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Noise
Vibration

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Measurement of Audible Noise from Wind Turbines – Phase 1 Report
Literature and Jurisdictional Review

Prepared for:

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1 Introduction

Aercoustics Engineering Limited (“AEL”) has been retained by the Ontario Ministry Of Environment (“MOE”) to provide Expert Advice on Measurement of Audible Noise From Wind Turbines. The first phase of this project involves a literature review and jurisdictional scan to obtain insight and understanding of issues related to noise measurements from wind turbines in other parts of the world.

The literature review involved collecting and reviewing scientific literature on measurement of wind farm noise, noise measurement procedures for wind turbine noise for other jurisdictions, evaluation of two wind farm compliance studies provided by the MOE, and the review of MOE NPC documents. The usefulness of each document was assessed and findings are presented in this report. Additionally, this report lays the framework for the development of a noise measurement protocol for wind turbine noise at receptors.

2 Literature Review

2.1 Scientific Literature

The scientific literature found on the measurement of noise from wind turbine generators for this study dated as far back as 1991 and as recent as 2010. A full list of the documents reviewed is included in the appendix. The summary of the scientific literature review is divided into the following main topics:

1. General method for assessing the noise contribution from the wind farm at receptor point
2. Measurement parameters used
3. Assessing ambient noise levels at the receptor and their influence on the measured levels
4. Addressing wind induced noise in the measurements
5. Assessment of tonality

2.1.1 General Methods for Assessing the Wind Turbine Noise Contribution

From the reviewed material, two main methods of assessing noise levels at a receptor point were used:

1. Measurements of the turbine noise emissions were conducted close to the turbine, and the noise contribution at the receptor point was subsequently calculated based on an atmospheric dispersion model [1],[2]. In some cases, the model is validated by a controlled noise source (loudspeaker source) [3],[4].

2. Measurements of noise immissions at receptor points due to turbines. The studies measured the noise impact from the turbines directly at distances up to ~800 metres away from the nearest turbine [5],[6],[7],[8],[9].

The studies that employ the first technique all use procedures that adhere, to various degrees, to *IEC-61400-11 Acoustic noise measurement techniques* [10] standard for measuring noise emission of wind turbines. The difference remains in applying different sound propagation models and parameters to predict the noise contribution at the receptor or point of interest.

Virtually all the studies that use the second method assess the effect of background ambient noise on their measured results, and provide some analysis techniques to remove the ambient noise from the noise of the turbines.

2.1.2 Measurement parameters

Given that the purpose of noise immission measurements is usually to determine compliance with the local jurisdictional requirements, the indices measured, analysed and reported adhered to the noise descriptor relevant for the local jurisdiction.

Di Napoli [5] measures LA_{eq} (intervals not specified).

Ziliani [6] measures LA_{eq} and LA_{50} in 10 minute intervals and then discards points where LA_{eq}-LA_{50}>5dB.

Delaire et al. [8] measure LA_{95} in 10 minute intervals in a pre-construction noise study aimed at quantifying the background noise levels that would be subtracted from future measurements post-construction.

Inspired by IEC-61400-11, Jiraska [9] and Almgren et al. [8] measure LA_{eq} in 1 minute intervals at the immision point in order to compare to the emission point.

Bullmore et al. [7] measured LA_{90} in 10 minute intervals. Bodwell [42] measured LA_{eq} in 1-hour intervals. It is our opinion that this metric is not able to capture the impact of the turbines as the averaging time is much too long, and the LA_{eq} is much more susceptible to gusts, transient events, etc.

In general, most of the studies report fairly confident noise immission levels within 750 metre setbacks. At higher distances, background noise levels begin affecting the immisions measured. Although, adequate explanations are not provided for a definitive cut-off point after which background noise is considered to have contaminated the noise measurements. From the summary above it is evident that many people have used different parameters to identify the contribution from the turbines and separate them from background noise. The common thread of successful parameters is:

1 If LA_{eq} is used, the intervals times are short enough to ensure a steady noise level during the interval. Almost all studies used 1 minute LA_{eq} measurements in line with IEC-61400-11. This requires an anemometer that is capable of providing data at the same interval rate.

2 If a statistical descriptor (LA_{xx}) is used, the averaging time for each interval is increased to 10 minutes. This is convenient as the turbine wind speed is also obtained in 10 minute intervals. However, the percentile level is always LA_{90} or LA_{95}. This is presumably to eliminate effects of contaminating events and outliers. As some studies have shown amplitude modulations present in the noise signal from the turbines themselves [5], there is a risk that the LA_{90} of even a 10 minute interval with no contaminating events can miss-report the noise contribution from the amplitude modulations.

2.1.3 Ambient noise levels

One of the main hurdles of quantifying the noise contribution from the wind turbines is signal separation. All the studies assess the influence of background noise in some way. Jiraska [9], Almgren et al. [8], Di Napoli [5] repeat measurements with turbines shut off. Bullmore et al. [7] compare downwind to upwind measurements as they were not able to shut turbines off. This technique is reported to work well for some sites (closer than 750m). Ziliani [6] predicts the noise level at the receptor given IEC type measurement near the turbines. Measurements at the receptor are then compared, and the difference between the prediction and the measurement is attributed to background noise (called “residual noise”). An interesting study by Bolin et al. [11] examines the annoyance perceived by wind turbine noise with varying levels of ambient noise due to wind. The study quantifies the amount of ambient noise needed to significantly reduce the perceived annoyance from wind turbine noise.

2.1.4 Addressing wind induced noise in the measurements

Methods for reducing wind induced turbulence noise on the microphone are discussed and compared by Kragh et al. [1]. Many techniques including using a ground plane, dual-stage wind screen, 2-microphone cross correlation and the use of vertical reflecting plane are discussed and resulting noise reduction reports are referenced. The report claims that they all achieve similar noise reduction performance, and proceeds to use the dual-stage wind screen approach. Reference studies for all the types are provided [12],[13],[14],[15],[16],[17],[18],[19]. Hessler [20] provides practical limitations on the more standard microphone wind screens available and widely used by consultants today. It compares the noise floor of the different types of wind screens measured in a silenced wind tunnel. The report concludes “because this wind-induced distortion essentially occurs in the lower frequencies, A-weighted sound levels are generally immune from any significant degradation in accuracy as long as an extra large wind screen in the order of 175mm in diameter is used and the wind speed at the microphone position is below about 5m/s”

2.1.5 Assessment of tonality

In Ontario, tonality is assessed subjectively, and the penalty is 5dB. Our literature review included standards and analysis methods for identifying tonal audibility and assigning a ‘penalty’ to the sound level to account for the perceived equivalent sound level in terms of annoyance. Two main methods used the concepts of Tone to Noise ratio (TNR) and prominence ratio (PR). TNR methods such as DIN 45681 [21] ISO-1996-2 [22] and ISO 7779 consider the sound energy in the tone bands as compared to the nearby masking bands and have been found to work the best in identifying and properly assessing the tonal audibility of a tone, and the corresponding ‘penalty’ or ‘adjustment’ to be added to the overall LA_{eq}. Schmidt et al. [23] provide a comparison between the measurement strategies and their assessment of tonal audibility compared to subjective evaluations of the same tones.

2.2 Noise measurement procedures for other jurisdictions and Ontario NPC documents

As part of the literature review, jurisdictional documents were obtained in order to document the current guidelines currently in place, or in the process of being put in place that deal with the assessment of wind turbine noise and, more specifically, procedures for measuring noise from wind turbine farms post construction. The jurisdictions researched included among others:

1 the United Kingdom
2 Denmark
3 the Netherlands

4 Germany
5 Sweden
6 Spain
7 New Zealand
8 Australia
9 Japan
10 US States: Wisconsin, New York, California and Minnesota
11 Canadian provinces: Quebec, Alberta and British Columbia

There were 3 categories of guidelines regarding the measurement of noise from wind turbines:

1 No specific policies regarding post-construction measurement methods
2 Noise levels measured at the turbine location according to IEC-61400-11; and noise impact calculated at point of reception using propagation models such as ISO-9613-2, Nord2000, etc to determine compliance. [25][38][26][31]
3 Noise levels measured at point of reception in order to determine compliance [24][27][28][29][30]

Most of Europe falls under the second category including Spain, Denmark, Sweden, the Netherlands and Germany.

In Germany noise immission guidelines are set by the Laender (equivalent to Provinces) as well as Federal guidelines and laws (e.g. TA Laerm). The latter form a framework, details of which may be modified to reflect local conditions.

The measurement of wind turbine sounds requires a high degree of specialization of personnel and equipment. The experience in Germany favours measurement protocols that are tailored to specifics of the locale, while conforming to general guidelines. Measurements always have to include an assessment of tonality and impulsiveness. The operating parameters of the wind turbine(s) at the time of the measurements must be reported as well.

The guidelines recognize that it is not possible to validate that WT immission levels that meet an allowable level of 35 dBA. Even for higher levels (40 dBA to 45 dBA) it is not always possible to do so. For this reason it is permitted to substitute a point of immission where background levels are more favourable without compromising WT immission levels. Night-time measurements are recommended, as sound propagation is more favourable (stable) and background sound levels are lower. The measurement period 1am to 4 am is seen as optimal.

Some jurisdictions favour the use of a vertical plane on which the microphones are mounted, an arrangement claimed to improve signal to noise ratio. It is cumbersome to use in moderate winds. Most practitioners tend to use ground planes as per IEC 61400-11 or similar standards. Measurement variability (uncertainty) plays an important role in the assessment. To this end reference must be made to VDI 2714 and VDI 3723. These are potential starting points for MOE guidelines for measurements of audible sound from wind turbines.

When noise impact is assessed based on data obtained by extended monitoring, the guidelines recommend “careful analysis”. In particular corrections for background sound is seen as problematic. Source identification methods optimized for the detection of WT sound may be used, but there is no specific guidance regarding data interpretation.

This literature review focuses on receptor based measurements. The jurisdictions that employ the 3rd category are examined. These are:

1 Recommended Practices for Wind Turbine Testing – 10. Measurement of Noise Immission from Wind turbines at noise receptor locations [24]
2 UK-ETSU-R-97: The Assessment and Rating of Noise from Wind Farms [30]
3 NZS 6808:2010: New Zealand Standard: Acoustics – Wind farm noise [28]
4 AS 4959-2010: Standards Australia: Acoustics – Measurement, prediction and assessment of noise from wind turbine generators [29]

2.2.1 Recommended Practices for Wind Turbine Testing – 10. Measurement of Noise Immission from Wind Turbines at Noise receptor locations

This document was developed through a series of meetings with participants of the International Energy Agency ("IEA") Research and Development agreement. The members of the working group included experts from Denmark, USA, The Netherlands, Italy, Germany, UK, and Sweden. It was first published in 1997. The document is a guide that recommends measurement techniques and methods for characterisation of the noise immission from wind turbines. Although no jurisdictions explicitly mandate the use of these guidelines for measuring noise immissions, it is a well accepted document in this field and contains some of the most in-depth methodologies for measuring noise immissions. It includes 3 methods for measuring equivalent continuous A-weighted sound pressure levels (LA_{eq}) and one method for measuring A-weighted percentiles (LA_{xx}). Tonality is assessed based on FFT measurements, and a comparison between the tone level and the noise level in the surrounding masking band. Requirements are also provided for instrumentation requirements, calibration, preferred weather conditions, measurement locations, etc for the measurements.

The two main obstacles identified from the outset of the document are wind induced noise over the microphone, and ambient noise levels contaminating the measured levels. To address those issues, the document suggests using secondary wind screens or vertical reflecting boards ('small' ones for mounting on the receptor wall, or 'large' ones for placing away from reflecting surfaces). Additionally, to address the noise contamination by ambient noise, the methods involve applying a correction to the overall levels based on measurements done to quantify the ambient noise level.

2.2.1.1 Equivalent continuous A-weighted sound levels (LA_{eq})

For the methods measuring equivalent continuous A-weighted sound levels (LA_{eq}) 3 methods include:

1 Measurement of noise level from turbine(s) alone
2 Measurement of combined noise level (turbine + background) at a target wind speed
3 Measurement of noise level from turbines(s) alone at a target wind speed

All the methods above are attended measurements. Method 1 and 3 measure the combined noise and background noise separately, and subtract the background levels from the combined levels to arrive at the noise levels from the turbines only. The background levels are determined by measurements taken when the turbines are parked. A third order regression curve is fitted to the background noise data, and the levels from the curve are used in the 'background-correction' of the levels measured with the turbines operational. If the background noise level is within 3dB of the combined noise level, the data point should be flagged and stated, and combined level is reduced by only 3dB, and reported as the upper limit of the turbine noise. In method 1, this is done for a variety of wind speeds. In Methods 3, it is done at a predetermined 'target wind speed'. The document suggests a target wind speed of 8m/s if regulations do not specify otherwise. In this case, the measurements are limited to wind speeds of ±2m/s of the target wind speed.

Method 2 measures the noise level with the turbines operational only. There is no correction due to background noise. The document notes that these measurements can be used to demonstrate that noise from turbine(s) is below a specified limit. It cannot, however, be used to demonstrate that the noise from the turbines is above a specified limit. This is because the contribution due to background noise is not quantified.

In all methods, averaging time is recommended between 1-10 minutes, with a minimum of 10 data points, and a minimum total measurement time of 30 minutes. In the cases with target wind speeds, a minimum of 10 data points are required on either side of the target wind speed

In method 3, once the data has been corrected, and the level at a specific wind speed is of interest to compare to the regulatory limit, a straight line is drawn through the measured levels (best fit) and the level at the target wind speed is compared against the regulatory noise limit in order to determine compliance.

In addition to these requirements, suggestions for techniques to employ for cases of low signal-to-noise ratio are presented, some with cautions about decreased precision and increased uncertainty. These suggestions include:

1 Change of time of day of measurements
2 Repositioning of microphone
3 Use of secondary windscreen
4 Measurement at reduced wind speeds*
5 Measurement at reduced distance*
*For these methods, corrections are later applied to the measurements to account for the higher signal measured

2.2.1.2 A-weighted percentiles (LA_{xx})

The main difference between this measurement procedure as compared to the continuous A-weighted sound level measurements is that unattended recording equipment may be implemented. The techniques described for the previous measurements still apply. The parameters are slightly different. LA_{10}, LA_{90} and LA_{95} are described as the most commonly measured percentiles. The method is recommended to be used in situations where the limit is expressed in percentiles and, in particular, when the limits are related to ambient sound measured previously (pre-construction) at the receptor location.

Wind measurements can be measured either at hub height, or at 10m height. A minimum of 20 measurements of 10 minutes each is required during times when the wind speed is within ±2m/s of the target wind speed. There is also a requirement that there be at least 10 measurements on either side of the target wind speed.

If the measured percentiles are below the limits, then background noise measurements are not required. If they are above those limits, the same measurement parameters must be completed with the turbines parked.

2.2.1.3 Tonality

Narrowband spectrum measurements are described for both fixed-speed turbines and variable speed turbines. For fixed speed turbines, at least 5 measurements of 1-2 minute duration are required within ±1m/s of the target wind speed. The resolution depends on the frequency of the tone:

Table 1: Frequency resolution for FFT measurements of tone from turbine

Tone frequency [Hz]	FFT Resolution [Hz]
< 2000	2.0 – 5.0
≥ 2000	2.0 – 12.5

A more intensive analysis is suggested for non-stationary tones. In most cases, the above measurement method is deemed to be sufficient. Calculation methods for tone level and masking band level are provided and the tonality is described as the difference between the two.

2.2.1.4 Uncertainty

Formulas for calculating the standard deviation of the corrected noise levels are provided.

2.2.1.5 Ambient survey

A good guide to assessing the ambient sound at a site pre-construction is included in Appendix 3 which includes recommendations on selection of which sites to measure, how to reduce the data, and how to arrive at a regression curve describing the background noise level.

2.2.2 UK-ETSU-R-97 The Assessment and Rating of Noise from Wind farms

This document was created by ETSU for the UK Department of Trade and Industry (DTI). This document was not created as a UK Government document, but was provided as a guidance document for the UK Government to assess noise from wind farms. Subsequently, the government planning documentation, “Planning Policy Statement 22 (PPS22)”, refers to the ETSU-R-97 as the study to use, when dealing with noise from wind farms. Although this document was created in 1996, it appears to be the current document which is still referenced in the UK. Furthermore, it does provide a comprehensive review of several of the issues which must be dealt with regards to the assessment and measurement of wind turbine noise. Also, being one of the first comprehensive studies several of the more recent studies, including the New Zealand and Australia studies have been based on this study.

2.2.2.1 Measurement Parameters

There are both wind and sound level measurement parameters which this document relies upon. The sound level descriptor which this document predominantly relies upon is an A-weighted L90 level using a 10 minute interval ($L_{A90,\ 10min}$). The sound level limits, the background sound level and the measured noise immission level use the $L_{A90,\ 10min}$. Although, it will be discussed further in later sections, this document does make use of FFT analysis for tonal penalties; as such recordings are also required. Furthermore, for background correction purposes the document allows for the correction being applied to L_{eq} and L_{90} levels but states that the L_{90} correction is not accurate. The wind speed is also to be measured in 10 minute intervals. The wind speed should be provided at a 10m height. The document recommends using a 10m high anemometer but also allows for the extrapolation of the 10m wind speed using the hub height wind speed using a standard wind velocity profile.

2.2.2.2 Sound Level Limits

The sound level limits which are recommended in this document have been developed for the UK and have been developed for day time and night time. They are also a function of the $L_{A90,10min}$ background sound level. It should also be noted that this document does not directly address indoor sound level limits but focuses on outdoor limits. However, the limits have been designed to somewhat accommodate indoor levels.

The quiet day time hours are defined as follows:

- All evenings 6pm to 11pm
- plus Saturday afternoons from 1pm to 6pm
- plus all day Sunday (7am to 6pm)

The night time hours are defined as being 11pm to 7am.

The reason that this document has addressed the hours in this manner is because the belief is that the use of outdoor amenity spaces during the quiet day time periods is greater and therefore the outdoor sound levels during these times is more critical, whereas during the night time period, most people will be sleeping indoors. As such the document recommends more stringent sound level limits during the quiet day time periods than during the night time period. The applicable sound level limit during the day time period is defined as being 5dB above the $L_{A90,10min}$ background sound level or 35dBA whichever is higher. The following statement is extracted from the document:

" The Noise Working Group has therefore concluded that in low noise environments the day time level of the $L_{A90,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dBA."

The following figure extracted from the document, outlines a typical example of the day time criterion:

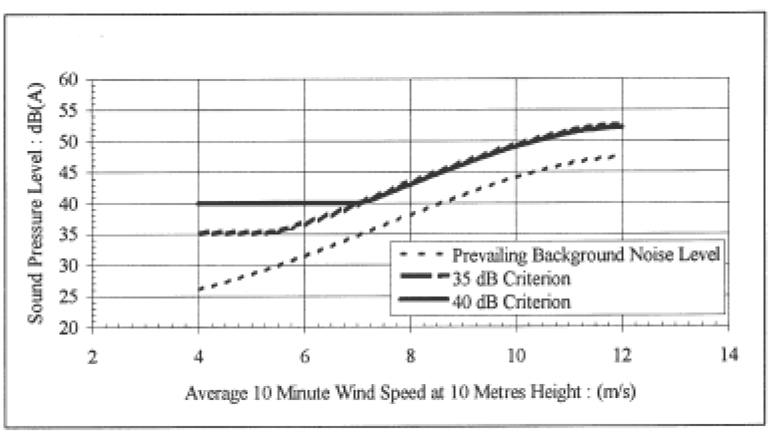


Figure 1: UK-ETSU-R-97 – Example of a Day time Sound Level Criterion

Similarly, the outdoor night time sound level limit is defined as 5dB above the $L_{A90,\ 10min}$ background sound level, or 43dBA whichever is higher. The exclusionary limit of 43dBA for night time is used since the concern is to minimize sleep disturbance inside a residence. This level was established to satisfy the WHO's 1980 guidelines to minimize sleep disturbance by ensuring that sound levels indoors did not exceed 35dBA L_{eq} sound level. Thus the 43dBA (L_{A90}) outdoor nighttime sound level limit is based on the UK premise that $L_{A90} = L_{eq} - 2$dB and assumes Outdoor Noise = Indoor Noise + 10dB, with an open window.

The following figure extracted from the document, outlines a typical example of the night time criterion:

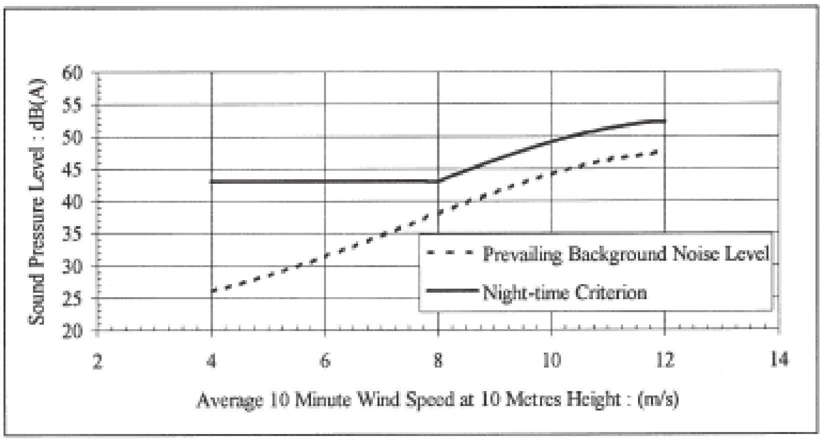


Figure 2: UK-ETSU-R-97 - Example of a Night Time Sound Level Criterion

2.2.2.3 Assessment of Background Sound Levels

As this document relies upon the background sound levels to determine the applicable limits, it is necessary to measure and monitor the background sound levels prior to site construction and operation.

The background sound levels and 10m high wind speeds are to be measured. The background sound levels are to be measured as $L_{A90,10min}$. The data is filtered by time of day as separate curves are required to be developed for day and night time periods. Also, data which includes periods of precipitation, and other events not considered part of the typical ambient environment are removed from the data set.

This data is to be correlated to the wind speed for the 10 minute interval and plotted against each other. A regression line is plotted through the day and night time data sets to develop the background sound level curves which will be used to develop the day and night time sound level limits.

2.2.2.4 Assessment of Blade Swish and Tonality

The document discusses the blade swish and outlines that it is a factor. However, it does not warrant any penalties for blade swish and states that further research is required.

The assessment of tonality which this document uses is somewhat subjective, in that it seems to indicate that the decision as to whether a particular noise is to be considered tonal is up to the auditor. However, once it has been assumed that there may be tones present, this document essentially prescribes the Joint Nordic Method [40],[41] for assessing tonality.

Once it is determined that tonality is an issue, this document prescribes a tonal penalty using a sliding scale between 1.5 to 5dB depending on the audibility of the tone. The maximum of 5dB is prescribed when the audibility of the tone exceeds 6.5dB which is consistent with the Joint Nordic Method.

2.2.2.5 Measurement and Assessment of Noise Immissions

This document does not require that compliance be demonstrated at all wind speeds, but rather at the critical wind speed. This may either be governed by complaints or may be governed by the typical wind speed in the area. In order to obtain an appropriate sample size, it is recommended that 20 to 30 measurement intervals ($L_{A90,\ 10min}$) be conducted within +/- 2m/s of the critical wind speed. The noise measurement location is to be at a height between 1.2-1.5m and is to be located approximately 10m from any building facades to ensure that reflections are not a concern.

The sound levels are filtered to remove intervals where poor weather conditions existed or where the sound levels are dominated by extraneous noise sources.

This data is then taken and correlated to the 10m high wind speed which is also measured. A regression line is plotted through the data set for the critical wind speeds and if it is determined that this curve is below the sound level limit curve and there are no tones then the wind farm is considered compliant and no further assessment is required.

If however, the curve falls above the limit line or with the inclusion of a tonal penalty the sound level curve is above the limit line, the data set is then to be background corrected to remove the ambient sound levels from the measured sound levels. This curve is then considered in comparison with the limit curve to determine compliance.

2.2.2.6 Discussion of UK-ETSU-R-97

The UK-ETSU-R-97 is overall a thorough document which has considered the majority of the complex issues surrounding the measurement and assessment of wind turbine noise. Although being 14 years old now, it does include several noteworthy points which are to be considered in developing a measurement protocol for Ontario.

There are several areas where this document provides recommendations which are not applicable to Ontario. The development of the sound level limits using the background sound levels is not a feasible concept as this would require extensive monitoring well before a wind farm is developed. This is also not practical from an assessment and enforcement perspective as each potential site could have significantly varying ambient conditions and subsequently different sound level limits.

The document relies upon the $L_{A90,\ 10min}$ level which may make sense as the limits are also defined using the same descriptor. However, since the Ontario limits are specified as L_{eq} levels it would be more appropriate to ensure that the levels measured are also primarily using L_{eq} levels and other descriptors to support the L_{eq} if required. The 10 minute interval time was selected as a matter of convenience to better correlate to wind speed intervals which may have been obtained from the turbine hub. Also, it is interesting to note that the tonal assessment requires a 2 minute measurement interval. With a modern day anemometer greater resolution can now be obtained, and modern sound level meters have the ability to store shorter interval durations over a long term period.

The interesting approach which this document takes towards defining a critical wind speed range under which compliance would be measured would make conducting an acoustic audit much simpler. This may be something that Ontario should consider as trying to measure whether a wind farm is compliant at all wind speeds can be labour intensive and obtaining the necessary sample size can take several weeks.

There are two other major factors which are considered in this document which could be of significance for Ontario. This is the data reduction and the background correction. It is clear that both of these factors must be accounted for in some manner in a measurement protocol.

2.2.3 NZS 6808:2010: New Zealand Standard: Acoustics – Wind farm noise

This standard, released in 2010, outlines sound level limits as a function of the measured on-site 10 minute LA_{90}+5 or 40dBA, whichever is higher. The noise levels are with reference to wind speed at hub height of the nearest turbine. They note the vulnerability of LA_{eq} measurements to wind gusting for its unacceptability as a metric. The standard assumes that the wind turbine noise LA_{90} at the receptor is equivalent to the predicted wind turbine noise LA_{eq} at the receptor, predicted using ISO 9613-2. For the purposes of compliance testing, LA_{90} levels are measured in 10 minute intervals and related to the wind speed at the hub. ON/OFF testing is permitted to establish the contribution from the turbine compared to the background noise. For the wind turbine noise measurements, 1440 data points is the standard's minimum requirement. It should be noted that the British study (UK-ETSU-R-97) forms the basis of most of the requirements and is used to support the requirements.

2.2.4 AS 4959-2010: Standards Australia: Acoustics – Measurement, prediction and assessment of noise from wind turbine generators

This standard was also released in 2010 shortly after the New Zealand standard. There are more similarities than differences, in terms of the compliance testing. Specialty wind screens are recommended for ambient noise measurements at wind speeds above 5m/s. There are two choices for measurements: attended and unattended. In the unattended case, 2000 data points are required covering a range for wind speeds (referenced to hub height). The LA_{eq} contribution is calculated as the LA_{90} +X dBA (where X = 1.5 dBA or more, based on consultant's justification). Based on the data, a regression curve is derived fitted to linear or up to third order polynomial equations describing the LA_{eq} with respect to wind speed. Attended measurements can also be conducted during which ON/OFF measurements are taken at a single receptor. Here, both the LA_{eq} and LA_{90} are measured in 10 minute intervals. If the LA_{eq} > (LA_{90} + 3dB), the data point is discarded. Attended measurements must consist of 10 data points above the critical wind speed by up to 3m/s and 10 data points below the critical wind speed by up to 3m/s. For attended measurements, $LA_{eq,turbines} = LA_{eq,ON} - LA_{eq,OFF}$ (using logarithmic subtraction).

2.2.5 Jurisdictional information about complaint response procedures

Based on the literature research and correspondence with various authorities, it has become evident that this area is very ill-defined in terms of procedures. There are different systems of authority, different windows during which complaints can be made, and different and sometimes ill-defined methods of dealing with the complaints.

In New Zealand, wind farm noise levels are verified during the commissioning stage (much like a noise audit in Ontario). Once this has been completed, there is always a possibility of noise complaints. The complaints go to the district councils. Depending on the council and their review of the complaint, if there is reasonable suspicion that the noise levels have changed since the commissioning, additional noise monitoring/measurement is requested. The council may also consider whether despite complying the noise is still unreasonable.

The wind farm operators generally prefer that complaints go to them in the first instance so they can act on them before they go to council. The latest New Zealand wind farm has provided a 24-hour free telephone number for complaints to the wind farm operator. In that instance, there is a requirement for all complaints to be logged by the operator and also forwarded to the council.

Generally, when the wind farm noise is being monitored for commissioning (audit process) the standard requires measurements at representative locations within the predicted 35dBA contour line – this has typically resulted in the order of 4 measurement points. Once a commissioning audit has been completed, no further measurements or audits are required throughout the life of the wind farm –unless the operator sought to change the turbines or add turbines.

When a complaint is received, there is no fixed procedure to determine if an audit is necessary, and this is currently a matter of judgement for the council.

In Denmark, noise immission measurements may be required by the local municipality at the time that the wind farm is put into operation or as a consequence of noise complaints from neighbouring properties. Whether each complaint warrants noise measurements is at the discretion of the council. The document that describes these procedures is the executive order of noise from wind turbines no. 1518, 2006 [38]

2.3 Review of MOE provided wind farm compliance studies

Two existing wind farm noise studies were provided by the MOE to be included as part of the material to be reviewed for this literature scan. The studies will be referred to as Study A and Study B.

2.3.1 Review of Study A

Study A makes use of attended and unattended measurements to to assess the noise contribution from the wind turbines at the receptors. The unattended measurements use the L_{Aeq} and L_{A90} levels measured in 10 minute intervals. An unattended monitor was located on the receptor property while another unattended monitor was located 100m from the nearest turbine in an effort to correlate the sound levels. The attended measurements were conducted using 20 minute intervals. Most of the conclusions and analysis were based on the L_{A90} levels for both the attended and unattended measurements.

Wind speed and direction were measured at a 10m height and also at a 1.5m height. The 10m high anemometer measured in 10 minute intervals, while the 1.5m high anemometer measured in 30 minute intervals.

Measurements were also conducted by attempting to cycle the turbines ON/OFF in order to isolate the contribution from the turbines. However, this was unsuccessful as these measurements were conducted during the day when the ambient noise was too high and therefore no change could be measured.

There was no objective tonal assessment carried out in this study. There is some minimal discussion regarding tonality. However, there was no tonal penalty or adjustment applied to the measured levels.

This study assesses the noise contribution of the wind farm by comparing the L_{A90} levels to the limit. This can be seen in the attended and unattended measurements. The study also makes an attempt at correlating higher noise contributions to periods where higher wind shear values (greater than 0.3) were present.

2.3.1.1 Discussion of Study A

In short, the methodology used in Study A is not appropriate as an acoustic audit of a wind turbine power plant. The descriptors used do not provide enough detail to make a conclusive assessment of the noise contribution from the turbines at the receptor locations. As such no reliable statements of compliance can be made.

There are a number of issues which are apparent with Study A. Study A does not discuss any filtering or data reduction which may have been conducted to obtain a better idea of the contribution of the turbine noise. Rather than trying to obtain more detailed information, this study relied upon the L_{A90} sound levels as the sole indicator of the turbine contribution. This is inappropriate as the sound level limits are based on L_{eq} levels.

The discussion regarding the tonal character of the noise from the turbines is vague and subjective. Based on the current MOE guidelines, a tonal penalty is prescribed on a subjective basis if the tones are perceived by the auditor. As such this study used the appropriate approach in not applying a penalty as the tones could not be perceived. However, given the nature of the wind turbine noise character and the more objective methods for assessing tonality from wind turbines, it would be prudent to conduct such an analysis as opposed to providing a somewhat vague and contradictory statement.

Similarly the conclusion of the study is also vague. There is no conclusive assessment of compliance within this study. The statements provided here are too vague. This may also be a result of the fact that at the moment there is no clear consensus as to what constitutes compliance. This report has made that assessment using the L_{A90} levels. It should be noted that the LA_{eq} values for these periods would therefore be higher, but with a chance that they would be contaminated from transient events. Furthermore, the distribution and uncertainty of the measurements is not fully discussed.

2.3.2 Review of Study B

Study B was conducted using long-term unattended measurements. Meters were deployed at a distance of 30m from the residences, at a height of approximately 1.5m.

The sound data was measured as 2 minute L_{eq} intervals. In addition to this octave band and 1/3 octave band spectra and L_n data was measured. Digital recordings for the first 30 seconds of each interval were conducted for reference purposes.

Wind speed and direction were obtained from 3 meteorological towers in the area. These towers were equipped with anemometers at various heights, ranging from 10m to 87m above grade. This data was obtained in 10 minute intervals.

The sound data was reduced by removing intervals where precipitation occurred, intervals where the L_{eq} was greater than the L_{10}, and intervals which were dominated by spurious events as identified by the audio clips. The remaining data set was then logarithmically averaged to provide equivalent 1-hour L_{eq} levels. L_{90} levels were also linearly averaged, and the study recognizes that this approach is not accurate but was done only for comparison. The 10 minute wind speed data was also linearly averaged to provide 1-hour intervals. The monitoring period covered 15 days, and the data was ultimately reduced to 400 hours worth of valid data. During this period there was also a period where the turbines were off and background levels could be measured. However, the data analysis techniques used do not 'background' correct the data. (i.e. adjusted for background noise)

Tonality was assessed subjectively and no penalty or adjustment was applied.

The analysis technique employed by this study uses a statistical approach in that it considers the total noise measured (L_{eq}) and compares this against the MOE sound level limits. The first pass considered all the hours of data collected and how many of those satisfy the sound level limit. The study then considered how many of the hourly intervals had a sound level which was more than 3dB higher than the MOE limit. The reasoning behind this margin is that as the levels presented included the background sound levels and the total turbine noise. As such, if the background was equal to the sound level limit an overall increase in the observed level would be 3dB. However, this data was still considered to have periods where the wind speeds were greater than 10m/s, and as the limits only provide guidance for wind speeds up to 10m/s an additional threshold or filter was created.

The final filters which were applied to the data set considered the sound levels as measured during the night time and early morning hours. It should be noted that there was one receptor which had consistently higher noise levels than others. The report seems to indicate that this receptor had higher background levels due to the proximity to trees and roads.

2.3.2.1 Discussion of Study B

In general this study has outlined an approach which considers the total sound level at the receptors and provides an analysis using a statistical approach.

There are some potential pitfalls and issues with the analysis technique that was employed. The first is in regards to the conversion of the interval data to hourly data. While this effectively serves to reduce the number of interval data sets and is also in line with the 1-hour L_{eq} sound level limits, the problem is that it potentially reduces the resolution of the information which could be useful. As the wind speed and sound levels are all converted to 1-hour intervals, the averaged data could potentially consist of a wide range of wind speeds and sound levels. It would be more prudent to perhaps look at the interval data binned by wind speed and then consider this statistical approach. By binning the data by wind speed using the 2-minute interval data, more information could potentially be gathered and the density of regression lines fit through the data would have been derived from a higher sample size. This would have improved the background sound levels which were measured. With the methodology employed in the study, the background sound level regression line is defined by a very small sample size. This is likely the rationale as to why the data was not background corrected.

The other issue with this study is how it defines compliance. The approach taken to define compliance as no more than 3dB greater than the MOE limit is reasonable. As this study does not directly background correct the data it is a reasonable approach to apply a margin to the limit.

The third issue with this study is that the tonal assessment carried out is a subjective one. This is of course in agreement with the current methodology in Ontario. However, the chosen interval time of 2 minutes lends itself to being able to apply the Joint Nordic Method [40],[41]for tonality assessment.

2.3.3 Comparison of the Two Studies

Study A used a more simplistic measurement methodology, which relies upon overall levels and a subjective analysis based on the auditor. Study B used a more sophisticated measurement methodology which does not rely as much upon the auditor's perception or subjective analysis (not including tonal assessment).

It is clear that both studies require the use of data reduction and filters to remove extraneous data points. Both studies provide subjective analysis of tonality. Study B proved to use a more robust measurement methodology and incorporated several of the parameters that are outlined in the framework of the recommended procedure (Section 4).

2.4 Conclusion of Literature Review

Based on the review of the literature, it is clear that a standardized approach is essential in order to ensure that these projects are all being evaluated equally and that the residents, the developers and the Province of Ontario are all protected. It is clear that the major challenges presented throughout the various documents are in relation to the following:

1. Measurement intervals and parameters
2. Instrumentation required
3. Measurement Period & Duration
4. Noise measurement position
5. Wind measurement position
6. Assessment of ambient noise levels
7. Tonality
8. Data Analysis & Impact Assessment

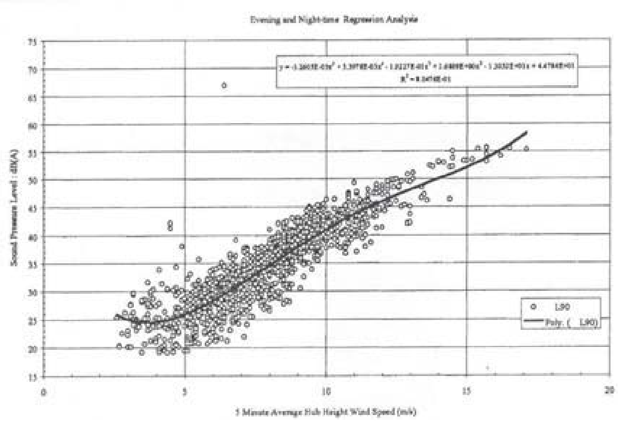
A summary of the information gathered from the literature review on each of these topics is outlined in Section 4 along with the logic and recommendation for the Ontario procedure in each category.

In General, however, there are 3 main schools of thought. The first resigns to the conclusion that the noise immissions are difficult to measure and quantify accurately, and thus, the jurisdictional noise limits are satisfied if the turbines are operating within specifications, and if the noise modelling was done in accordance with the standards. The 2nd and 3rd schools of thought attempt to quantify the noise immission levels but in two fundamentally different forms. One uses a percentile (LA_{90}) and the other LA_{eq}. The other differences between the two schools stem as a consequence of this initial difference. More details are presented in Section 4.

3 Gaps in the current science

Out of the studies and standards reviewed, some vulnerabilities were identified and are outlined in this section. The New Zealand Standard [28] was opposed by Massey University with a negative vote (the only one). The reasoning for the negative vote has been obtained [33] as part of the lit review. Although the main reasons for the disagreement pertain to the noise limits, the modeling methodology, there is criticism for the use of $LA_{90,10min}$, and a minimum of 1440 data points. The argument presented is that the amount of data required forces the measurements to be performed unattended, and thus, cannot guarantee what is causing the noise levels measured. This is a concern because the ambient noise measurements pre-construction could be affected and increased. This would, in turn, allow for a higher noise limit (the higher of background + 5dB or 40dBA). Although the document does state that a positive vote would have been made if the noise limits were set to lower levels and using $LA_{eq,\ 10\ min}$. The document also criticises the British study that the standard was largely based on – the UK ETSU-R-97 [30] for its assessment of ambient noise from LA_{90} measurements. The document provides this commentary:

> *Typical data pairs of wind speed at hub height and background level measured at a local residence, shows a wide spread of data – often 20 dB or more. The following figure, taken from the British report [30] that featured prominently in the formulation of the Standard, is used to illustrate this point. Even though the data spread is so wide, it is considered acceptable to take a medium value as the relationship.*



> *Mathematically this is suspect as the data spread is far too wide, and one is comparing an L90 (mathematically a 10 percentile level) with a linear parameter from which a 50 percentile level is deduced. In other use of such data, it is usual to take one or two standard deviations down from the average as a more reasonable relationship.*

Other vulnerabilities in the current standards involve the admission within the standards themselves of inconsistencies. Both the UK-ETSU-R97 and the IEA recommendations acknowledge that the subtraction of Percentile values from each other in an attempt to background-correct measurements does not strictly apply, but reference a paper by Nelson [34] for more information about subtracting percentiles from each other.

Bowdler [37] provides a comprehensive criticism of the UK-ETSU-R-97. Similar to the Massey University criticism, most of the disagreement is over the limits and their appropriateness. One main form of criticism is the adoption of the LA_{90} and its comparisons to other British standards for environmental noise which are always measured in LA_{eq}. Although, the suggested remedy is to add the 2dB back to the LA_{90} measurement to arrive at the LA_{eq}. This adjustment is just as suspect as the assumption that the blanket statement that LA_{90} is 2dB below the LA_{eq} level.

It should also be considered that some jurisdictions such as Germany [36] and Japan [35] have concluded that reliable measurements of wind turbine noise immissions cannot be guaranteed. Rynell [39] investigates in his Master's thesis methods for signal analysis for determining the noise immission of wind turbines. He uses a detection method deemed DEMON (Detection of Envelope Modulation On Noise). The method proves unsuccessful at filtering out the wind turbine noise part from a noisy signal. Although this study does not categorically mean noise immissions are not possible, it highlights the difficulty in measuring and quantifying the noise contribution with such noise signals.

4 Recommendations for the framework of a new procedure

This section outlines the framework for a procedure for measuring and quantifying the noise impact noise from wind turbine farms at receptor locations. The outline is based on the literature review thus far, and the internal discussions within Aercoustics, and through discussions with the MOE.

4.1 General assessment method

The purpose of this procedure is to establish a confident and repeatable method whereby the noise contribution from a wind farm can be measured. Noise contributions are recommended to be obtained through measurements at the receptor in question (not calculated based on measurements at the turbine). This method is recommended so that the overall impact from all the wind turbines in the farm is accounted for in-situ. The advantage of measuring the noise at the turbine location is that one can expect better signal/noise close to the turbine. However, the studies reviewed have been able to demonstrate that wind turbine noise impact at receptors can still be obtained with reasonable confidence at the receptor location at distances up to ~800m away from the turbine.

4.2 Measurement intervals and parameters

4.2.1 Information Gathered from Literature Review

The scientific literature has shown two main schools of thought on the parameters to be measured and the corresponding intervals at which to measure those parameters. The sound level is either quantified by an equivalent sound pressure level for the interval (LA_{eq}) or a statistical index that would typically be used to isolate an ambient noise level during a long measurement with possible short term events.

Of the two methods, both have advantages and disadvantages. The energy averaging method gives an equivalent sound pressure level for the interval that can readily be compared to established MOE limits (prescribed in hourly LA_{eq}). The drawback with using this index is that the interval time should be sufficiently short (1-2 minutes) so as to capture steady situations. The LA_{eq} is more susceptible to influence from short sudden events that generally do not relate to the noise from the wind turbines, or the ambient noise due to wind. This increases the overall amount of data and processing work involved.

The method that uses a statistical index alleviates the amount of data by increasing the length of each interval (usually 10 minutes). The disadvantage to this method is that it is susceptible to under-reporting the noise contribution from varying sources –including wind turbine noise at a receptor. If one considers a 10 minute interval during which the wind turbine is the dominant and only source of noise, the time signal would show amplitude modulation relating to each individual “swish” from the turbine. An LA_{90} for this interval would show the ambient level near the bottom of the amplitude modulation, and thus, not capturing the noise level contribution from the turbines. Since at the end of the measurements, they have to be compared to MOE sound level limits which are prescribed in LA_{eq}, it leaves further gaps in consistency.

Furthermore, all the documents that advocate using the LA_{90} index do so for comparing against the same index either with the turbines parked, or compared to measurements pre-construction of the wind farm. The contribution of the turbines is inferred by logarithmically subtracting the two measured LA_{90} levels. The UK and IEA documents both acknowledge that strictly speaking the logarithmic subtraction is only valid when subtracting one L_{eq} value from another.

4.2.2 Recommended Approach for Ontario

The recommendation for this aspect of the procedure is to use LA_{eq} measurements, but in conjunction with some form of statistical information that can be used to identify outlying points, individual events, etc, and still be able to capture the equivalent sound pressure level of the interval.

Since LA_{eq} measurements are recommended, the interval time for each measurement should be between 1 and 2 minutes. It is worth noting that the new IEC-61400 standard is also moving towards shorter interval times for emission measurements (10 seconds). 1/3rd Octave Band measurements are recommended for each of the intervals, along with the overall LA_{90} for each interval.

Based on the minimum amount of data required (see section 4.4) the measurements lend themselves more to unattended monitoring type measurements. As such, it is recommended that Audio recording (time signal) be simultaneously carried out for the purposes of verification during post processing. The measurements would be used to verify audibility of the source during specific data points where the turbine is expected to be dominant. Most modern instruments already have this capability.

4.3 Instrumentation

4.3.1 Information Gathered from Literature Review

Instrumentation required for the noise measurements are described in the literature. Noise measurement instrumentation is specified to adhere to established standards not unlike NPC-102. The only aspect which is not defined in NPC-102 is measures put in place to reduce wind-induced pseudo-noise. IEA [24] provides recommendations for 3 methods they describe:

1. large vertical measurement board
   This consist of a flat vertical board with minimum dimensions of 1.5m x 1.8m, made of "acoustically hard" material such as ply-wood, of a minimum thickness of 12mm. The microphone is mounted flush with the board and parallel to the ground.

2. Small vertical measurement board
   The concept is the same as the large board, except that it is mounted on the building facade, and thus, need not be as big. (0.5 x 0.7m). The thickness is also limited to 30mm.

3. Secondary windscreen
   This wind screen is recommended to be used in conjunction with a primary windscreen if necessary, and It could, for example, consist of a spherical wire frame, of 250 mm in

diameter, covered with a 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm. The frequency response of the microphone system is required to be documented, although, no specific test standard is specified

According to IEA, wind speed is recommended to be measured with an accuracy of ±0.2m/s or higher in the intervals between 4 – 12 m/s. However, an anemometer with a lower accuracy of ±0.4m/s is required for the background noise portion of the measurements.

4.3.2 Recommended Approach for Ontario

For Ontario, the procedure is recommended to require at least one method of reducing wind-induced pseudo noise on the microphone. They all seem to show similar noise reduction performance. If secondary wind screens are used, calibration of the measured level based on the insertion loss of the secondary wind screen would need to be addressed.

The anemometer is recommended to have an accuracy of ±0.2m/s or higher. The resolution of the anemometer is recommended to be 0.1m/s or higher. The anemometer is also recommended to be traceable and follow the calibration schedule presented in Table 2 below.

The noise measurement system is recommended to comply with NPC-102 with the following calibration schedule:

Table 2: Calibration schedule for measurement system

Equipment	Calibration interval
Acoustic calibrator	12 months
Microphone	24 months
Integrating sound level meter	24 months
Spectrum analyser	36 months
Data recording / playback system	24 months
Anemometer	12 months

* This schedule is in line with that proposed by IEA Recommendations.

4.4 Measurement Period & Duration

4.4.1 Information Gathered from Literature Review

Based on the literature review and the guidelines, there are varying opinions on the required amount of data. Although, it should be mentioned that the requirements are in relation to differing measurement metrics and information. For example, the Australian standard [29] requires 2000 data points when measuring 10 minute L_{A90} values, but with an optional attended measurement method with the turbines on/off. For those attended measurements, only 10 data points above and 10 below the critical wind speed (within 3m/s) are required. The New Zealand standard [28] requires a minimum of 1440 data points measuring 10-minute intervals.

The IEA [24] also provides different recommendations based on the approach taken. For measurements of L_{Aeq} which are 1-10 minute long, and intended for attended measurements, it is recommended that at least 10 data points be obtained spanning a minimum total time of 30 minutes. The same is recommended for obtaining background noise levels (with turbines parked). In cases where noise immissions are of interest only for a target wind speed, at least 3 data points are recommended to be obtained above and 3 points below that target speed within 2m/s of the target speed. There is also a requirement for the total measurement period to be at least 10 minutes for these measurements.

In the case of measuring A-weighted percentiles (meant for unattended measurements), the IEA recommends at least 20 periods of 10 minutes each where the wind speed is within 2m/s of the target wind speed, with at least 10 measurements on either side of that target wind speed.

4.4.2 Recommended Approach for Ontario

In order to ensure that these audits are conducted in a consistent manner amongst all parties, it is recommended that the measurements be carried out under similar meteorological conditions to those used in the acoustic model. This would potentially include only conducting the measurements during the summer night time conditions.

Since the recommended measurements are LA_{eq} measurements with relatively short intervals, the total number of data points is recommended to be higher than those proposed in the literature. Additionally, the number of points required is recommended to be categorized by wind speed. The procedure must ensure that a minimum number of measurements is obtained at all specified wind speeds, and that those measurements must meet certain criteria in order to be acceptable data points. The criteria should be designed in such a way as to exclude points where transient noise events are taking place, or data points where weather conditions are unstable for the duration of the measurement. More of the rules of inclusion are presented in section 4.9. The total amount of data at each integer wind speed is recommended to be no less than 1 hour. For example, at the integer wind speed of 6 m/s, there should be a minimum of 60 1-minute LA_{eq} measurements that meet the requirements of inclusion.

4.5 Noise measurement position

4.5.1 Information Gathered from Literature Review

Virtually all the documents surveyed considered the sound level limit as applicable to the outdoor noise level. With this, virtually all measured noise immissions outdoors. With regards to microphone and anemometer position, both UK-ETSU-R-97 [30] and DIN 45645 [31] provide good guidelines on the distance away from reflecting surfaces for the microphone, as well as locations for the anemometer mast. UK-ETSU-R-97 states, regarding the location:

"Monitoring should be undertaken at the locations to which the noise limits apply, ie the noise sensitive properties around the wind farm from which complaints have been received."

Implying that noise measurements only be taken in cases where a complaint has been made. Additionally, measurements are recommended to be taken at least 10 metres away from building facade to minimize reflections. It gives 3.5 metres as the closest allowable measurement point to a facade (although, these would be for sensitive outdoor receptor locations such as patios). Measurements are recommended at a height of 1.2m for the sake of convenience.

The IEA Recommendations [24] suggest a microphone height of either 1.2-1.5 metres or 5 metres. Since the guide provides measurement options for free-field microphone positions as well as with the use of vertical reflecting boards (of 2 sizes), different distances are recommended. For the free-field case, Appendix 1 gives guidelines on the reasoning behind the distance requirements:

“The "free- field" value is here defined as the level at a point where the level of the reflected sound is 6 dB or more below that of the direct sound (including ground reflections in both cases).”

Based on this premise, 3 cases are provided, the last of which seems the most applicable to practice. In this case a 5 metre distance from the facade is recommended.

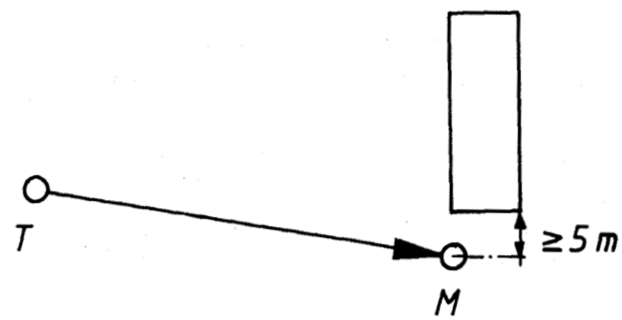


Figure 3: IEA recommended distance from a building facade in order to avoid reflections from the building [24].

T = turbine location, M = Monitoring location

The IEA recommendations also note that in many cases in practice, the problems involved with choosing microphone position for a free-field value can be avoided by using a measurement board.

4.5.2 Recommended Approach for Ontario

The measurement position with respect to the receptor building is recommended to follow the IEA recommendations of 5 metres away from the facade. This seems both a practical and applicable requirement. The measurement height is recommended to be at 4.5 metre or 1.5 metre height, depending on whether the receptor is single storey, or two storey dwelling. This requirement will keep consistent with the MOE sound level limits and the heights at which the receptor was modelled during the assessment stage.

With regards to the measurement location and the number of locations required in an audit scenario, we recommend the number be dependent on the results from the modelling. Measurement locations should be considered for all receptors or groups of receptors for which the predicted noise level is within 3dB of the sound level limit.

4.6 Wind measurement position

4.6.1 Information Gathered from Literature Review

In the literature reviewed, wind measurements have been taken from both 10 metre height, as well as hub height (usually ~80m). They have been measured at the turbine locations, receptor locations, or wind farm location (location within the wind farm area that has anemometers setup for monitoring wind conditions). The New Zealand standard [28] and the Australian standard [29] both refer to wind speed measured at hub height. The UK-ETSU-R-97 [30] document recommends measuring at 10 metre height at the location of pre-construction background noise survey. The IEA document [24] recommends measuring the wind speed at a point which is “relevant for the noise generation”. They pay particular attention to ensuring that the measurements of wind are made in locations of un-disturbed flow. This means measuring upwind of the turbines. However, the document does have a a section on wind speed measurement position at the receptor in which it recommends placing the anemometer “in the vicinity of the microphone and at a height of 10m”. It is worth noting that the UK-ETSU-R-97 document sites the 10 metre height as being sufficiently below the lowest part of the turbine blade as to reflect an undisturbed section of the flow.

4.6.2 Recommended Approach for Ontario

Wind measurements are recommended to be carried out at the receptor. 10 metre height has become the standard for wind measurements when correlated to turbine noise. Although some studies have argued that results are more consistent when compared to the hub height wind speed [8]. In either scenario, the wind speed measurements have played a crucial part in the overall assessment of compliance. In the case of Ontario, it is specifically important as the sound level limit varies with the wind speed at 10 meters height. The recommendation is to measure the wind speed at the point of reception, and at the same interval duration as the noise measurements. The anemometer is recommended to have the ability to be calibrated and be traceable.

4.7 Assessment of ambient noise levels

4.7.1 Information Gathered from Literature Review

In virtually all the noise immission studies, standards and papers examined in the literature review, the influence of background noise during the measurements was assessed. The consensus in virtually all of the studies has been to quantify the ambient noise levels and to subtract those from measurements taken during wind turbine operation. The method that has been applied varies. The New Zealand and Australian standards [28][29] quantify the ambient levels prior to the construction of the turbine farm. This process is used to obtain the applicable sound level limit. The philosophy of those two approaches stems from the UK-ETSU-R-97 document [30]. The IEA [24] recommends measuring the noise with the wind farm parked.

4.7.2 Recommended Approach for Ontario

The procedure is recommended to assess the ambient noise levels at the point of reception, preferably post-construction and during the same measurement campaign as the turbine measurements. This is to account for the experienced ambient noise level as a function of wind speed. The measurements are recommended to be performed on the same measurement campaign in order to minimize the difference in ambient conditions as compared to measurements with the turbines running. Fowler’s report [32] on the Toora wind farm site in New Zealand showed ambient noise levels increased when comparing preconstruction monitoring results to post-construction but pre-operation measurements.

The ambient noise measurements should cover the same range of wind speeds as the measurements with the turbines ON, and should meet prescribed minimum requirements for the number of intervals measured.

In addition to this, it is essential to conduct these measurements during periods where the ambient noise is minimized. It may be required to limit these measurements to night time periods when the ambient is quieter.

It should also be added that measurement of ambient noise levels is not recommended to be mandatory if one can show that the sound level limits are satisfied with measurements taken while the turbines are operational.

4.8 Tonality

4.8.1 Information Gathered from Literature Review

As discussed in section 2.1.5, the general consensus in assessing tonality has shifted towards using a sliding scale that considers tonal audibility, and an objective method for determining tonality and applying a penalty to the sound spectrum. However, there are varying degrees of enforcement and application. For e.g. The New Zealand Standard assess the tonality objectively using 1/3rd Octave spectra, and applies a +5dB penalty if a tone is determined. The Australian Standard prescribes objective assessment of tonality with the following verbiage:

> *“Tonality can be objectively determined by the methodology contained in IEC 61400-11 or other methods such as the Joint Nordic Methodology or ISO 1996-2 or those developed and/or accepted by the Relevant Regulatory Authority.”*

UK-ETSU-R-97 and the IEA recommend the Joint Nordic Method [40],[41], which is quite similar to ISO 1996-2 [22]. IEC 61400-11 also uses this type of analysis [10].

4.8.2 Recommended Approach for Ontario

Tonality in Ontario is assessed in a subjective manor, and the tonal penalty is 5dB irrespective of the severity of the tone. Many studies researched use a sliding scale for tonality based on an objective measurement and assessment procedure for tonal audibility. It is recommended that this objective measurement and assessment procedure be adopted within Ontario.

4.9 Data Analysis & Impact Assessment

4.9.1 Information Gathered from Literature Review

This area is quite important in the measurement procedure. The approach taken is believed to have the most influence on the obtained results. There is no clear consensus on what analysis to use. The main issue lies in ensuring noise levels measured during transient events are discarded. The Australian Standard [29] uses a metric of $LA_{eq,10min}$ > ($LA_{9010min}$ + 3dBA) as a test of acceptability. The New Zealand standard [28] does not specify how to determine extraneous sounds, but states:

> *“Extraneous sound levels caused be events, including precipitation, insects, fauna, and so on, should, as far as is practical for an unattended monitoring exercise, be identified and removed from the data set”*

The UK-ETSU-R-97 prescribes removing measurements affected by effects such as rainfall.

Regression analysis is performed on all the remaining data up to third order polynomials to determine the trend of noise level versus wind speed. The IEA recommends a 2nd order polynomial to assess background noise vs. wind speed, and a linear regression to determine background-corrected turbine noise contribution vs. Wind speed.

4.9.2 Recommended Approach for Ontario

For the procedure in Ontario, the analysis is recommended to apply the following data reduction steps to the acquired 1-minute LA_{eq} data:

1. Remove all data between 05:00 – 19:00
   This is to remove times where the ambient level is higher. Unless a very specific case occurs where the noise levels in the frequency range of the wind turbine noise are higher at night time, this data reduction will lower the ambient noise conditions, and provide a signal-to-noise ratio. A relatively early exclusion period is chosen (5AM) to account for activity in rural and farmland areas where farm work is known to start early.

2. Identify any influence from insects, or other extraneous but constant sources of noise and verify through sound recordings. Noise from insects can be removed from the 1/3rd Octave spectra of each measurement. It has to be shown, however, that the contribution of the wind turbine noise in those frequencies is minimal.

3. Intervals identified where rainfall occurred from one hour before and after the rainfall period should be removed.

4. 1-minute intervals where the max/min wind speed differs from the average wind speed by more than 2 m/s should be removed in order to avoid gusty periods.

With these reductions, the data that remains will represent the environmental noise level during steady, night time conditions.

Once the data has been filtered, all the remaining data should be plotted against wind speed. Both sets of data (turbines ON and turbines OFF) are recommended to be fitted with a regression line of up to 3rd order polynomial curve through the range of measured data points. It is important to note that the regression cannot be used to identify noise levels outside of the measured wind speed range.

At this point, the "Turbine ON" data set can be background-corrected by logarithmically subtracting the levels from the two regression curves. The resulting LA_{eq} at each integer wind speed can be used as the noise contribution of the wind farm at the receptor.

4.9.3 Uncertainty and data quality

Even with the steps recommended in the procedure in place, there is the possibility that the measured data levels will be highly variable and not representative of the precise noise contribution from the wind turbines. With this, there is recommended to be a measure of statistical variation (for e.g. Standard deviation) that should be tabulated and reported for the resulting data for each wind speed as an indication of the uncertainty and the variability of the measured levels. A maximum standard deviation for the data in each integer wind speed should fall below a set level (to be determined from the field testing phase).

4.9.4 Assessment of compliance

Finally, it is recommended that a clear statement of compliance or non-compliance be provided based on the data analysis. The statement should include contributions at each integer wind speed as compared to the sound level limit.

This is currently a vague area especially in the context of wind turbine noise in Ontario. Because no strict requirements have been laid out in a procedure for measuring noise immission from wind turbines, different studies have adopted different strategies in both quantifying the noise contribution from the wind farm and assessing whether the wind farm is in compliance. Having a unified approach to measuring and reporting the noise immission will go a long way in helping make reasonable conclusions about the noise immission from a specific site.

While this document serves the purpose of developing a procedure to quantify the noise immission from wind farm noise, it is ultimately a decision of the MOE as to how wind farms will be assessed, and what level of noise contribution from the wind farm is deemed acceptable when compared to the MOE prescribed sound level limits.

4.10 Summary of Recommended procedure

The following table summarizes the recommendations in this section

Table 3: Summary of recommendations for a new procedure

Aspect [reference section]	Metric / parameter recommended	Comment
Measurement Interval [4.2]	1 minute	
Noise measurement [4.2]	1/3rd Octave LAeq	
	Audio recording	For listening purposes
[4.5]	Height: 1.5 / 4.5m at receptor location	depending on receptor modelled during assessment
Wind screen [4.3]	Large secondary windscreen	Insertion Loss must be documented. Other methods also allowed see section 4.3
Wind measurement [4.3]	Resolution 0.1m/s	Accuracy ±0.2m/s
	Height: 10m	
[4.6]	Measured at receptor location	
Total measurement time [4.4]	Minimum 60 1-minute data points for each wind speed bin.	For example, 60 intervals at 6m/s (±0.5m/s).
Ambient noise measurements [4.7]	Measured with WT parked	Same number of minimum data points required
Tonality [4.8]	Assessed using Joint Nordic Method or ISO-1996-2	To be determined based on ability to be automated
Data analysis [4.9]	Data points rejected if measured during: - Daytime (5 AM – 7 PM) - Rainfall (with 1 hour buffer period) - Gusty wind conditions Influence of insects may be removed from individual spectra WT noise impact can be derived from background correction of data allowed.	

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