1990: Acoustics - Sound level meters - Non-integrating.

Appendix A:

The G-weighting network for infrasound measurements

The G-weighting network has a close relation to the shape of the hearing threshold curve in the infrasound region and also includes a sharp cut off at frequencies above 20 Hz. The G-weighting is so defined that it has a gain of 0 dB at 10 Hz; that is, the G-weighted sound pressure level of a pure tone at 10 Hz is equal to the un-weighted sound pressure level. Between 1 Hz and 20 Hz the curve approximates a straight line with a slope of 12 dB per octave. Below 1 Hz and above 20 Hz, the curve has cut-offs with rates of 24 dB per octave.

Table A1. Nominal frequency response for G-weighting characteristic 1/3rd octave frequency

1/3 Octave Centre Frequency (Hz)	Relative Response (dB)
0.25	-88
0.315	-80
0.4	-72.1
0.5	-64.3
0.63	-56.6
0.8	-49.5
1.00	-43.0
1.25	-37.5
1.6	-32.6
2	-28.3
2.5	-24.1
3.15	-20.0
4.0	-16.0
5.0	-12.0
6.3	-8.0
8.0	-4.0
10.0	0.0
12.5	4.0
16.0	7.7
20.0	9.0
25.0	3.7
31.5	-4.0
40	-12.0
50	-20.0
63	-28.0
80	-36.0
100	-44.0

Source: ISO 7196-1995 [2]

Appendix B:

Examples of application of the guideline

B.1 Illustrating annoyance due to infrasonic noise

Measurements were taken of noise inside offices near (i) the pumping station of a sewage works and (ii) a blast furnace in a steel works. Measurement results are given in Tables B1a and B1b in 1/3rd octave band sound pressure levels in the range 2 Hz to 100 Hz. The measured spectra are added to the G-weighting network corrections to derive the overall G-weighted level, dB(G).

Table B1a. Infrasonic measurements inside office near a pumping station

1/3 Octave Centre Frequency (Hz)	Sound Pressure Level dB		
	Measured Spectra	G-weighting Corrections	Corrected G-weighted spectra
2.0	70	-28.3	41.7
2.5	74	-24.1	49.9
3.15	73	-20.0	53.0
4.0	72	-16.0	56.0
5.0	72	-12.0	60.0
6.3	72	-8.0	64.0
8.0	74	-4.0	70.0
10.0	78	0.0	78.0
12.5	79	4.0	83.0
16.0	92	7.7	99.7
20.0	102	9.0	111.0
25.0	104	3.7	107.7
31.5	104	-4.0	100.0
40	96	-12.0	84.0
50	98	-20.0	78.0
63	92	-28.0	64.0
80	96	-36.0	60.0
100	98	-44.0	54.0

Overall: 113 dB(G) exceeds the limit of 85 dB(G) adopted for offices.

Table B1b. Infrasonic measurements inside office near a blast furnace

1/3 Octave Centre Frequency (Hz)	Sound Pressure Level dB		
	Measured Spectra	G-weighting Corrections	Corrected G-weighted spectra
2.0	81	-28.3	52.7
2.5	83	-24.1	58.9
3.15	84	-20.0	64.0
4.0	86	-16.0	70.0
5.0	91	-12.0	79.0
6.3	100	-8.0	92.0
8.0	110	-4.0	106.0
10.0	93	0.0	93.0
12.5	92	4.0	96.0
16.0	92	7.7	99.7
20.0	97	9.0	106.0
25.0	90	3.7	93.7
31.5	80	-4.0	76.0
40	86	-12.0	74.0
50	88	-20.0	68.0
63	82	-28.0	54.0
80	90	-36.0	54.0
100	101	-44.0	57.0

Overall: 110 dB(G) exceeds the limit of 85 dB(G) adopted for offices.

B.2 Example illustrating use of guideline for rating acceptability of non-tonal low frequency noise

Measurements were carried out inside and outside a residential property in a quiet rural area (Table B2a). Measurements were made using a dual channel sound level analyzer during late evening or early morning hours, under calm, cloudless and dry weather conditions. Care was taken to switch off all domestic electrical and gas appliances within the property during the measurements.

The occupants of the property had consistently over a period of 3 years reported annoyance and disturbance. caused by noise. The intrusive noise was often so close to inaudibility in level that most people were not able to hear it.

The 1/3rd octave band analyses of the noise recordings are presented in the frequency range 20 to 200 Hz. These spectra are compared with the hearing threshold levels (L_{HS} from Table 1).

Table B2a shows the results of noise measurements made inside a room (dimensions 4.25m x 3.5m x 2.48m) and outside the house during late night hours. The inside levels with doors and windows closed lie above the audibility threshold curve for frequency components 50 Hz to 200 Hz with dominant components at 160 Hz and 200 Hz.

During the above measurements a low frequency 'roar' was heard inside the house by a resident. The L_{pALF} level of 40.8 dB indicates unacceptable non-tonal low frequency noise when compared with the recommended limit of 20 dB from Table 4. Noise mitigation in the frequency range 125 Hz to 200 Hz would achieve an acceptable level.

Table B2a. Assessment of audibility

1/3 Octave Centre Frequency (Hz)	Sound Pressure Level dB			
	Indoors, door and windows closed 1.40 am to 1.50am	Outdoors 1.40 am to 1.50am	Audibility curve L_{HS} dB (Table 1)	Indoor exceedence on audibility curve
20	32	36	74	-
25	30	35	62	-
31.5	45	50	55	-
40	43	48	46	-
50	42	47	39	3
63	37	44	33	4
80	39	47	27	12
100	40	45	22	18
125	47	47	18	29
160	51	48	14	37
200	48	40	10	38

To those who could hear the noise, it was typically audible with the door and windows closed. The noise appeared to be subject to background masking, being more audible at night than during the day. The complainant at various times described the noise as a 'roar', a noise similar to that of a diesel truck with its 'engine at idle', 'a throbbing siren' or 'rumbly noise'.

The results of the measurements may be summarized as follows:

Table B2b. Assessment of non-tonal noise

1/3 Octave Centre Frequency (Hz)	Sound Pressure Level dB		
	Indoors, door and windows closed 1.40 am to 1.50am	A-weighting network corrections	Corrected A-weighted spectra
31.5	45	-39.4	5.6
40	43	-34.6	8.4
50	42	-30.2	11.8
63	37	-26.2	10.8
80	39	-22.5	16.5
100	40	-19.1	20.9
125	47	-16.1	30.9
160	51	-13.4	37.6
200	48	-10.9	37.1
$L_{pA,LF}$	-	-	40.8

Note: 1/3rd octave band spectra for centre frequencies less than 31.5 Hz are not tabulated as their contributions were more than 20 dB below the dominant 160 Hz and 200 Hz components.