

A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act¹

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ABSTRACT

The Canadian Environmental Assessment Act (CEAA) requires certain projects with federal government triggers to undergo an environmental assessment before receiving federal government approval. On request under CEAA, Health Canada provides advice on the health effects of noise to responsible authorities for wind turbine projects. The advice that Health Canada provides on the health effects of noise is generally based only on well-accepted scientific evidence for a link between noise exposure and health. For quiet rural areas, in which annoyance reactions towards intruding noise may be augmented, this paper proposes noise mitigation if predicted wind turbine noise levels exceed 45 dBA at noise sensitive receptors. In this proposal, a cautious approach is adopted by using predicted noise levels that are evaluated at the wind speed that produces the highest wind turbine noise, and background noise is evaluated in calm winds. This accounts for sheltering by obstructions. Wind speed gradient effects related to stable atmospheric conditions are also accounted for with this approach. The proposal is based on predicted project-noise related changes in long-term high annoyance, rattle and sleep disturbance. Noise mitigation for wind turbine construction noise is proposed based on potential for expectation of complaints.

Keywords: wind turbines, health, annoyance, environmental assessment, construction noise

1. INTRODUCTION

The development of a guidance document on how to assess noise impacts in environmental assessments of wind turbines (including wind farms) has been necessitated by the growing number of requests for Health Canada's advice on this topic. As of 2006, Canada became one of 13 countries to exceed 1000 MW of wind capacity (Environmental News Service, 2007). This was in large part due to a doubling of wind energy capacity in 2006 in Canada to 1459 MW and it has been projected that Canada will increase this capacity to at least 10000 MW by 2015 (Environmental News Service, 2007). The development of wind energy in Canada is partially related to financial support through provincial incentive programs and federal government programs coordinated by Natural Resources Canada (Natural Resources Canada, 2007).

The *Canadian Environmental Assessment Act* (CEAA) requires certain projects with federal government triggers, such as federally funded wind turbine projects, to undergo an environmental assessment before receiving federal government approval. For example, wind turbine projects may be subsidized by Natural Resources Canada, which then plays the role as one of the responsible authorities

¹Portions of this paper were presented by DSM at Wind Turbine Noise, Lyon, France, 2007.

under the *CEAA* for that project. The intent of the environmental assessment process is principally to ensure that projects are not likely to cause significant adverse environmental effects. It is the responsible authorities' decision as to whether a project fulfills this intent. Environmental effects may include health effects from project related noise and, as such, the responsible authorities for wind farm projects often request specialist information and knowledge in this area from Health Canada to help make their decision (Canadian Environmental Assessment Agency, 2003, Health Canada, 1999).

Health Canada's expertise on: (i) noise measurement and (ii) the health effects of noise stems from Health Canada's mandate to administer the *Radiation Emitting Devices Act (REDA)*. This Act controls the sale, lease, importation and advertising of radiation emitting devices. The link to environmental noise follows from the fact that acoustical radiation is included under the *REDA*.

As the *CEAA* only requires that, on request, the specialist information and knowledge provided is within Health Canada's possession, Health Canada's advice is solely related to effects on human health. Here, human health is defined in the broad terms given by the WHO, and which have been fully adopted by Canadian federal, provincial and territorial governments (Health Canada, 1999) as: "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" and, "*the extent to which an individual or a group is able, on the one hand, to realize aspirations and to satisfy needs, and on the other, to change or cope with the environment*" (World Health Organization, 1999).

Given that the advice pertains to another authority's (i.e., the responsible authority) decision on the significance of an effect, the advice that Health Canada provides on the health effects of noise is generally based only on well-accepted scientific evidence for a link between noise exposure and health. Other considerations, such as, economical, financial and planning are left up to the judgment of the project's responsible authority.

To decide which mitigation criterion should be recommended by Health Canada to responsible authorities, an evaluation method for the potential health effects of wind turbine noise is needed. Although federal legislation exists for noise from some sources such as aircraft and motor vehicles, there is no general national policy for environmental noise that could be applied to wind turbine noise in Canada. It is arguable that for wind turbine noise (and many other environmental noise sources), mitigation advice under *CEAA* from Health Canada should be made solely by reference to provincial (or even municipal) legislation, policies and guidelines because environmental noise control, *in situ*, is mainly under these jurisdictions. However, this would lead to inconsistent advice across Canada because considerably different noise mitigation criteria for wind turbines exist in several different provinces. It is up to the responsible authorities to determine how, or if, to use Health Canada's advice and provincial mitigation criteria.

As a starting point for the development of a Health Canada guidance document on how to assess noise impacts in environmental assessments of wind turbine projects, this paper provides proposals for criteria for evaluating the potential health effects of wind turbine noise. The rationale behind the proposals is discussed.

2. PROPOSED CRITERIA FOR PREDICTED SOUND LEVELS

It is recommended that, at a height of 1.5 m at the most exposed facade of a noise sensitive receptor² in quiet rural settings³, the predicted sound level produced by wind turbine operation not exceed 45 dBA. The prediction is to be determined using the wind speed yielding the maximum sound power from the wind turbine and

² Health Canada considers a noise sensitive receptor to include residences as well as all hospitals, schools, day-cares and seniors' residences for which a significant effect is plausible from either project construction or operation noise; in addition to any sites within the study area where socially significant First Nations cultural or religious ceremonies take place

³ The characterization of an area as "quiet rural" is ultimately left up to the project proponent to determine through community consultation. However, until the proponent makes this determination, Health Canada assumes an area to be a quiet rural area when the human made background sound levels are below 45dBA during the day and 35dBA during the night. In such areas, population density is typically less than 8 dwellings per square kilometre (Alberta Energy Utilities Board, 2007).

should include consideration for noise shielding, barriers, air/ground absorption, etc., using ISO 9613-2 (ISO, 1996) or other appropriate methods. The sound level due to wind turbine noise at the noise sensitive receptor is evaluated as if all noise sensitive receptors are sited under favourable propagation conditions. Based on the cautious assumption that the turbines operate continuously at approximately their maximum sound power output, the same criterion value is applied to day and night time L_{eq} values (L_d and L_n , respectively). In the rare cases where turbines have been erected in more urbanized areas, higher levels are proposed for the criterion value of the assumed continuous sound level. In these latter cases, the proposed criterion value is the wind turbine sound level that leads to a 6.5% increase in the percentage highly annoyed (%HA).

In subsequent sections it is demonstrated how the proposal described here compares to various international, national and Canadian provincial noise criteria.

3. COMPARISON WITH ANSI, WHO AND INTERNATIONAL CRITERIA

It has been established that noticeable noise-induced rattle increases annoyance more than noise without vibration (Schomer and Averbuch, 1989; Schomer and Neathammer, 1987; Paulsen and Kastka, 1995; Ohrstrom, 1997). If sound levels at the receptor are kept below 45 dBA, the ANSI S12.2 (American National Standards Institute, 1995) room criterion for rattle will not be exceeded in the 63 Hz⁴ octave band.

A 45 dBA L_{eq} for constant noise is also consistent with the WHO's recommendation that the equivalent sound level indoors should not exceed 30 dBA for continuous background noise for a good night's sleep (World Health Organization, 1999), or 35 dBA for speech intelligibility indoors in smaller rooms. Dwellings constructed to older Canadian residential standards attenuate exterior noise by at least 20 dB with windows closed (Canadian Mortgage and Housing Corporation, 1981). In 1974, the EPA reported sound level reductions for aircraft noise due to houses in cold climates in the U.S.A. with windows open as being 17 dB. The WHO also used the 15 dB reduction for a windows slightly open situation.

The 45 dBA recommendation is below all specified WHO guideline levels for effects from sleep disturbance, speech disturbance, moderate annoyance, or hearing impairment (World Health Organization, 1999). However, a detailed comparison with the variety of criteria from other countries is beyond the scope of this paper. Even the simplest quantitative comparison is challenging because of the differences in the way that the sound level is predicted.

For example, at wind speeds of 8 m/s, measured at a height of 10 m at the wind turbine, criterion values for predicted sound levels for Denmark (Pedersen and Halmstad, 2003; South Australia Environment Protection Agency, 2007), New Zealand, (NZS 6808:1998) and South Australia (South Australia Environment Protection Agency, 2007) are all nominally 40 dBA outside of residences in quiet rural areas. At face value, it appears that these criteria are all more protective than the one proposed in this paper, but a conclusive quantitative comparison can only be made with complete modelling of the sound level because of its dependence on prediction model, sound power as a function of wind speed, the limit period (day and/or night), and the implied area type. As indicated in the South Australia interim guidelines for wind turbine noise (South Australia Environment Protection Agency, 2007) its criterion level can vary between 35 and 43 dBA depending upon the measured background sound level i.e., the wind noise. New Zealand also uses the wind for background levels (NZS 6808:1998), while in Denmark, the criterion level is simply 40 dBA at a wind speed of 8 m/s; other wind speeds not being considered (South Australia Environment Protection Agency, 2007). Guidance from the United Kingdom (Department of Trade & Industry, 1996) yields separate day and night criterion levels. For night, the criterion level is equivalent to about 45 dBA for a steady wind turbine noise at a wind speed of 8 m/s but increases up to about 54 dBA

⁴ In ANSI S12.2 (American National Standards Institute (ANSI), 1995) recommendations are given for the 16, 32 and 63 Hz octave bands, but 63 Hz is the lowest measured band in the normative section of IEC 61400-11 (IEC, 2006).

at a wind speed of 12 m/s. Interestingly, up to wind speeds of 7 m/s, the daytime criterion is lower in the U.K., equivalent to a steady wind turbine noise Leq of 37-42 dBA for quiet areas, rising up to 54 dBA for wind speeds of 12 m/s.

4. CANADIAN PROVINCIAL GUIDELINES, POLICIES AND LEGISLATION

In the application of the proposed criteria, in order to take into account regional variations in noise sensitivity to industrial installations, applicable provincial or territorial legislation, guidelines and policies need to be met. In the provinces and territories, wind turbines are evaluated under the category of stationary or industrial noise sources. Although Quebec's limits are not specifically designed for wind turbines, it is the only province with limits that, if complied with during operation, should always yield L_n values that will not exceed those that could result from compliance with this paper's proposed criterion. For Zone I land use (i.e., isolated single family detached or semidetached dwellings, schools, hospitals or other teaching, health or convalescent institutions), Quebec's night time limit is a one hour Leq of 40 dBA. This limit increases to 45 dBA for Zone II land use (i.e. multi-family dwellings, mobile home parks, institutions or camping grounds) (Ministère du Développement durable, de l'Environnement et des Parcs, 2006). Environmental noise limits in Nova Scotia (Nova Scotia Environment and Labour, 1990) and Manitoba (Manitoba Environment, 1992) are higher, where night time limits are respectively Leq 55 dBA and Leq 50 dBA.

Ontario, Alberta and British Columbia (B.C.) are the only Canadian provinces with guidance specific to wind turbines. For Ontario, this limit increases with increasing wind speed. In Ontario, in quiet areas, for wind speeds below 6 m/s, the noise limit is 40 dBA and at 11 m/s the noise limit rises to 53 dBA (Ontario Ministry of the Environment, 2004). These limits could be as much as 8 dBA higher than the 45 dBA criterion proposed here. In a quiet rural area, application of Alberta's Energy Utilities Board Directive 038 (Alberta Energy Utilities Board, 2007) would yield a criterion with a night time Leq of 40 dBA for wind speeds between 6-9 m/s, the only speeds for which the Directive prescribes predictions. Alberta's Directive considers this range to be the one yielding a worst case condition. Of note, in Alberta, existing noise due to wind turbines and other energy projects are not considered background noise, but are considered to contribute to the noise produced by the new project. The recommendations in this paper are expected to be more conservative than the Alberta Directive under some conditions. One example would be a situation where, as a function of wind speed, the maximum value of the sound power level from the wind turbine is 5 dB greater than any value between 6-9 m/s. Generally, though, for quiet rural areas, the Alberta Directive is expected to be more conservative. The province of British Columbia adopted a "*Land use operational policy, wind power projects on Crown land*" (British Columbia Ministry of Agriculture and Lands, 2007). The policy specifies an outdoor maximum wind turbine sound level of 40 dBA from wind turbines at a residence or land residentially zoned that is not owned by the project proponent. It is to be predicted at wind speeds where the sound power level has become constant, typically between 8-10 m/s; otherwise 11 m/s is to be used. As in the case with the Alberta limits, if these wind speeds do not yield the maximum sound power level, there may be some situations where the recommendations in this paper could lead to operations that are less annoying or sleep disturbing than the B.C. regulation. Generally, though, B.C.'s limits are more conservative.

5. DOSE-RESPONSE FOR PERCENTAGE HIGH ANNOYANCE (%HA)

The proposed sound level criteria are based on project-related changes in high annoyance. These changes are evaluated in terms of changes in the %HA, from the noise environment due to human made sources without the wind turbine(s), to the noise environment with the wind turbines, as per Eq. 1 (ISO, 2003).

$$\%HA = 100/[1 + \exp(10.4 - 0.132L_R)] \quad (1)$$

where, L_R is the rating level, the Ldn of the wind turbine noise source, adjusted by 10 dB in quiet rural areas (see below).

Our proposed criteria considers loss of amenity insofar as it accounts for the findings that in quiet rural areas there is a greater expectation for and value placed on peace and quiet (ISO, 2003; U.S. Environmental Protection Agency, 1974; Schomer, 2002). Annoyance reactions are expected to be higher in such locations and this increase may be equivalent to up to a 10 dB increase in the intruding noise. The cautious approach taken in this proposal is to always adjust project sound levels by + 10 dB in quiet rural settings.

The second factor determining the proposed criterion value is the U.S. Federal Transit Administration's (FTA) (Hansen *et al.*, 2006) consideration that a 6.5% increase in the %HA corresponds to a severe noise impact⁵. In Canada, some provincial environmental noise criteria show some consistency with the use of a 6.5% increase in %HA (Transport Quebec, 1998, British Columbia Ministry of Transportation and Highways, 1993). An increase of 6.5% leads to a criterion level of 43 dBA. Using Eq 1, 6.5% HA is associated with Ldn = 58.6 dBA, which corresponds to Ldn = 48.6 dB in a quiet rural area (with 10 dB adjustment), assuming no high annoyance under baseline conditions. For a constant level source, which, in this proposal, wind turbines are assumed to be, Ldn = Leq + 6.4 dB, hence Ldn = 48.6 dBA corresponds to Leq = 42.2 dBA. In reality, there will be a small percentage of the population in quiet rural areas that are highly annoyed by human made sources prior to wind turbine installation. For example, even a baseline %HA as low as 1% yields a criterion level of 43.3dBA Leq. Furthermore, the Ldn in this proposal represents a long term average and wind turbine operations will not always yield maximum sound power levels. For these reasons, the criterion level has been rounded up to 45 dBA.

Wind turbines are assumed to be similar to other industrial sources⁶ without audible tones or impulses in the generation of a typical community response of high annoyance (ISO, 2003). It would be preferable if the proposed criteria could be based on a dose response relationship that was specific to wind turbines, but this is not yet judged to be feasible by the authors. Independently verified dose response relationships are available for transportation sources as shown in a review by Miedema and Vos (1998), but there have only been two published dose response relationships available that are specific to wind turbines (Pedersen and Waye, 2007; Pedersen and Waye, 2004). This is likely to increase as more countries include wind energy as part of their attempt to find alternative energy sources.

One study of older wind turbines from Sweden (Pedersen and Waye, 2004) suggested that the percentage "very annoyed" (also identified as "highly annoyed" by Pedersen and Waye (2004)) by wind turbine noise in a quiet area was 0% at a predicted value of 32 dBA Leq (predicted steady noise at a wind speed of 8 m/s), rising steeply to 20% at a sound level of 39 dBA. Pedersen and Waye (2004) suggested that the %HA by wind turbine noise was higher than for transportation noise sources at the same sound level. They also suggested that for wind turbine noise, the rise in %HA with sound level was more rapid than for transportation noise sources. However, it should be noted that a great deal of scatter is typically observed in the response of individual communities (Schomer, 2002) and this older study may represent a localized sample as it was made in small villages and country homes within a 30 km² area.

Using the proposal in this paper (i.e., 10 dB rural adjustment), and assuming constant turbine noise levels day and night, the %HA as a function of Ldn is plotted in Figure 1 as "ISO shifted 10 dB." For comparison, the %HA from Pedersen and Waye (2004) is plotted against Ldn by assuming the turbine Leq is constant day and

⁵ Health Canada adjusts the %HA curve by 10 dB in quiet areas. In contrast, in quiet areas with Ldn less than 43 dBA the U.S. Federal Transit Administration does not use the %HA curve and instead adopts a criterion level of ambient Ldn plus 15 dB.

⁶ ISO 1996-1 (ISO, 2003) indicates that there is insufficient information about the %HA dose-response relationships for continuous industrial noise. This standard assumes that annoyance caused by industrial noise is not different from that caused by road traffic noise. The standard did note though, that experience in some countries indicates that industrial noise can be more annoying than road traffic noise, even if it does not contain clearly audible tones or impulses.

night, consistent with the Swedish model used by Pedersen and Waye, which does not distinguish between day and night. (see “Pedersen and Waye quiet area 2004” in Figure 1), Compared to the Pedersen and Waye (2004) original curve the conversion from L_{eq} to L_{dn} causes a shift of 6.4 dB to the right (assumes L_{eq} is constant day and night).

The differences between the two curves in Figure 1 are likely smaller than shown if, as assumed in this paper, it is most appropriate to predict the sound levels at the receptor using the maximum sound power level from the turbine, rather than 8 m/s wind speed as was done by Pedersen and Waye (2004) using a Swedish model (Swedish Environmental Protection Agency, 2001). If the Pedersen and Waye (2004) %HA data were plotted as a function of sound levels based on the turbine’s maximum sound power level the Pedersen and Waye (2004) curve would likely shift to the right. It is unclear from their study if the sampled population perceived the wind turbines as a novel source. This may have influenced the %HA in their study insofar as it has been noted in the ISO standard (ISO, 2003) that in newly created situations, higher community annoyance can be equivalent to an additional 5dB. Therefore, another possible factor that may have affected the Pedersen and Waye (2004) results could be related to the novelty of the wind turbines. The novel source adjustment is not used in the proposal provided here because only the long term effects for a given level of operational noise are considered in Health Canada’s advice.

Figure 2 shows that in the follow up study, which consisted of a mix of rural and suburban areas, (Pedersen and Waye, 2007) the reported percent “rather” or “very” annoyed as a function of L_{eq} (converted to L_{dn} by assuming constant turbine noise levels day and night) appeared consistent with the percent “annoyed” (in contrast to “highly annoyed”) by road traffic noise, reported by Miedema and Oudshoorn (2001). Miedema and Oudshoorn (2001) also derived a dose response relationship for %HA, which at some levels show a few more %HA than would be predicted using Eq. 1. However, the difference is smaller than the ISO adjustment for quiet areas, which Miedema and Oudshoorn (2001) do not mention.

The results in these two figures could suggest higher annoyance for wind turbines than the proposal in this paper, however, the scatter in the Pedersen and Waye (2004; 2007) data precludes a definitive conclusion. More studies on the annoyance of wind turbines would be required to improve exposure metrics and confidence limits on the dose-response relationship.

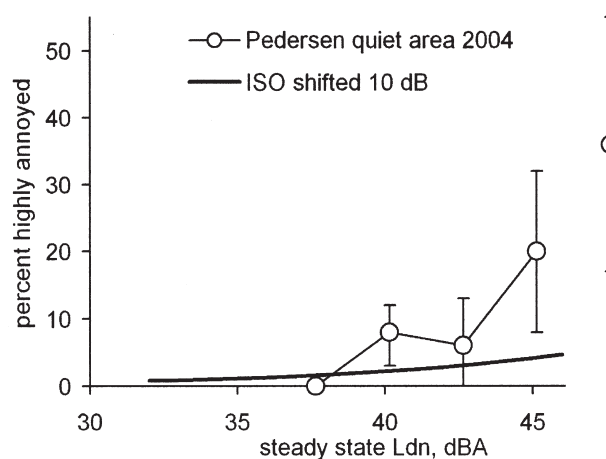


Figure 1: Comparison of wind turbine survey results to %HA, HA, in a quiet rural area. Pedersen and Waye (2004) wind turbine data is based on 8 m/s wind speed and L_{dn} was calculated by assuming continuous operation with the same L_{eq} day and night. The %HA in “ISO shifted 10 dB” is the dose response relationship for road traffic or industrial noise as per ISO (2003) shifted 10 dB lower to allow for an expectation for peace and quiet in a rural area. Error bars show 95% confidence intervals. The data point on the far right of the plot represents data taken at undisclosed levels above 46.4 dBA L_{dn} .

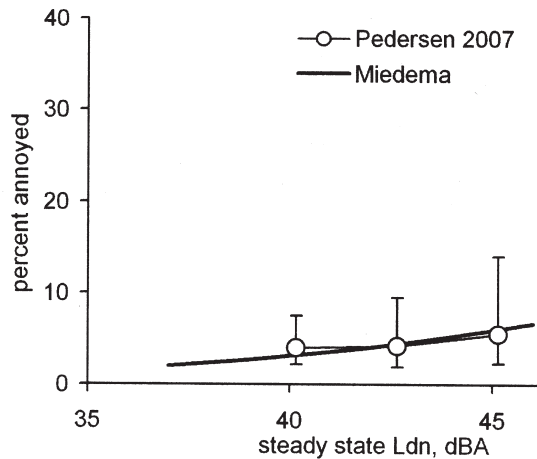


Figure 2: Comparison of wind turbine survey results to percent annoyed, A, due to traffic in an unspecified mix of area types (e.g., rural to suburban) from Miedema and Oudshoorn (2001). Pedersen and Waye (2007) wind turbine Ldn is based on 8 m/s wind speed and Ldn was calculated assuming continuous operation with the same Leq day and night. Error bars show 95% confidence intervals. The data point on the far right of the plot represents data taken at undisclosed levels above 46.4 dBA Ldn.

6. ADJUSTMENTS COMPARED TO OTHER INDUSTRIAL SOURCES

Quiet areas

The lack of a specific dose response relationship for wind turbines and health effects requires that effects be evaluated by applying the relationships for other sources. It is common to apply sound level adjustments to other sources, but it is not immediately obvious what, if any, should be applied to wind turbines.

In quiet rural areas where wind turbines are typically sited, it is proposed that a 10 dB adjustment be applied to project noise compared to industrial sources in urbanized settings. This is a precautionary adjustment based on the statement in ISO1996-1:2003 (ISO, 2003) indicating that research has shown that there is a greater expectation for and value placed on “peace and quiet” in quiet rural settings which may be equivalent to up to 10 dB.

Tonal noise

It is not common for modern wind turbine designs to be associated with audible tonal noise, however, it needs to be verified whether the project gives rise to tonal sound. This sound level information should be available if the manufacturer’s specifications conform to the requirements of International Electrotechnical Commission (IEC) standard *IEC 61400-11 (2006) on Wind turbine generator systems - Part 11: Acoustic noise measurement techniques* (IEC, 2006). In accordance with the ISO 1996-1 standard, audible tonal sound is adjusted by +5 dB in the determination of noise annoyance. To the extent that tonal noise is present, the proposed criterion level of 45 dBA will need to be reduced.

Low frequencies

Even though research shows that annoyance is greater when low frequency noise is present (ISO, 2003; Schomer and Averbuch, 1989), modern turbine designs are not normally associated with audible levels of low frequency or infrasound (Leventhall, 2006). In particular, for a recent United Kingdom government contract, Hayes McKenzie (Hayes McKenzie, 2006) investigated infrasound and low frequency noise at three wind turbine sites where complaints had occurred. The resulting report concluded that infrasound was well below the threshold for audibility and that, although low frequency noise may have been just above the threshold of audibility, it was less than the low frequency noise from traffic noise. Furthermore, the low frequency noise was less than UK and Danish criteria for indoor low frequency noise.

Sound levels in the 63 Hz 1/3rd octave band can be obtained from measurements following IEC 61400-11 (IEC, 2006). The proposed criterion sound levels are based on a comparison of sound levels from the project in the 63 Hz octave band⁷ to the ANSI S12.2 (ANSI, 1995). ANSI specifies that in the 63 Hz octave band, moderately noticeable vibrations are associated with a sound level of 70 dB, or 44 dBA. Therefore, a 45 dBA limit in quiet rural areas should adequately protect against low frequency noise impacts from wind turbines. Since the proposed criterion in urban areas can potentially exceed 45dBA, comparison should be made to the ANSI rattle criteria to determine if vibrations due to wind turbines are likely to occur (ANSI, 1995).

Aerodynamic modulation and other potential sound level adjustments

Other sound level adjustments that would help predict community reaction/annoyance towards wind turbines were also considered in the development of the proposed criterion. These other adjustments have not been applied due to lack of supporting data. In ISO1996-1 source specific adjustments are applied to aircraft and electric rail, which reflect human response to these, but no similar adjustments have been proposed for wind turbines.

Wind turbines create a characteristic “swooshing” sound (Pedersen and Waye, 2007; IEC, 2006, van den Berg, 2004). This “swooshing” sound can change the character of the ambient wind noise by adding a one to two Hz cyclic amplitude modulation. Although the Hayes McKenzie report (Hayes McKenzie, 2006) did not find concerns for infrasound and low frequency noise at the sites studied, it did find that audible aerodynamic modulation was a source of complaints against wind turbines (especially at night) in four cases. The audible modulation of aerodynamic noise was not sufficient to cause awakenings, but did interfere with returning to sleep, if awakened. The Hayes McKenzie report recommended that in the presence of high levels of aerodynamic modulation an adjustment should be considered.

A follow up study, the Salford Report (Moorhouse *et al.*, 2007), was therefore performed and published in July 2007. The findings of this study for the four sites noted above were that (Moorhouse *et al.*, 2007) the conditions for aerodynamic modulation would be present only 7%-15% of the time. The report concluded that both the incidence of aerodynamic modulation and the number of people affected was low. As a result, the United Kingdom’s government reached the conclusion that: *“Based on these findings, Government does not consider there to be a compelling case for more work into AM [aerodynamic modulation] and will not carry out any further research at this time; however it will continue to keep the issue under review.”* (Department for Business, Enterprise & Regulatory Reform, 2007).

In Canada, the only jurisdiction to specify an adjustment for modulation is the province of Ontario, in its land use guidelines (Ontario Ministry of the Environment, 1997; 1978). Ontario specifies a +5 dB adjustment for a project that contains an audible multi-frequency beating, but notably, this adjustment is not applied to Ontario wind turbines (Ontario Ministry of the Environment, 2004). The ISO has no adjustment for modulation (ISO, 2003). For the above reasons, an adjustment for aerodynamic modulation has not been applied to the proposed wind turbine criterion.

Although there is insufficient information at present, another plausible adjustment for consideration stemmed from an analysis of the similarities between certain aspects of aircraft noise and wind turbine noise. ISO (ISO, 2003) suggests a +3 dB to +6 dB adjustment on aircraft noise compared to road traffic noise, but no mechanistic interpretation for this range of adjustment is provided in the standard. It has been hypothesized that the adjustment is primarily due to the aircraft noise being a high, distant source (Kryter, 1982) and thereby yielding, on average, a higher, more uniform exposure than ground based sources which can be shielded or in an acoustic shadow. Also, associations have been found with annoyance and fear

⁷ In ANSI S12.2 (American National Standards Institute (ANSI), 1995) recommendations are given for the 16, 32 and 63 Hz octave bands, but the 50 Hz 1/3rd octave band is the lowest measured band in the normative section of IEC 61400-11 (IEC, 2006).

of aircraft crashes (Fields, 1993). Thus, when large turbines are built close to homes (e.g. less than 5 times the turbine height), they may share some similarities to aircraft. However, another characteristic of aircraft noise that could lead to the adjustment is the relatively high levels of low frequency noise causing rattles (Fidell *et al.*, 2002) or an increase in loudness (Schomer, 2004), both of which should not be applicable to wind turbine noise.

7. JUSTIFICATION FOR USE OF THE PREDICTED WORST CASE

The proposed criterion sound level is the predicted sound level determined for a worst case condition where; the wind turbine sound power level is the highest found as a function of wind speed and all noise sensitive receptors are sited under favourable propagation conditions.

Frequently, wind speed at the receptors is assumed to equal the wind speed associated with the noise levels obtained using the IEC standard (IEC, 2006). However, this can create a risk of unexpected annoyance from intruding wind turbine noise because the wind speed at the noise sensitive receptor may be significantly lower than that at the turbine hub due to sheltering by obstructions, wind speed gradients related to stable atmospheric conditions, or temporal variations in wind speed.

The United Kingdom's Department of Trade and Industry (Department of Trade & Industry, 1996) has suggested that, in some cases, receivers can be sheltered from the wind so that there is no masking of the turbine noise by ground level wind noise. Environmental assessments in Canada have shown some wind turbines are sited on hilltops, which could leave residences between hilltops exposed to wind turbine noise but sheltered from background wind noise. For wind turbine sites on level ground, sheltered areas due to treed wind breaks are common to avoid winter whiteout and snow drifting. These stands of trees can attenuate wind noise heard on the ground, yet may do little to attenuate wind turbine noise (i.e. turbine noise may not be masked at the receptor).

Due to the typically large setback distances between wind turbine and receiver, changing or unsteady winds can result in different wind speeds at the two locations. This also has the potential to reduce any masking of wind turbine noise by wind.

Also, under conditions of atmospheric stability, (i.e., clear or partially clear nights) wind speed at receptors may be significantly lower than wind speed at the turbine hub. According to IEC 61400-11 wind speed at a height of 80 m is predicted to be only 1.4 times greater than that at 10 m height (IEC, 2006). Yet, Van den Berg (van den Berg, 2004) has shown that the wind speed at night is up to 2.6 times higher at the turbine hub than on the ground (at 10 m). Over flat terrain in Australia, with a surface roughness similar to that used in IEC 61400-11, over a one year period, Botha measured average night time wind speeds 1.8 times higher at 80 m than at 10 m (Botha, 2005). Based on atmospheric stability data from the Netherlands (Salomons *et al.*, 1994), worst case conditions might be expected on terrain with roughness length $z_0=0.5$ m (or more) on clear nights when wind speed on the ground may be less than 5 m/s and speed at the turbine hub can exceed 10 m/s. Therefore the wind turbine noise can be well above the background sound level due to the wind at receptors since some turbine noise levels peak at wind speeds between 9 to 12 m/s (Vestas, 2007).

The noise level criteria proposed here should not be considered as strictly applied limits. It is possible that the noise from the wind turbine could be masked by wind noise. This situation can be identified by historical data for wind speed as a function of height and documented wind noise at the noise sensitive receptor.

Prediction

In Canada, predicted noise levels for wind turbines are usually based on ISO 9613-2 for propagation, including all applicable shielding and other effects. ISO 9613-2 has a standard uncertainty of ± 3 dB (ISO, 1996). There may be unanticipated or site specific conditions that may cause larger uncertainties. As a result, it is proposed that a cautious approach in environmental assessments would be to prepare

mitigation measures if it is reasonable to expect, within plausible uncertainties, proposed criterion levels to be measurably exceeded during operation.

8. AUDIBILITY

In the authors' experience, an increase in community reaction can occur if an intruding noise, which was supposed to be inaudible or barely perceptible, is readily heard by the community. Therefore, it is also proposed that environmental assessments avoid statements that suggest wind turbines are inaudible, or that changes of up to 5 dB are either not, or barely noticeable. Health Canada's knowledge of some community complaints and follow ups regarding wind farms suggests that in some cases wind turbine noise can be identifiable (i.e., audible/noticeable). The EPA "Levels" document (U.S. Environmental Protection Agency, 1974) states that when the "normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day - night sound level" the community is expected to have "no reaction although noise is generally noticeable." In the "Levels" document, sporadic complaints would be expected for a 3 dB increase in environmental noise level due to an identifiable intruding noise.

9. CONSTRUCTION NOISE

In Canada, construction noise limits are typically governed by municipal noise by-laws. One exception is the province of Quebec, where, for isolated single family dwellings the daytime limit is 45 dBA and the night time limit is 40 dBA (Ministère du Développement durable, de l'Environnement et des Parcs, 2006). Due to typically large setback distances from residences, wind turbine construction noise is not usually an issue at noise sensitive receptors. For consistency with advice on other industrial sources, it is proposed that, if potential health effects from construction noise are to be assessed, then, for each representative noise sensitive receptor, the environmental assessment should provide the following: (i) expected duration of construction (years, months or weeks or days), (ii) an estimate of noise levels and (iii) any plans to monitor or mitigate construction noise or complaints arising from construction noise.

It is also proposed that short term construction noise be evaluated using the US EPA "Levels" document method of assessing qualitative complaint reactions (U.S. Environmental Protection Agency, 1974). If the resulting levels are predicted to result in widespread complaints or a stronger community reaction (according to (U.S. Environmental Protection Agency, 1974)), noise mitigation is proposed. Health Canada has used the Alberta Energy Utilities Directive 38 (Alberta Energy Utilities Board, 2007) for guidance as to whether construction noise should be considered temporary. In this Directive, a temporary facility is one that is in operation for less than 60 days (Alberta Energy Utilities Board, 2007 pg 34).

Based on an interpretation of the US EPA "Levels" document, for receptors in quiet rural areas, it is proposed that an Ldn of 57 dBA can be used as a typical criterion value. This measured value is based on a normalized value of 62 dBA. Following the EPA document, the corrections needed to determine the measured value from the normalized value can be obtained by assuming: (i) a quiet rural community (-10 dB), (ii) the community is aware that the operation causing noise at a given noise sensitive receptor is of limited duration (following the Alberta EUB), a duration of less than 60 days is required to apply this correction (+10 dB), and (iii) pure tone or impulsive character is present in the construction noise (-5 dB).

10. CONCLUSIONS

To provide protection from high annoyance, sleep disturbance and speech interference, the health effects and standards literature, as well as published data on wind turbines, provide support for a proposed criterion value of 45 dBA for wind turbine noise at residences. The criterion value refers to the sound level at a receptor predicted for the maximum sound power level as a function of wind speed. Complaint reactions and their follow ups for wind turbines and other noise sources indicate that it is advisable for environmental assessments to not refer to inaudibility

or lack of noticeability of wind turbine noise. The criteria proposed in this paper appear to be a useful starting point for comparison to applicable provincial guidelines and provision of advice on wind turbine noise, if requested by responsible authorities under the CEAA.

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