Noise guidelines: Assessing low frequency noise

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Level 3, 200 Victoria Street, Carlton VIC 3053
1300 372 842 (1300 EPA VIC) epa.vic.gov.au

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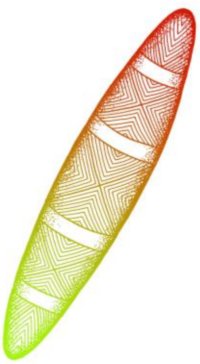

EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work and depend. We pay respect to Aboriginal Elders, past and present.

As Victoria's environmental regulator, we pay respect to how Country has been protected and cared for by Aboriginal people over many tens of thousands of years.

We acknowledge the unique spiritual and cultural significance of land, water and all that is in the environment to Traditional Owners, and recognise their continuing connection to, and aspirations for Country.

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Contents

Glossary

This glossary defines the terms for the purpose of this guideline.

Term	Definition

Commercial, industrial and trade premises	Is defined the Regulations and includes any premises except the following:
	• residential premises (other than common plant under the control of an owners' corporation)
	• a street or road, including every carriageway, footpath, reservation and traffic island on any street or road
	• a railway track used by rolling stock in connection with the provision of a freight service or passenger service:
	    ○ while travelling on a railway track or tramway track; or
	    ○ while entering or exiting a siding, yard, depot or workshop
	• a railway track used by rolling stock in connection with the provision of a passenger service, while in a siding, yard, depot or workshop and is:
	    ○ powering up to commence to be used in connection with the provision of a passenger service; or
	    ○ shutting down after being used in connection with the provision of a passenger service
	• the premises situated at Lower Esplanade, St Kilda, Luna Park, and being the whole of the land more particularly described in Certificate of Title Volume 1204 Folio 109.
	
	Note: The maintenance, cleaning or loading of rolling stock stabled in a siding, yard, depot or workshop are included within the meaning of commercial, industrial and trade premises.
	
	Examples
	
	Common plant under the control of an owners' corporation at residential premises includes:
	• common air conditioning units
	• car stackers and lift equipment in apartment buildings.
	
	These must be assessed as noise from commercial, industrial and trade premises in accordance with the Noise Protocol.

Term	Definition
C-frequency weighting	Frequency weighting, as specified in *Australian standard AS IEC 61672.1-2019*. that gives more emphasis to low frequency sounds than the A-frequency weighting.
Duty holder	The owner, occupier or person in control of the commercial, industrial or trade premises.
Engineering calculation method	Calculation algorithm relying on a combination of acoustic principles and empirical relationships. A suitable engineering calculation method must have been validated against extensive measurement. Also, the set of conditions for which it is fit for purpose must be documented in a verifiable reference, together with the uncertainty of calculation.
Excited	An element of a structure vibrating, following an impact or a contact with a moving object.
Fast (F) time weighting	Time weighting characteristic of a sound level meter as specified in *Australian Standard AS/NZS IEC 61672.1*.
Free field conditions	Noise measurement conditions where the sound pressure levels recorded by the microphone are not affected by the reflection of sound on surfaces, other than the ground.
Frequency	Property of sound that measures the rate of repetition of the sound wave, in Hertz (Hz) or cycles per second.
Frequency spectrum*	Distribution of the energy or the magnitude of a sound across each frequency component.
$L_{Ceq,T}$	Overall equivalent sound pressure level measured using C-frequency weighting. As an overall level, it combines the sound energy of all frequencies.
$L_{eq,T}$ (also known as $L_{Zeq,T}$)	The equivalent continuous sound pressure level. It is the value of the linear or Z-weighted sound pressure level of a continuous steady sound that has the same acoustic energy as a given time-varying linear or Z-weighted sound pressure level when determined over the same measurement time interval T.

Term	Definition
Low frequency noise	Noise with low frequency components containing significant acoustic energy within a frequency range defined by one-third octave bands 10 Hz to 160 Hz.
Narrow-band spectral analysis	A sound analysis approach based on a high resolution in the frequency domain such as Fourier analysis or 1/12th octave band analysis.
Octave band	A division of the frequency range that can be used to analyst eh frequency spectrum of the measured sound. Noise is measured in octave bands using frequency filters as specified in *Australian Standard AS IEC 61260.1:2019 Electroacoustics—Octave band and fractional-octave-band filters.*
One-third octave band	A division of the frequency range that can be used when octave bands don't provide sufficient resolution. Each octave band comprises three one-third octave bands. Noise is measured in one-third octave bands using frequency filters as specified in *Australian Standard AS IEC 61260.1:2019 Electroacoustics—Octave band and fractional-octave-band filters.*
Percentile level $L_{10,T}$, $L_{50,T}$, $L_{90,T}$	Sound pressure level that is exceeded respectively 10%, 50% and 90% of the time during a measurement of duration T.
Sensitive receiver	That part of the land within the boundary of a parcel of land that is outside the external walls of any: • dwelling (including a residential care facility) or residential building • dormitory, ward, bedroom or living room • classroom or any other room in which learning occurs. Or, in the case of a rural area only, that part of the land within the boundary of: • a tourist establishment • a campground • a caravan park.
Spot measurements	A survey measurement, typically of short duration, that's conducted using a handheld sound level meter to get an indication of the sound levels, as they vary within the area surveyed.

Term	Definition
Structure-borne noise	Noise caused by the vibration of the elements of a structure. The source of vibration that results in structure-borne noise is within the building where it's perceived or within a structure with common elements that transmit vibration.
Threshold of hearing	The level at which an individual can hear a sound at a given frequency.

Unreasonable noise	Section 3(1) of the Act defines unreasonable noise as noise that:
	• is unreasonable having regard to the following:
	    o its volume, intensity or duration
	    o its character
	    o the time, place and other circumstances in which it is emitted
	    o how often it is emitted
	    o any prescribed factors*, or
	• is prescribed to be unreasonable noise.

Z-frequency weighting	Means the sound pressure level when no frequency weighting is applied, as specified in *Australian standard AS IEC 61672.1-2019.*

*Frequency spectrum is a prescribed factor in Regulation 120 of the Environment Protection Regulations 2021. It applies to noise from commercial, industrial and trade premises only.

Introduction

This guideline is for acoustic consultants and other qualified professionals who assess low frequency noise (10 to 160 Hertz (Hz)). This guideline is also for:

- duty holders at commercial, industrial and trade premises to understand and manage low frequency noise emissions
- EPA authorised officers to determine whether the emission of low frequency noise from commercial, industrial and trade premises is unreasonable under section 166 of the *Environment Protection Act 2017* (the Act).

Use this guideline to:

- understand the risk of harm from the emission of low frequency noise
- assess and address low frequency noise.

This guideline should also be used when you're designing new commercial, industrial and trade premises or installing new equipment or plant at existing premises.

When this guideline applies

The assessment methods and guidance set out in this guideline only applies to noise emitted from commercial, industrial and trade premises.

This guideline does not apply to:

- music noise from entertainment venues
- noise from residential premises
- noise from wind turbines.

The New Zealand Standard *NZS 6808:2010 Acoustics – Wind farm noise*, or its predecessor *NZS 6808:1998 Acoustics – The assessment and measurement of sound from wind turbine generators* is used to assess wind turbine noise.

The assessment of low frequency noise using this guideline is separate from an assessment for compliance with the regulatory noise limits. The regulatory noise limits for commercial, industrial and trade premises are set out in the:

- Environment Protection Regulations 2021
- *Noise limit and assessment protocol for the control of noise from commercial, industrial and trade premises and entertainment venues* (publication 1826)

What is low frequency noise?

Low frequency noise is often described as rumbling or droning noise. It can be generated by machinery such as pumps, compressors, diesel engines, fans, generators and boilers. Low frequency noise can also be produced by natural sources such as surf in coastal areas and wind. Electrical appliances in homes and buildings, such as refrigerators, can emit low-frequency noise.

Low frequency noise may also occur when an object or machine transmits vibration to the structure of a building, generating 'structure-borne' noise. This is when a building's structural elements, such as walls or floors vibrates and radiates noise following an impact or a contact with a moving object. The noise can be heard inside other rooms to where the object or machine is housed.

In this guideline, low frequency noise is defined as noise with significant acoustic energy in one-third octave bands ranging between 10 Hz to 160 Hz.

How low frequency noise affects people

Low frequency noise can affect people in the same way as other types of noise. This can include sleep disturbance, annoyance, impaired task performance, daytime tiredness, and disturbed daily cortisol pattern due to stress. These effects can cause some people to experience nausea and headaches.

The human range of hearing is often described as being from 20 Hz to 20,000 Hz (20 kHz). However, low frequency sound at frequencies less than 20 Hz can be audible. Its audibility depends on the sound pressure level measured in decibels (dB) and the hearing sensitivity of whoever can hear it.

Sensitivity to sound varies greatly between individuals. The person investigating low frequency noise may not hear the sound that someone has reported. However, it may be audible by others. The perceived loudness of low frequency sounds increases rapidly with increasing noise level (measured in decibels). This means low frequency sounds only just above the threshold of hearing can be perceived as loud by some people (Moorhouse, Waddington and Adams 2011).

This doesn't mean that any audible sound is unreasonable.

Characteristics of low frequency noise that can increase its effect

Characteristics that can increase the effects of low frequency noise, particularly how disturbing it is, include:

- the presence of tones (a sound with energy concentrated at one or two single frequencies, often described as a drone or hum)
- fluctuating noise level (rapid increase and decrease in noise level)
- frequency modulation (small variations in the frequency of the noise)
- rattles or vibration caused by low frequency noise.

Low frequency noise with tones can induce greater fatigue and can interfere with task performance more than low frequency noise without tones or with the tones masked by other noise (Leventhall, 2003).

How the effect of low frequency noise varies with your location

The effect of the low frequency noise also varies with the location of where it's heard. Low frequency noise is often experienced indoors. Inside a room, low frequency noise levels can vary due to interference caused by sound reflections on the room surfaces. Sound levels can then increase or reduce depending on where a person is positioned. This effect depends on the dimensions of the room and the frequency spectrum of the noise.

Common sources of low frequency noise

The presence of any of these sources at a premises does not necessarily mean that a low frequency noise issue will occur.

Table 1: Sources of low frequency noise

Type	Noise source
Commercial/industrial/trade	• aircraft • blasting • boilers • cooling towers • cooling fans • compressors • diesel engines • electrical installations • extraction fans • heavy machinery • large generators • loading and unloading activities • metal thudding • motors • power stations • pumps • shipping and ships in the harbor • steam releases • shakers • transformers • ventilation plant • vibratory screens
Residential	• air conditioners • electric appliances • fish tank pumps • heat pumps • refrigerator • spa bath pumps
Natural causes	• sea, including surf • seismic activity • thunder • wind • wind effects on structures

Legislative framework

Under section 166 of the Act, a person must not emit an unreasonable noise or permit an unreasonable noise to be emitted from any place or premises that is not residential premises.

Understanding unreasonable noise

Noise is assessed as being unreasonable having regard to the characteristics of the noise and the circumstances in which it is emitted, as defined under ***unreasonable noise*** in section 3(1) of the Act.

An assessment of unreasonable noise can also include any prescribed factors. Regulation 120 of the Environment Protection Regulations 2021 (the Regulations) makes frequency spectrum a prescribed factor when assessing noise from commercial, industrial and trade premises. The frequency spectrum from 10 Hz to 160 Hz must be used to assess whether the low frequency noise is unreasonable.

Other factors which may be considered in an assessment include:

- how often the noise occurs
- how long the noise continues
- its character such as the presence of tones, fluctuations, or pulsing.

If an authorised officer reasonably believes that unreasonable noise has been or is being emitted, the officer may issue an improvement or prohibition notice to the duty holder.

How to reduce low frequency noise levels

If a low frequency sound can be traced to a known source, this increases the potential to take action to reduce the noise.

Hierarchy of controls

The hierarchy of controls is a step-by-step approach to eliminate or reduce risk, including controls from the highest level of protection, elimination, to the lowest, administrative controls.

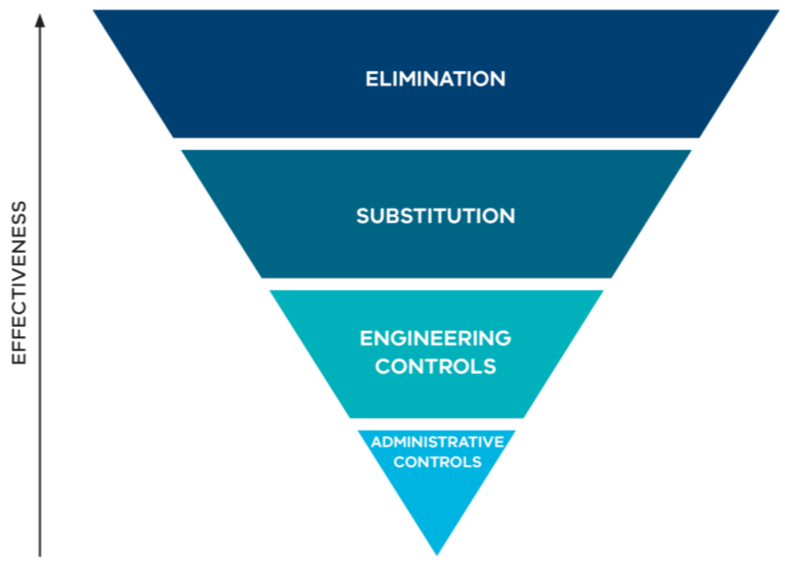
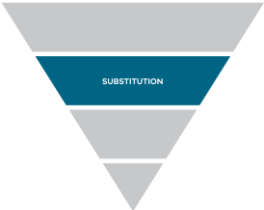


Figure 1: Hierarchy of controls

Elimination

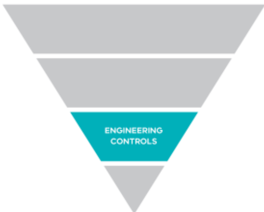
Elimination is the most effective way to address potential hazards and risks from low frequency noise. Avoiding harmful noise emissions through plant design and siting is an example of elimination. Another example is implementing an effective inspection and maintenance plan to prevent issues occurring, due to equipment malfunction or wearing.

Substitution



Substitution involves replacing a process or equipment that generates low frequency noise with an alternative with lower hazard and risk. For example, replacing a noisy machine at a premises with a quieter one.

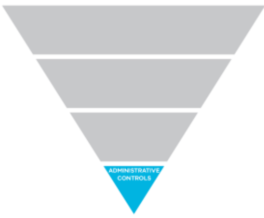
Engineering controls



The use of engineering controls includes using isolation to reduce the hazard and risk of low frequency noise, for example:

- installing silencers that are specifically designed for low frequency noise mitigation
- adding damping to panels of equipment enclosures
- replacing rubber mountings or fittings, to reduce vibration transmission.

Administrative controls



Administrative controls are actions that aim to lessen the potential for harm from a hazard or risk through training, policy, procedure, or change in operating practices. For example, operating noisy processes during the day as opposed to the evening or night periods.

Proposed industry developments and extension of existing premises

The risk of unreasonable noise generated by low frequency noise is often difficult to predict for new premises. Therefore, the design of existing or proposed commercial, industrial and trade premises should consider unreasonable noise from low frequencies being emitted beyond the boundaries of the premises.

Low frequency noise issues can be difficult and more expensive to address once they have occurred. Therefore, design features and measures to minimise low frequency noise should be incorporated at the very beginning of a project.

When planning and designing a commercial, industrial and trade premises development, whether it's a new premises or an extension of existing premises, it's essential to understand the hazard and risk of emission from low frequency noise.

Actions to minimise hazard and risk from low frequency noise should be documented and supported by an assessment report, prepared by a suitably qualified acoustic consultant or practitioner.

Justification for the design should be provided in the development proposal, planning application, and/or environmental management plans.

Review the proposed equipment

Understanding the hazards and risks associated with the proposed equipment is key to preventing and mitigating the emission of low frequency noise. This can be done by:

- reviewing the literature available, asking manufacturers and industry peers and understanding:
  - the character and risk of low frequency noise emissions from the proposed equipment
  - which alternative equipment or process can be used to minimise low frequency noise emissions
  - how to avoid or minimise low frequency noise emissions
  - the potential noise mitigation measures and their effectiveness.
- conducting measurements of the same or similar equipment at already existing facilities. This can provide valuable information on the:
  - hazard and risk of low frequency noise emissions
  - potential tones within the low frequency range of 10 Hz to 160 Hz that may be problematic.

Review the proposed installation

The planning and design stage of an installation is when the most effective noise elimination or minimisation measures can be incorporated. Things to consider in the review of any proposed installation include:

- plan for installation, set-up, and operation of all equipment according to manufacturer's instructions, and following industry best practice to minimise the generation of low frequency noise
- ensure the design does not result in large elements, such as panels, walls, or slabs, being excited and/or causing airborne vibration
- consider increasing the stiffness and/or the damping of panels and other vibrating elements
- avoid rigid connections with the building structure or with other elements that can transmit vibration, resulting in structure-borne noise
- seek advice from vibration isolator manufacturers to select and design adequate solutions for your chosen equipment
- ensure installation instructions of the isolators are provided and followed rigorously
- prepare an inspection and maintenance plan to make sure the equipment will be maintained adequately to prevent low frequency noise issues arising in the future, as the facilities and equipment age.

Predicting low frequency noise

Predicting expected noise levels at noise sensitive receivers may be compared against the relevant low frequency threshold levels (Table 2 for indoor or Table 3 for outdoor measurements). However, noise level calculations in the low frequency range can be problematic and of limited accuracy.

The use of noise calculations should be restricted to indicative estimations only. Due to this, calculations should only be used as a screening tool to assess the risk of low frequency noise from the proposed development and/or extension of existing commercial, industrial and trade premises.

Other factors you should consider:

- Noise data provided by equipment manufacturers and suppliers of noise control solutions may not be available at low frequencies. The frequency range of most acoustic testing standards doesn't extend below one-third octave band 50 Hz.
- Equipment noise levels from measurements conducted at other facilities can be used as an input for noise calculations. However, the uncertainty associated with using data from another site needs to be considered.
- Engineering calculation methods for the outdoor propagation of sound should be used with caution. The procedures such as those within ISO 9613-2:1999 or CONCAWE (1981), can be based on empirical data in octave bands rather than one-third octave bands, meaning the value of attenuation factors at low frequencies may not be documented.

Using extrapolation in low frequency noise calculations

It may be acceptable to use extrapolation to estimate noise emission levels in the low frequency range if the trend is known from:

- measurement
- verifiable literature references, for example, Bies, Hansen & Howard (2018) and Joint Departments of the Army and the Air Force USA (1995).

Similarly, correction factors applied to represent the propagation of sound from the source to the receiver may be evaluated by extrapolation, considering the trend observed at the lower end of the frequency spectrum.

Any assumption made should be conservative to address the increase in modelling uncertainty introduced by extrapolating data. For example, use a flat value when the frequency spectrum trend shows a reduction in noise as frequency decreases.

Acoustic consultants and other qualified professionals who assess low frequency noise must detail and justify the approach used to estimate noise levels in their assessment report. This should include any uncertainty in the calculation method.

Threshold levels for assessing low frequency noise

Low frequency noise emitted from commercial, industrial and trade premises should be assessed by comparing its frequency spectrum to the relevant threshold levels. Specifically, Z-frequency weighted (unweighted or linear) measurements in one-third octave bands from 10 Hz to 160 Hz are compared with low frequency threshold levels (Table 2 for indoor or Table 3 for outdoor measurements).

The threshold levels are not set limits. Rather, they are levels that indicate a potential risk of problematic low frequency noise. The disturbance from low frequency noise depends on the:

- noise level
- characteristics that can increase annoyance with the noise, for example, tonality, frequency modulation
- baseline noise levels in the absence of the noise of concern.

Indoor low frequency threshold levels

Table 2 provides indoor noise threshold levels to be used for indoor measurements. The noise threshold levels for indoor low frequency noise are based on the levels proposed by Moorhouse, Waddington and Adams (2011).

Table 2: Indoor one-third octave low frequency noise threshold levels from 10 Hz to 160 Hz

Indoor one-third octave low frequency noise threshold levels													
One-third Octave (Hz)	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
L_{eq} (dB)	92	87	83	74	64	56	49	43	42	40	38	36	34

Outdoor low frequency threshold criterion

Table 3 provides outdoor noise threshold criterion to be used for outdoor measurements. The noise threshold level for outdoor low frequency is based on the assumed façade noise reductions given in Downey and Parnell (2017).

Table 3: Outdoor one-third octave low frequency noise threshold levels from 10 Hz to 160 Hz

Outdoor one-third octave low frequency noise threshold levels													
One-third Octave (Hz)	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
L_{eq} (dB)	92	89	86	77	69	61	54	50	50	48	48	46	44

Assessing low frequency noise from existing premises

The assessment and measurement of low frequency noise, as outlined in this guideline, should only be conducted or supervised by someone suitably qualified and experienced in noise assessments and measurements. For example, an acoustic consultant or practitioner who is eligible for membership of the Australian Acoustical Society.

The general assessment method adopted for low frequency noise is broadly based on the approach proposed by Moorhouse, Waddington and Adams (2011) and makes use of the adjustments for outdoor noise assessment proposed by Downey and Parnell (2017).

Figure 2 summarises the steps involved in the assessment of low frequency noise from an existing commercial, industrial and trade premises.

For circumstances where the source of low frequency noise is known, proceed through the following steps in Figure 2.

If the source of low frequency noise is unknown, locating the source of the noise can be complicated. It can be difficult to accurately determine the sound that causes the disturbance and its source. In this case, proceed through the steps in Figure 2. A method for identifying the source is provided in Step 7 – Assess the noise source of low frequency.

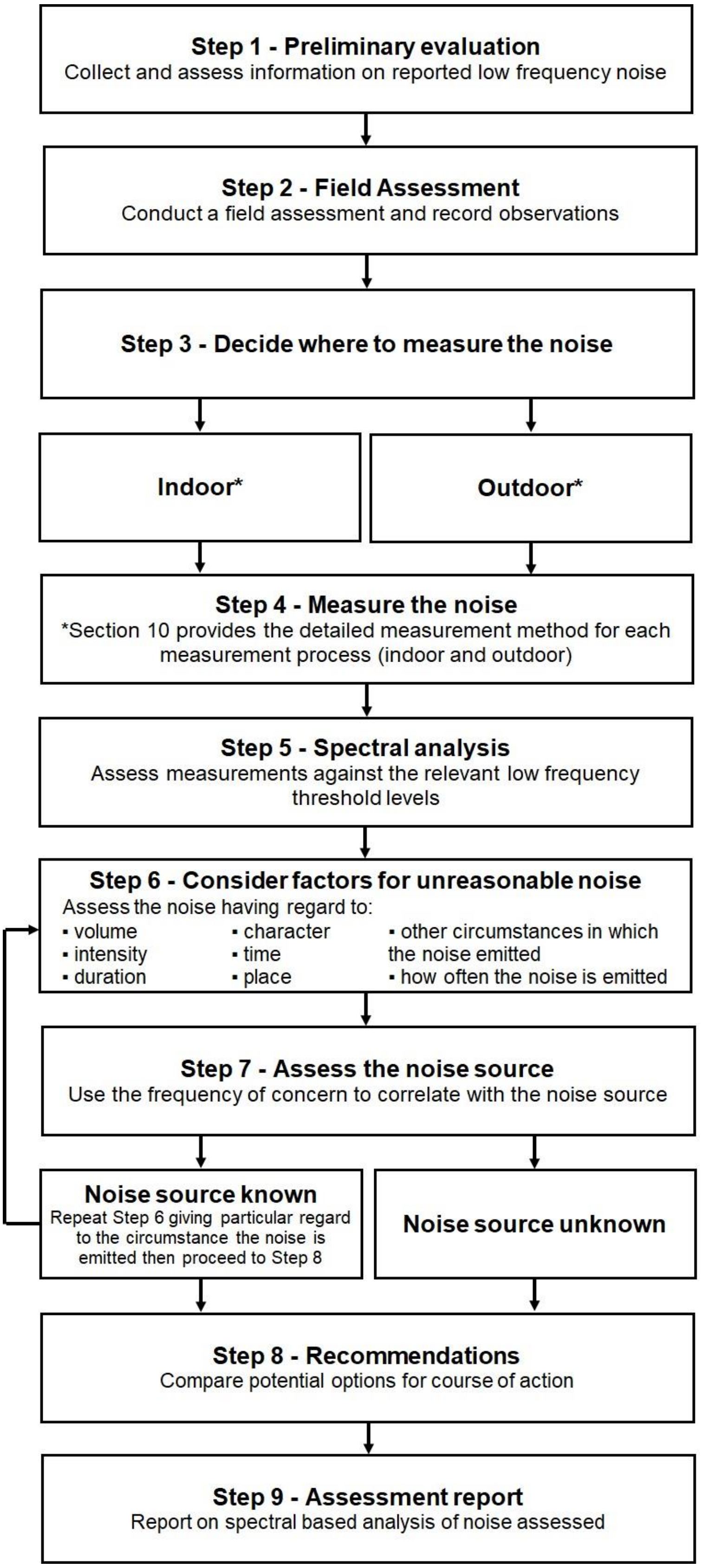


Figure 2: Assessment of low frequency noise from existing premises

Step 1 – Preliminary evaluation

Collect and assess information on reported low frequency noise.

The following information should be considered:

- times and places where the noise occurs
- observations from other people, whether they can or can't hear the noise in the same places
- indication of whether the noise is still present when the power to the residence is switched off
- descriptions of the noise, for example, low throbbing, rumbling, droning, whirring, or thumping noise
- details of the alleged source of the noise, if known
- strategies used to relieve the effects of the noise.

Use the following checklist to determine whether a low frequency noise may be present:

The way the person reporting the noise describes it can assist in determining whether it relates to low frequency sound. For example, low frequency noise is often described as a:

☐ low rumble, droning, or thumping sound

☐ vibration that travels through the air

☐ pulse or pressure in the ears

☐ sensation of vibration felt in the chest or the ear

☐ sound perceived by some people, that is deemed loud and/or may cause discomfort or even sickness, and is not necessarily heard by others

☐ sound that can be heard indoors but not outdoors, or a sound that is louder indoors

☐ sound heard in some rooms and not in other rooms

☐ sound whose intensity varies at different positions across the room

☐ vibration which is felt or noticed (rattling of furniture or windows) even when there is no obvious source of vibration such as industry or rail line

☐ sound more audible at night than during the day.

If, based on the information collected, low frequency noise is expected to occur, proceed to Step 2 – Field assessment.

Step 2 – Field assessment

Conduct a field assessment and record observations.

Attend the site of the reported noise to determine if a low frequency sound can be heard and record observations. If possible, do this at a time when the low frequency noise is expected to be most prominent.

It's preferable to conduct this field assessment in the presence of the person reporting the noise.

If the reported noise occurs at the time of field assessment, take an attended noise measurement.

If the noise isn't occurring or isn't at its most prominent, a further measurement should be considered.

Survey the surroundings to identify the location and source of the sound emitted. Narrow-band spectral analysis can assist in this assessment, to identify the specific frequency of tones. If the noise source is identifiable, provide adequate justification in the noise assessment.

Step 3 – Decide where to measure the noise

The measurement point may be inside or outside the affected building at the sensitive receiver's premises. See section 'Measurement method' for the description of measurement locations. The choice of the measurement location needs to be justified in the assessment report.

Step 4 – Measure the noise

See the section 'Measurement method' for further guidance on measuring the noise.

Step 5 – Spectral analysis

Assess measurements against the relevant low frequency threshold levels.

Compare the measured levels in each one-third octave bands with the corresponding threshold levels from 10 Hz to 160 Hz (Table 2 for indoor or Table 3 for outdoor measurements).

Step 6 – Consider factor for unreasonable noise

Assess the noise having regard to the definition of unreasonable noise in section 3(1) of the Act.

If the measured noise level exceeds the relevant threshold level in any one-third octave band, it should be considered a potentially significant low frequency noise emission.

Frequency spectrum is a prescribed factor for unreasonable noise under Regulation 120. The following factors should be considered when assessing noise as unreasonable:

- **volume** – represented by the total volume affected and how far the noise has spread
- **intensity** – represented by the measured noise levels in decibels
- **duration** – represented by how long the noise occurs
- **character** – represented by what the noise sounds like. This should include whether the noise characteristics present are known to increase annoyance, such as tonality, frequency modulation, or fluctuations of the noise level at a specific frequency
- **time** – when the noise is predominantly heard, for example, during the day or evening, or at night
- **place** – location where the noise is heard, for example, indoors and/or outdoors
- **other circumstances in which the noise is emitted** – represented by understanding why noise is emitted. For example, what noise controls have been applied, and what is available to control the noise
- **how often the noise is emitted.**

Step 7 – Assess the noise source of low frequency

Use the frequency of concern to correlate with the noise source.

Based on spectral analysis, use the identified exceeded frequency within the one-third octave band spectrum to confirm the identified source, or to try to pinpoint the source of low frequency noise if unknown. This may require a further field assessment, including observations and/or measurements at the identified source for verification.

Narrow-band spectral analysis is recommended for these investigations, as it can identify the precise frequency of tones to help track their source.

If the source is confirmed, repeat step 6 giving regard to the circumstances in which the noise is emitted before proceeding to step 8.

Step 8 – Recommendations

Compare potential options for course of action.

Depending on the spectral analysis regarding low frequency noise, recommendations to consider may include:

- further investigation to identify the source of the alleged or known low frequency sound emitted from a premises
- further investigation to identify potential actions and the preferred option to address low frequency sound emitted from a premises and its impacts
- a detailed implementation plan of remedial action including consideration of a staged approach, where appropriate, to address low frequency sound emitted from a premises and its impact.

If the findings conclude that no further action is required, adequate justification is to be provided within the assessment report. This recommendation is only to be considered when all other options have been exhausted.

Step 9 – Assessment report

Report on spectral based analysis of noise assessed.

Report findings in a detailed noise assessment report. This should include:

- whether low frequency noise is evident based on the assessment conducted
- the noise source (if known)
- recommendations for a course of action, for example, further investigation or remedial works to minimise or mitigate the low frequency noise identified and its impact.

The 'Assessment report' section provides more information on the reporting requirements when preparing an assessment report.

Measurement method

Noise indicator

The main indicator to be measured and assessed is the equivalent sound pressure level with Z-frequency weighting $L_{eq,T}$ (sometimes also referred to as $L_{Zeq,T}$) in each one-third octave bands from 10 Hz to 160 Hz. *T* is the duration of the measurement or the logging period.

The measurement should be conducted using the Fast ('*F*') time weighting.

Other indicators, such as percentile levels $L_{90,T}$, $L_{10,T}$, or $L_{50,T}$, may also be measured in each one-third octave band of interest. This can provide further data that may be useful to assess the risk of low frequency noise impact.

If the sound level meter doesn't have filters extending down to one-third octave band 10 Hz, the overall C-frequency weighted level ($L_{Ceq,T}$, and, if relevant, percentile levels) will need to be measured to validate the assessment across the full frequency range of interest. For more information, see the following section 'Assessing when using equipment with a limited frequency range'.

Measurement time

Conduct the measurement, whether attended or unattended, at a time when the low frequency noise is expected to be most prominent, so it's investigated when it has the worst impact.

Unattended measurements should be conducted over a minimum of three days to ensure the data collected represents the noise investigated. The measurement should include weekend days as well as weekdays as relevant to the occurrence of the noise.

If the noise is assessed at several measurement points, simultaneous measurements are preferred. If several sound level meters are used, their clocks should be synchronised.

Measurement duration

Each measurement undertaken should have the same duration. The duration of each measurement, including the logging period for an unattended measurement, should:

- be selected to represent the noise and its variation over time
- be at least five minutes, and if longer, allow five-minute values to be derived
- include at least five full cycles if the noise investigated is observed to have repetitive cycles.

If the noise occurrence varies with time, or if the noise source is known and can be switched ON/OFF, the measurement duration should allow for temporal variations as follows:

- **attended measurement:**
    - several separate measurements should be undertaken to represent ON/OFF sequences, with preferably three or more measurements (ON-OFF-ON or OFF-ON-OFF) and no less than two measurements (ON-OFF or OFF-ON).
- **unattended measurement:**
    - the logging period should be set to capture periods across which the noise is present (ON) and periods across which the noise does not occur (OFF).

Indoor measurement location and procedure

Measurement of low frequency noise within an affected building should be made in the room where the noise is most affecting the occupants. The measurement is to be assessed against the indoor low frequency threshold levels (refer Table 2).

Indoor measurement point(s)

The primary indoor measurement location should represent the noise experienced by the occupant(s) of the room. The measurement location is at an expected occupancy position where the low frequency noise is reported to be most intrusive. If this is not possible, another expected occupancy position should be chosen.

Conduct spot measurements if there is more than one expected occupancy position and it's not practical to measure at more than one location. Spot measurements can assist with identifying the most critical location as dictated by the indoor noise threshold levels given in Table 2.

The microphone should be positioned to represent the location of the occupant's head. It should not be less than 0.3 metres (m) from any room surface.

Figure 3 illustrates the measurement points for an indoor assessment. In this example, two expected occupancy positions can be considered. The time when low frequency impact occurs is determined by the selection of the measurement point. If the impact occurs at night only, measurement should be conducted for the bed position. If it occurs during the day, the desk position could be considered instead.

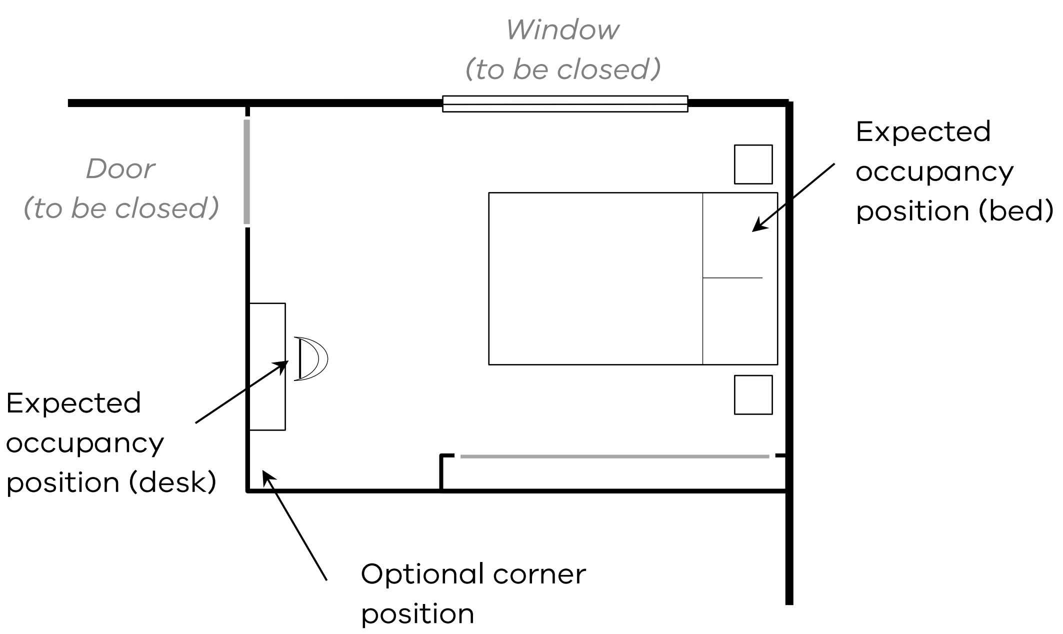


Figure 3 Indoor measurement points.

Optional corner measurement

In principle, the distribution of sound in a rectangular room is such that, for any frequency, the sound level in corners reaches a maximum value. If a further investigation into the low frequency noise is necessary, an additional measurement may be considered at a 3D corner position, which is the corner of an intersecting ceiling and walls, or floor and walls.

The microphone should be positioned at a fixed point within 0.1 m from the intersection of three solid surfaces. Chose a corner position away from doorways and windows, and where possible, select the most sound-reflecting of two opposing surfaces; this is typically the most rigid of the two surfaces.

For example, the optional corner position shown in Figure 3 is away from the door, the window, and the built-in robe.

This measurement is not meant to be assessed against the indoor noise threshold levels unless the corner is an expected occupancy position. The measurement can however give a useful indication that noise levels in the room may be higher than those for expected occupancy positions.

Room conditions

An indoor measurement is conducted:

- with all windows and doors closed
- with the room furnished as normal but unoccupied
- in the absence of rain, with outdoor wind speed less than 3 m/s and with no audible, wind-induced noise indoors.

The influence of internal noise sources such as appliances, ventilation, air conditioning systems, and other building services must be minimised by turning them off, or by conducting measurements when they are not operating.

Indoor measurement procedure

If the noise is steady, use a handheld sound level meter to conduct a scanning measurement by moving the microphone slowly and silently across the space within 0.3 m of the expected location of the occupant's head. To be valid, this measurement should be repeatable, with a variation of less than 3 dB in each one-third octave band of interest.

If a scanning measurement is not practicable, or cannot be validated, measure at a fixed microphone point. Preliminary spot measurements should be taken around the measurement location. This should consider the potential head movements of the occupant(s), to identify precisely where the highest noise levels occur in the frequencies relevant to the indoor noise threshold levels.

For either approach:

- measure the noise levels at the primary indoor measurement point(s), in each one-third octave band from 10 Hz to 160 Hz
- assess the measured frequency spectrum in one-third octave bands from 10 Hz to 160 Hz against the indoor noise threshold levels, with no reflection adjustment applied.

Outdoor measurement location and procedure

Outdoor measurement points

The preferred outdoor measurement location should represent free field conditions, for which the sound pressure levels recorded at the microphone are not affected by the reflection of sound on surfaces other than the ground.

For this guideline, an outdoor measurement point 10 m away from any reflecting surface (other than the ground) is deemed to satisfy the free field conditions for the frequency range of interest.

If a measurement in free field conditions is not possible, the noise levels measured would need to be adjusted to account for sound reflections. A precise determination of the reflection adjustment in the low frequency range can be complex and its value in each individual one-third octave may vary for the following reasons:

- a 'destructive interference' between the incident sound and its reflection can occur and affect the measurement. This may be the case at frequencies for which the wavelength is approximately four times the distance between the reflecting structure and the measurement point. Destructive interference can result in a significant reduction in sound level in the affected one-third octave band
- the amount of sound energy reflected is influenced by the design of the reflecting structure: its shape, dimensions, building materials, their texture, and the assembly fixture.

The section 'Outdoor measurement procedure', item 3 below provides the details of a simplified approach to use when measurement in free field conditions is not possible. This simplified approach avoids any single one-third octave band from being compromised because of destructive interference.

If the reflection adjustment can be determined with reasonable accuracy across the frequency range of interest, an alternative measurement procedure is acceptable provided the method used is described in detail and justified in the assessment report.

Outdoor measurement procedure

For low frequency noise measured outdoors and assessed against the outdoor noise threshold levels, the following steps apply:

1. Survey the surroundings of the noise sensitive receivers' premises and conduct spot measurements. This provides an understanding of the frequency spectrum of the noise. Take note of the order of magnitude of the noise levels in each one-third octave band of interest and the presence of prominent tones that are 3 dB above the adjoining one-third octave bands. Narrow-band spectral analysis can be useful to identify tones.
2. If free field conditions are achieved for a measurement point approximately 1.5 m above ground and the frequency spectrum at this point represents the noise observed in item 1 of this procedure:
    a. measure the noise levels at this point, in each one-third octave band from 10 Hz to 160 Hz, and
    b. assess the measured frequency spectrum against the outdoor noise threshold levels without applying a reflection adjustment.

3. If no suitable point can be identified to represent free field conditions:
   a. identify a measurement location outside the building, on the side reported as most affected by low frequency noise. Ensure there is sufficient clearance to allow for measuring within 2 m in front of the facade, with no reflection other than the ground and the building facade.
   b. measure at two points, as shown in Figure 4, at the same height, approximately 1.5 m above the ground, and precisely at:
      i. Point A – 1.2 m from the building facade
      ii. Point B – 1.9 m from the building facade.

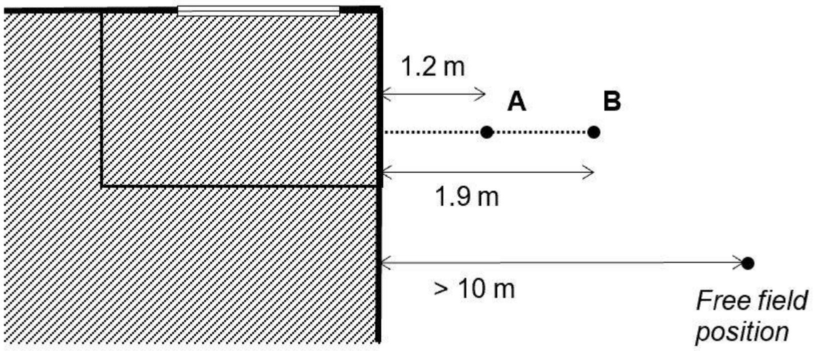


Figure 4: Outdoor measurement points (not to scale)

   Destructive interference can occur due to facade reflection and will likely compromise certain frequencies. At Point A, the one-third octave bands likely to be compromised are 63 Hz and 80 Hz. At Point B, the one-third octave bands likely to be compromised are 40 Hz and 50 Hz.

   c. Check that the noise at both measurement points represent the noise observed in item 1 of this procedure for all frequency bands (other than one-third octave bands likely to be compromised):
      i. If both measurement locations represent the noise observed in 1, proceed to 3(d).
      ii. If one or both measurement points do not represent the noise observed in 1, select another measurement location where both Points A and B represent the noise being investigated. As shown in Figure 4, Points A and B need to be along the same line perpendicular to the facade, respectively 1.2 m and 1.9 m from the facade.
   d. Measure the noise levels at both Points A and B, in each one third octave band from 10 Hz to 160 Hz using Z-frequency weighting. If this is practicable, the two measurements should be conducted simultaneously.
   e. Take the highest value of the two measurements in each frequency band, discarding the one-third octave bands likely to be compromised specified in 3(b), and apply a generic reflection adjustment of −2.5 dB.
   f. Assess the frequency spectrum obtained from 3(e) against the outdoor noise threshold levels given in Table 3.

Microphone setup

Measuring equipment should be installed securely to minimise the risk of microphone vibration. This is particularly important if the microphone or the sound level meter is installed on a tripod, stand, pole, or boom.

For all outdoor measurements, the microphone should be fitted with the windshield provided or specified by the sound level meter manufacturer.

Field calibration checks

The field performance of the measurement system must be checked with a portable reference sound source (acoustic calibrator or pistonphone) with a nominal frequency of 250 Hz or lower.

Conduct calibration checks immediately before and after each measurement sequence, and at regular intervals during long-term measurements. If possible, calibration checks conducted at nominal frequencies within the one-third octave band range from 10 Hz to 160 Hz are preferred.

The reference sound source must meet the Class 1 (Type 1) requirements set out in Australian Standard AS IEC 60942, and hold a current calibration certificate issued by a calibration laboratory accredited with the National Australian Testing Association (NATA, 2019).

The calibration checks should be conducted for the whole measurement system, including any extension cable used.

If the measurement system registers a calibration discrepancy of 1.0 dB or more between consecutive checks, any measurement in the interval between the two checks must be considered invalid and the measurement should be repeated.

An electrical self-check of the measurement system should be conducted immediately before and after each measurement sequence, and at regular intervals during long-term measurements.

Weather conditions

Measurements that have been taken when rain or wind may affect the measured noise levels should be discarded. Wind can affect the assessment not only when it generates noise at the microphone, but also when it influences the propagation of sound (leading to a different assessment outcome). Wind can also induce low frequency noise when it moves or vibrates buildings and structures.

Collect outdoor weather data at the measurement site using an anemometer and a rain gauge. The validity of data may also be assessed based on observations made at the site, using the Beaufort wind scale (as detailed in Appendix C of Australian Standard AS 1055:2018). It is also acceptable to consider reports from the nearest Bureau of Meteorology weather station.
For unattended measurements, weather conditions should be recorded every half-hour, or at shorter intervals.

It can reasonably be assumed that a measurement conducted either indoors or outdoors under wind speeds of 3 m/s or less (Beaufort wind scale 0, 1 or 2 in AS 1055:2018) is not affected by wind.

Outdoor measurement conducted with wind speed 3 m/s to 5 m/s (Beaufort wind scale 3) may be valid, provided the effect of wind on the measurement is carefully considered. This consideration should be documented in the assessment report.

Extraneous noise

Extraneous noise refers to any noise which is not part of the noise being assessed and is not relevant to the typical ambient environment at the measurement location.

When measuring low frequency noise, common sources of extraneous noise include local traffic (road and rail), construction works, aircraft flyovers, thunder, wind effects on structures or on the microphone diaphragm. Other sources of extraneous noise can include other types of low frequency noise outlined in Table 1.

Exclude any extraneous noise from the measurements. Data validity should be confirmed by site observations or by listening to audio recordings to ensure that the measurement was not affected by extraneous noise. Alternately, extraneous noise can be excluded by pausing the sound level meter during attended measurements, or by discarding it during post-processing of recorded attended and unattended measurements.

Observation records

Observations made during the field inspection and measurement period should be recorded. This may mean that a noise observation record is made by the occupant of the premises where the low frequency noise is being investigated.

These records can be useful in helping with the investigation of the reported low frequency noise They can also be used for comparison with measured results and data validation.

The noise observation record should include:

- the time the noise is heard (start and end)
- noise description
- details of the location where each observation occurred
- the effects of the noise
- any other factors that may influence the noise, or its impact, such as weather conditions.

Audio recordings

Audio recordings may be conducted with both attended and unattended measurements to inform validation and allow for post-processing. It is essential that the occupants of sensitive receivers' premises, where measurements are conducted, are informed when audio recordings take place and that their agreement is provided.

If the audio signal is digitally recorded to allow for post-processing, the recording must include a calibration tone generated from the reference sound source used for field calibration checks. Digital recordings must be conducted with a sampling rate adequate for the post-processing analysis, without distortion or saturation, using a lossless compression format with automatic gain controls, and limiters disabled.

Measuring equipment

The measurement system for noise assessments is typically a sound level meter, which consists of a microphone connected to the main unit through a pre-amplifier. A portable reference sound source (acoustic calibrator or pistonphone) is also required to check the performance of the measurement system during the field measurements.

Unattended noise measurements are conducted using a noise logger that measures continuously and provides integrated information at regular intervals. A noise logger typically comprises of a sound level meter in a weatherproof case. The microphone is commonly fitted to a small pole extending above the case. It may also be placed on a tripod or a boom and connected to the main unit using an extension cable.

The measurement system must:

- meet the Class 1 (Type 1) requirements set out in Australian Standard AS IEC 61672.1
- have intrinsic electronic noise sufficiently low so it doesn't affect the measurement
- have a noise floor and a dynamic range adequate for the sound measured. The peak sound pressure level of the noise measured should be at least 10 dB below saturation at any time
- have an electrical self-check function
- have reliable data storage
- include one-third octave-band filters, which must comply with the relevant requirements specified in Australian Standard AS IEC 61260.1 for the frequency range of 10 Hz to 160 Hz.

To ensure measurements are fully traceable, all instrumentation used for sound measurement and field calibration must hold a current calibration certificate issued by a calibration laboratory accredited with the National Australian Testing Association (NATA, 2019).

If audio recordings are conducted for post-processing data, the recording device should have a linear frequency response consistent with the requirements of Australian Standard AS IEC 61672.1. The intrinsic noise should be sufficiently low to ensure analysis can be conducted without having to apply adjustments for a low signal-to-noise ratio. The recording device should also be capable of disabling all automatic gain controls and limiters and allow for a lossless compression recording format.

Assessing when using equipment with a limited frequency range

The measurement system used preferably has one-third octave band filters across the full 10 Hz to 160 Hz frequency range. It may still be possible to conduct a valid assessment across the low frequency range using a meter that has a limited frequency range that does not extend down to one-third octave band 10 Hz.

This can be verified by including a measurement using C-frequency weighting when conducting the assessment. Comparing the overall C-frequency weighted level to the values in the first row of Table 4 allows for verification if some one-third octave bands have to be discarded from the assessment.

Table 4: Overall 'C' weighted levels (L_c) below which the given 1/3 octave bands can be discarded

Overall C weighted levels below which the given 1/3 octave bands can be discarded						
Overall C-frequency weighted level L_C	> 76 dB(C)	≤ 76 dB(C)	≤ 71 dB(C)	≤ 66 dB(C)	≤ 60 dB(C)	≤ 54 dB(C)
One-third octave band that can be discarded	None	10 Hz	10 Hz and 12.5 Hz	10 Hz to 16 Hz	10 Hz to 20 Hz	10 Hz to 25 Hz

Assessment report

The assessment report must document the method used clearly and accurately with sufficient details to make sure that:

- the noise assessment measurements, calculations, and analysis can be replicated by another suitably qualified acoustic practitioner
- any deviation from the procedures of this guideline found necessary during an assessment, is justified
- all assumptions and uncertainties are documented, together with details on how they have been taken into account when drawing conclusions for the assessment.

Measurement results and input data for calculations must be from verifiable sources that are referenced.

The information provided for each assessment position should include:

- details of the low frequency noise sound assessed, its source (if known), and the aim and scope of the investigation
- details of relevant site-specific data, for example, operating conditions of the industry premises being investigated for low frequency noise
- details of assessment positions including the address of assessment location and/or GPS coordinates
- justification for chosen measurement location (indoor or outdoor)
- justification and details of the measurement point(s) and reflection adjustment(s) adopted if an alternative method was used instead of item 3 in section 'Outdoor measurement procedure'
- the noise threshold criterion used (indoor and/or outdoor) for each corresponding threshold level from 10 Hz to 160 Hz
- results and interpretation, including relevant noise level data, such as spectral data
- a statement of whether (or not) the noise complies with the noise threshold levels for each corresponding threshold level from 10 Hz to 160 Hz.

Reporting requirements for noise measurements indoors and outdoors

The following needs to be reported for all noise measurements:

- dates and times of noise measurements
- list of all equipment used including brand, model serial number, and calibration status, as well as any specific settings used
- information gathered during the preliminary survey and spot measurements, and how it informed the measurement methodology adopted
- justification for the selection of microphone position and orientation
- for indoor measurements, provide a detailed description and sketch of the room including the shape and dimensions, materials and furnishings, and precise measurement location of the coordinates of each measurement point
- for outdoor measurements, the measurement points used, their distance from sound-reflecting surfaces and the microphone height above ground level – the report should include one or several sketches summarising this information

- date, time, and measured levels for field calibration checks conducted and nominal frequency of the reference sound source used
- atmospheric conditions at the time of measurement
- other relevant information, for example, field notes/observations, description of building facade and other reflecting surfaces, and photographs of microphone position demonstrating that it is an appropriate location.

References

Victorian Government legislation and publications

Victorian Government (2017), *Environment Protection Act 2017*, No. 51/2017
https://www.legislation.vic.gov.au/

Victorian Government (2021) Environment Protection Regulations 2021

Environment Protection Authority Victoria (EPA) 2021, *Noise limit and assessment protocol for the control of noise from commercial, industrial and trade premises and entertainment venues* (publication 1826)

Australian and international standards

International Standard 1996, *Acoustics— Attenuation of sound during propagation outdoors—Part 2: General method of calculation*, ISO 9613-2:1999, International Standard Organization, Switzerland.

Standards Australia 2004, *Electroacoustics—Sound Calibrators*, AS IEC 60942—2004, Standards Australia, NSW, Australia.

Standards Australia 2018, *Acoustics— Description and measurement of environmental noise*, AS 1055:2018, Standards Australia, NSW, Australia.

Standards Australia 2019, *Electroacoustics—Octave-band and fractional-octave-band filters specifications*, AS IEC 61260.1—2019, Standards Australia, NSW, Australia.

Standards Australia 2019, *Electroacoustics—Sound level meters specifications*, AS IEC 61672.1—2019, Standards Australia, NSW, Australia.

Standards New Zealand 1998, *Acoustics – The assessment and measurement of sound from wind turbine generators,* NZS 6808:1998, Standards New Zealand, Wellington, New Zealand.

Standards New Zealand 2010, *Acoustics – Wind farm noise,* NZS 6808:2010, Standards New Zealand, Wellington, New Zealand.

Other references

Bies D A, Hansen C H & Howard C Q 2018, *Engineering noise control*, 5th ed., CRC Press, Taylor & Francis Group, Florida, USA.

Conservation of Clean Air and Water in Europe (CONCAWE) 1981, *The propagation of noise from petroleum and petrochemical complexes to neighbouring communities*, Report no. 4/81, Den Haag, Netherlands, May 1981.

Downey, G and Parnell, J 2017, *Assessing low frequency noise from industry – a practical approach*, 12th ICBEN Congress on Noise as a Public health Problem, Zurich, Switzerland, June 2017.

Joint Departments of the Army and the Air Force USA 1995, *Technical Manual: Noise and Vibration Control*, TM 5-8054/AFJMAN 32-1090, Headquarters, Departments of the Army and the Air Force, Washington, DC, USA, 26 May 1995.

Leventhall G 2003, *A review of published research on low frequency noise and its effects*, Contract ref: EPG 12/50, Department of Environment, Food and Rural Affairs, London, UK.

Moorhouse A, Waddington D & Adams M 2011, *Procedure for the assessment of low frequency noise complaints*, Department of Environment, Food and Rural Affairs, London, UK.

National Association of Testing Authorities (NATA) 2019, *Specific Accreditation Guidance: Calibration reference equipment table June 2019*, NATA, Australia.

Further reading

Acoustical Society of America (ASA) 2016, *Quantities and procedures for description and measurement of environmental sound, Part 7: Measurement of low-frequency noise and infrasound outdoors and in the presence of wind and indoors in occupied spaces*, ANSI/ASA S12.9-2016/Part 7, Acoustical Society of America, NY, USA.

Association Française de Normalisation (AFNOR) 2017, *Acoustique — Basses fréquences — Méthode de mesurage (Acoustics - Low frequency noise - Measuring method)*, XP S31-135 (02/2017), Association Française de Normalisation, La Plaine Saint Denis Cedex, France.

Baliatsas C, van Kamp I, van Poll R, Yzermans J 2016, *Health effects from low-frequency noise and infrasound in the general population: Is it time to listen? A systematic review of observational studies*, Science of the Total Environment 557-558 (2016), pp. 163-169.

Environment Protection Authority Victoria (EPA) 2019, *Industry guidance: supporting you to comply with the general environmental duty* (publication 1741).

Olivia D, Hongisto V, Keränen J, Koskinen V 2011, *Measurement of low frequency noise in rooms, Indoor environment laboratory*, Turku, Finish Institute of Occupational Health, Helsinki, Finland.

van Kamp I, Breugelmans O, van Poll R, Baliatsas C 2017, *Burden of disease from exposure to low frequency noise: a Dutch inventory*, 12th ICBEN Congress on Noise as a Public health Problem, Zurich, Switzerland, June 2017.