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NZS 6808:1998

New Zealand Standard

Acoustics –
The Assessment and Measurement of Sound from Wind Turbine Generators

(2)

COMMITTEE REPRESENTATION

This Standard was prepared by the Technical Committee AV/5/6 Wind Turbine Generators for the Standards Council established under the Standards Act 1988.

The committee consisted of representatives of the following:

Bel Acoustic Consulting
DesignPower NZ
Electricity Corporation of New Zealand
Energy Efficiency and Conservation Authority
Garrad Hassan Pacific
Local Government New Zealand
Malcolm Hunt Associates
Ministry of Health
National Environmental Noise Service
Philip Dickinson Acoustics
TransAlta NZ
WindTorque

In addition the following organizations were invited to comment:

Ministry for the Environment
The Consumers Institute
The New Zealand Acoustical Society

AMENDMENTS

No	*Date of issue*	*Description*	*Entered by, and date*

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RELATED DOCUMENTS

Reference is made in this document to the following:

NEW ZEALAND STANDARDS

NZS 6801:1991 Measurement of sound

NZS 6802:1991 Assessment of environmental sound

IEC STANDARD

IEC DIS 1400:- - - - Wind turbine generator systems
Part 11:- - - - Acoustic noise measurement techniques (in preparation)

ISO STANDARDS

ISO 1996:- - - - Acoustics – Description and measurement of environmental noise
Part 1:1982 Basic quantities and procedures
Part 2:1987 Acquisition of data pertinent to land use
Part 3:1987 Application to noise limits

ISO 9613:- - - - Acoustics – Attenuation of sound during propagation outdoors
Part 1: 1993 (E) Calculation of the absorption of sound by the atmosphere
Part 2: 1996 General method of calculation

OTHER PUBLICATIONS

Berglund, B. and Lindvall, T. 1995. Community Noise – Archives of the Centre for Sensory Research Vol. 2, Issue 1. Document prepared for the World Health Organization.

International Energy Agency. Expert Group Study on Recommended Practices for Wind Turbine Testing and Evaluation. Part 4. Acoustics – Measurement of Noise Emission from Wind Turbines. 3rd Edition 1994.

ETSU-R-97. The Assessment and Rating of Noise from Windfarms, Sept. 1996 (Department of Trade – UK).

ETSU W/13/00392/REP. Low Frequency Noise and Vibrations Measurement at a Modern Windfarm, first published 1977.

Laboratory and Field Studies on Infrasound and its Effects on Humans – Ulf Landstrom. Journal of Low Frequency Noise and Vibration Vol. 6, No.1, 1987.

The users of this Standard should ensure that their copies of the above-mentioned New Zealand Standards or of overseas Standards approved as suitable for use in New Zealand are the latest revisions or include the latest amendments. Such amendments are listed in the annual Standards New Zealand *Catalogue* which is supplemented by lists contained in the monthly magazine *Standards* issued free of charge to committee and subscribing members of Standards New Zealand.

FOREWORD

The purpose of this Standard is to aid both windfarm development and Territorial Local Authority planning procedures by providing a suitable method for the measurement and assessment of sound from Wind Turbine Generators (WTGs). This Standard also provides guidance on the limits of acceptability for sound received at residential and noise sensitive locations emitted from both windfarms and single WTGs. This Standard may be applied during the WTG/windfarm development planning process, to confirm compliance with resource consent conditions covering sound levels, and for the investigation and assessment of noise complaints arising from WTGs.

REVIEW OF STANDARDS

Suggestions for improvement of this Standard will be welcomed. They should be sent to the Chief Executive, Standards New Zealand, Private Bag 2439, Wellington 6020.

NOTES

NEW ZEALAND STANDARD

ACOUSTICS – THE ASSESSMENT AND MEASUREMENT OF SOUND FROM WIND TURBINE GENERATORS

1 SCOPE

1.1
This Standard covers the prediction of sound from wind turbine generators (WTGs), the measurement of sound from WTGs, and the assessment of the received sound. It is designed to provide a level of investigation and reporting that may be specified by land use planning procedures under any relevant legislation (e.g. an act of Government/bylaw of Territorial Government), particularly the assessment of environmental sound. For the purposes of this Standard, sound is defined as being airborne vibration within the audible frequency range. See note below.

1.2
This Standard is applicable to both horizontal and vertical axis wind turbines that are used for the purpose of generating electricity i.e. WTGs, including ancillary equipment in the immediate vicinity of the turbines. Sound sources not in the immediate vicinity may be more appropriately measured and assessed using other Standards (see list of Related documents). This Standard does not address wind turbines used for water pumping or milling purposes, nor does it address sound from service equipment used at the windfarm for maintenance and construction.

1.3
This Standard deals specifically with the measurement of sound from WTGs in the presence of wind, a situation which has high potential for fluctuations and errors due to both increased background sound levels and wind effects at the microphone. The measurement of sound in the outdoor environment can produce reasonably accurate and repeatable results if the recommended procedure is followed. Measurements conducted in accordance with other more general Standards (e.g. NZS 6801) should not be used for the measurement of sound arising from WTGs themselves. However NZS 6801 needs to be referenced for measuring background sound and other matters as described in 4.5 of this Standard.

NOTE – WTGs may produce sound at frequencies below (infrasound) and above (ultrasound) the audible range. Ultrasound attenuates rapidly over moderate distances. Reference to overseas studies on infrasound reveals that:

(a) Sound spectra for modern WTGs indicate that compliance with the limits in this Standard (clause 4.4.2) will ensure that infrasound pressure levels will be well below the threshold of perception.

(b) Any potential adverse effect of infrasound would occur at levels greater than the threshold of perception (see Related documents).

2 INTRODUCTION

2.1
It has been necessary to develop specific guidelines for the prediction, measurement and assessment of sound from WTGs because the requirements of other acoustic Standards are unsuitable for application to WTGs. These other Standards require the assessment of sound levels in the absence of wind, a situation that does not apply for operating WTGs. Acoustic Standards of other countries use different sound level descriptors to those in use in New Zealand and those Standards that are applicable to WTGs, do not cover the prediction, measurement and assessment in one practical document.

2.2
The normally applied method for the measurement of sound (set out in NZS 6801) is designed to be applied to measurements in windspeeds below 5 m/s. This is not suitable because WTGs operate in windspeeds typically from 4 m/s – 30 m/s and emit higher sound levels as windspeed increases.

2.3
The normal way of specifying maximum environmental sound levels (set out in NZS 6802), uses methods to quantify sound that relies on a measurement of the upper centiles of the distribution of sound levels (e.g. L_{10}). It is not appropriate to assess WTG sound on this basis because it is not possible to exclude wind effects when measuring low level WTG sound in a windy environment; sound from WTGs is similar to continuous background effects.

2.4
To measure and assess WTG sound to a satisfactory level, it is necessary to measure the lower centiles of sound level distribution (e.g. L_{95}). For this measurement, in order to ensure that the setting of acceptable limits provides a necessary level of environmental protection (with an adequate safety margin), a change is required to prescribed guidelines. Acceptable limits are derived from standard limits specified in international WTG publications but made consistent with New Zealand environmental sound standards.

2.5
The prediction of sound from WTGs has been derived from standard acoustic formulae. These are sourced from two WTG publications included in references listed in the Related documents. Details are included in 4.3.2.

3 DEFINITIONS AND SYMBOLS
For the purposes of this Standard the definitions of terms used in this Standard shall be those set out in NZS 6801 with the following additions:

AGL. Above Ground Level.

DIS. Draft International Standard.

HUB HEIGHT. The height in metres above ground of the central point of the wind turbine rotor.

L_w. The A-weighted sound power level in decibels.

$L_w = 10 \log_{10} W/W_o$

where

$W_o = 10^{-12}$ watts

W = sound power in watts.

TIME INTERVAL. The time period measured to an accuracy of ±1 %.

WINDFARM. A collection (group) of wind turbines installed in close proximity to one another and electrically interconnected to a common grid.

WINDSPEED. A measurement of the speed of the prevailing wind over a discrete time period. Measurement in m/s with a tolerance of 0.5 m/s.

WIND TURBINE. A device used for extracting kinetic energy from the wind.

WIND TURBINE GENERATOR (WTG). Wind turbine used to generate electricity.

NOTE –

(1) The word "sound" is used throughout this Standard where the context implies objective and/or quantifiable prediction, measurement, monitoring or assessment. The word "noise" is used where the context implies subjective assessment and/or loud, intrusive sounds (e.g "noise complaints", "noise sensitive" and "traffic noise" in the context of background sound level measurement).

(2) Throughout this Standard, sound pressure is always A-weighted.

4 PRELIMINARY PLANNING ISSUES – PRE-INSTALLATION

4.1 Section overview

4.1.1
This section assists in the planning and impact assessment of WTG developments by providing a method of calculation, to be used in advance of WTG installation, of the WTG sound level likely to be received at locations of interest in the vicinity of the proposed windfarm. It suggests a design limit for this sound level based on the avoidance of sleep disturbance and also sets out a method for measuring the pre-installation background sound at these locations of interest.

4.2 Pre-installation calculations and measurement

4.2.1
It is recommended that, for each location of interest, (see 4.5.1) a WTG sound level (L_{eq}) prediction be carried out and, if warranted (see 4.5.1), the background sound level (L_{95}) be measured in accordance with NZS 6801. In order to make an assessment of the predicted level, it is necessary that the predicted level be regarded as an L_{95} equivalent because the use of L_{eq} measurements would not be practicable in the presence of wind. L_{95} is typically 1.5 dB – 2.5 dB lower than its L_{eq} level. The error in this approximation is discussed in 4.4.2 of this Standard and is compensated for in the allowable sound level margin above the background level.

NOTE –

(1) The responsible territorial authority may require that the predicted level be checked after installation by measurement (L_{95}) of the actual WTG sound level at the location. (The necessity for the use of L_{95} measurements, is explained in 2.4 and discussed further in 4.4.2).

(2) Versions of NZS 6801 later than 1991, may use L_{90} as the background sound level. For wind turbines, however, L_{95} will continue to be used for this purpose.

4.3 Wind turbine sound level predictions

4.3.1
Prediction of sound levels from a windfarm or WTG is used to determine their environmental sound impact before the development takes place, e.g. for the purposes of participating in planning procedures under the relevant legislation.

4.3.2
The predicted outdoor sound level from the proposed WTG installation should be calculated according to equation 1. This equation is generally accepted as being slightly conservative (i.e. over-prediction of the sound levels) and is the same as that used in IEC DIS 1400-11. ➤

$$L_R = L_w - 10 \text{ Log } (2\pi R^2) - \Delta L_a \quad \text{(Eq.1)}$$

where

L_R = the sound pressure level from a single WTG at 1.2 m to 1.5 m above local ground level in dBA at distance R

L_w = the sound power level of the WTG in dBA. Measured according to IEA (International Energy Agency) procedures relating to WTG sound measurement or IEC DIS 1400-11

R = the distance between the source and the receiver in metres

$\Delta L_a = \alpha_a R$

α_a = attenuation of sound due to air absorption, in dBA/m for broad band sound which is typically 0.005 dBA (refer ISO 9613-1). This value is dependent upon the spectral character of the sound and the atmospheric conditions.

4.3.3

Equation 1 is based on hemispherical spreading of the sound from the source and does not take into account attenuation due to screening effects, i.e. where there is no line of sight between the WTG and receiver locations. Acoustic absorption and reflection effects due to vegetation and ground cover are also ignored. The sound level (L_R) predicted at a distance (R) is that at 1.2 m – 1.5 m above local ground level, which is assumed non-reflective. Thus, a good estimate can be derived when predicting sound propagation through free space (e.g. across open gullies), and a conservative estimate (i.e. over-prediction), for propagation across flat locations where ground absorption may be significant. For instances where the turbine is not in line of sight from the observation point, there may be an additional attenuation of up to 12 dBA. The degree of attenuation will depend upon a number of factors influencing the direct and indirect sound paths between the source and the receiver.

NOTE – Further information on the calculation of attenuation of sound outdoors may be obtained from ISO 9613 (see Related documents).

4.3.4

The sound power level (L_w) (refer IEC DIS 1400-11) of the WTGs used in the propagation model for predicting sound levels at a distance should be obtained from the WTG manufacturer. These levels should be measured in accordance with IEC or IEA recommendations. In all cases, the Standard adopted by the manufacturer to specify the L_w shall be stated in reports. These values relate to the WTG operational at a windspeed of 8 m/s at 10 m AGL.

4.3.5

The prediction of sound levels in the vicinity of a windfarm shall give an expected level of sound with all WTGs operating. For multiple WTGs, the resultant sound level at any location shall be calculated by considering the contribution of each individual WTG likely to be audible at the site and then adding these energy values by inverse logarithmic addition. Following prediction calculations, 4.5.1 is to be used to determine whether background sound levels should be measured prior to the windfarm development.

4.3.6

A worked example of prediction and background sound measurement is included as Appendix A.

4.4 Guide to acceptable limits

4.4.1 *Background*

In order to determine acceptability of predicted WTG L_R or windfarm sound levels it is necessary to compare these predicted levels with background sound levels measured in accordance with 4.5. The measured background sound levels are used to quantify the existing sound climate which can be quite low as WTG sites are often located in areas with a rural character. In order to provide a satisfactory level of protection against the potential adverse effects of WTG sounds, this Standard recommends an upper

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limit of acceptable WTG sound levels outdoors at the residential locations of 40 dBA L_{95} (refer to 4.4.2). This has been based on an internationally accepted indoor sound level of 30 to 35 dBA L_{eq} commonly used as a design level to protect against sleep disturbance (refer Berglund & Lindvall). See 4.4.2, Notes (1) and (2) for the relationship between L_{eq} and L_{95}. A reduction from outdoors to indoors of typically 10 dB with open windows has been assumed.

4.4.2 *Acceptable limit*

As a guide to the limits of acceptability, the sound level from the WTG (or windfarm) should not exceed, at any residential site, and at any of the nominated windspeeds, the background sound level (L_{95}) by more than 5 dBA, or a level of 40 dBA L_{95}, whichever is the greater.

NOTE –

(1) The level predicted (L_R) is based on the Leq source level of the turbines under consideration and hence the predicted level is also an L_{eq} level. This predicted level needs to be assessed against a recommended acceptable level and possibly a measured background level, both determined using an L_{95} descriptor.

(2) Overseas studies on windfarm sound (refer ETSU-R-97), have shown that L_{95} is typically 1.5 dB – 2.5 dB lower than L_{eq} measured over the same period. Similarly L_{eq} is typically 1.5 dB – 2.5 dB lower than L_{10}, assuming a normal distribution of sound levels. Hence L_{95} is typically 5 dB lower than L_{10}. For this reason, a 5 dB only margin should be applied above the L_{95} results, rather than the "background plus 10" approach which, subject to specified reservations, is taken in NZS 6802.

4.4.3 *Special audible characteristics*

These limits of acceptability are specified without any adjustment applied for special audible characteristics. Predicted or measured L_R levels from WTGs with known special audible characteristics shall be adjusted by adding +5 to the level. This adjustment is a penalty to account for the adverse subjective response likely to be aroused by sounds containing such characteristics (see section 5.3 for compliance assessment for sounds containing special audible characteristics).

4.4.4 *Territorial Authority compliance level*

Nothing in this Standard prevents the Territorial Local Authority from specifying an alternative compliance level (at residences or noise sensitive areas) on a site-by-site basis, taking into account individual circumstances and characteristics (e.g. distance to WTG(s), other sound sources, amenity values, etc.).

4.5 Background sound level measurements

4.5.1

This Standard recommends that background sound level measurements be carried out where predicted sound levels of 35 dBA or higher are calculated for the relevant locations. It is recommended that measurement positions be selected to include locations at or within the nearest affected residential property boundary, (the notional boundary – if a rural property), and near the location of representative positions for any other residential locations within the vicinity of a WTG or windfarm.

4.5.2

The locations selected for sound level measurements shall be more than 5 metres from any significant vertical reflecting surface, or other structures or objects (such as trees, power lines, etc.) so that "natural" wind sound generated at or near the microphone is excluded as far as possible from the measurements. The microphone shall be protected from extraneous wind sound by using a manufacturer's purpose designed wind shield. Instrumentation shall be in accordance with section 4 of NZS 6801. In addition, cables, supporting tripods and any other equipment associated with the measurement system shall be so secured as to avoid extraneous wind sound generated in close proximity to the microphone.

NOTE – If a particular residential location is, for example, surrounded by trees, some of the tree induced background sound may be considered as part of the general overall background sound at that location. For locations influenced by such factors as traffic noise, the background sound level measurements should include times in the early morning when traffic noise drops to a minimum.

4.5.3

Background L_{95} levels shall be measured in accordance with NZS 6801 at positions indicated in 4.5.1. Concurrent measurement of windspeed and direction shall be taken within the windfarm site at a known height above ground level.

NOTE – As background sound level measurements vary as a function of windspeed and direction, it is necessary to undertake measurements of windspeed and direction concurrently with background sound level measurements.

4.5.4

For the measurement of background levels, the same location should be used for the measurement of windspeed and direction before and after installation. Care must be taken to ensure the measurement of windspeed and direction is not significantly affected by the WTG(s). Measurement time intervals should be synchronized to allow for meaningful correlation of wind data with measured background sound levels. Monitored data should cover the range of windspeeds and wind directions generally expected at the windfarm site.

4.5.5

Background sound level measurements shall be correlated with the windspeeds measured at the windfarm or WTG site. A regression curve shall be used to describe the average background sound level versus the windfarm windspeed relationship. It may be necessary to separately correlate background sound levels with windspeed for different wind directions and/or time of day.

4.5.6

Background sound level measurements (L_{95}) shall be conducted in accordance with NZS 6801 excluding any reference to 'Zero Met' conditions (see 5.3.3 of NZS 6801), and measurement positions less than 5 metres from reflecting surfaces (see 5.2.2 of NZS 6801). Data should be obtained for the windspeed range of 5 m/s – 8m/s, i.e. slightly above the typical cut-in windspeed of currently commercially available WTGs.

NOTE – It is suggested that 10 minute L_{95} background sound measurements be taken at the relevant residential and/or other noise sensitive locations over the required range of windspeeds and wind directions as measured within the windfarm area. Most importantly, this should cover the lower range of windspeeds within which it is anticipated that the wind turbine sound would be most noticeable. It is expected that, at least, 10 to 14 days of continuous monitoring will be required to give a suitable range of data. Typically, this will result in excess of 1440 data points which should be plotted against the appropriate corresponding windspeed data. The windspeed should be monitored on the windfarm site and measured preferably at the WTG hub height. Windspeed should also be monitored over a 10 minute time period and be average values. Having a number of data pairs (windspeed and sound level), the regression curve can be fitted to the data to obtain the function relating the windspeed and the existing background sound level.

5 POST INSTALLATION SOUND COMPLIANCE TESTING

5.1 Section overview

5.1.1

This section outlines a precise method for the post installation compliance testing of sound from WTGs in the far field, i.e. at distances where the cyclic variations in sound due to blade rotation are no longer discernible. The procedure is based upon the method outlined in 4.5 with the exception that the WTGs will now be operational. Acceptable limits are outlined in 4.4.2.

5.1.2

Once the WTG (or windfarm) is installed and operational, it may be necessary to monitor the sound level in the surrounding area. If so, measurements shall be taken of the sound level, and in addition, consideration needs to be given as to whether there are any special audible characteristics of the sound which may justify analysis and possible application of a penalty which must be taken into account when determining acceptability (see 4.4.3).

5.2 Compliance level testing

(NOTE – The procedure outlined below should be followed whether or not background sound levels have been measured.)

5.2.1

Sound from WTGs shall, where practical, be measured at the same locations where the background sound levels were determined. The method of measurement shall be consistent with the measurement of background sound levels as described in 4.5 with the exception that the WTG (or complete windfarm) will now be operational.

5.2.2

Compliance level testing shall take place at the same positions and across a similar range of wind conditions for which background sound level data has been previously collected.

5.2.3

As with the background sound level measurements, the compliance level testing shall take place at known windspeeds in the range 0 m/s to rated windspeed (typically 13 m/s – 15 m/s) measured at an anemometer height consistent with the background level measurements. As a check on sound levels generated at higher windspeeds, it is necessary to obtain measurements at windspeeds in excess of 15 m/s. For dual-speed WTGs, this shall be above the cut-in speed for the higher generating capacity.

NOTE – WTG sound measurements should be taken over a representative range of windspeeds and directions, each measurement being typically 10 minutes in time duration, as described above for background sound level determination. If typically 1440 data points were collected over the required windspeed range, it would be possible to repeat the regression analysis.

An assessment of any special audible characteristics should be undertaken.

5.3 Special audible characteristics

5.3.1

Sound from a WTG that has special audible characteristics (clearly audible tones, impulses, or modulation of sound levels) is likely to arouse adverse community response at lower levels than sound without such characteristics. At present, there is no simple objective procedure available to quantify special audible characteristics, and subjective assessment is therefore necessary, supported by objective evidence (e.g. frequency analysis) where appropriate.

5.3.2

When sound has a special audible characteristic, the measured sound level of the source shall have a 5 dB penalty applied. This is because the subjective reaction to a sound containing a special audible characteristic is generally found to be similar to a sound 5 dB louder, but without the special audible characteristic. A maximum penalty of 5 dB shall be applied by adjustment of the measured sound level by arithmetic addition of +5 dB .

NOTE – The objective method for determining whether a sound exhibits a tonal character shall be that used in IEC DIS 1400-11 for assessing wind turbine tonal character close to the turbine, i.e. The Joint Nordic Method. The method takes a number of narrow band spectra over a period of 2 minutes and compares the sound level of the tonal frequency to the 'masking sound level' in that of a critical band positioned around the tonal frequency. As the method takes the five highest tonal values within the 2 minute monitored period, it automatically considers those cases where the sound level of the tonal frequency is fluctuating.

5.4 Compliance assessment

To determine conformance with the limits set out in 4.4.2, a comparison shall be made between the best fit regression line of the background sound levels and the regression curve of the operational windfarm corrected for any special audible characteristics. If the background levels were not measured prior to installation (4.5.1), it may be necessary to obtain background sound level measurements for limited