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Exhibit RJ-02
THE “HOW TO” GUIDE
TO
SITING WIND TURBINES
TO PREVENT HEALTH RISKS FROM SOUND

By:

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"A subset of society should not be forced to bear the cost of a benefit for the larger society."

I. Introduction

A new source of community noise is spreading rapidly across the rural U.S. countryside. Industrial-scale wind turbines (WT), a common sight in many European countries, are now actively promoted by federal and state governments in the U.S. as a way to reduce coal-powered electrical generation and global warming. The presence of industrial wind projects is expected to increase dramatically over the next few years, given the tax incentives and other economic and political support currently available for renewable energy projects in the U.S.

As a part of the widespread enthusiasm for renewable energy, state and local governments are promoting “Model Ordinances” for siting industrial wind farms which establish limits for noise and other potential hazards. These are used to determine where wind projects can be located in communities, which are predominantly rural and often extremely quiet during the evening and night. Yet, complaints about noise from residents near existing industrial wind turbine installations are common. This raises serious questions about whether current state and local government sitting guidelines for noise are sufficiently protective for people living close to the wind turbine developments. Research is emerging that suggests significant health effects are associated with living too close to modern industrial wind turbines. Research into the computer modeling and other methods used to determine the layout of wind turbine developments, including the distance from nearby residences, is at the same time showing that the output of the models may not accurately predict sound propagation. The models are used to make decisions about how close a turbine can be to a home or other sensitive property. The errors in the predicted sound levels can easily result in inadequate setback distances thus exposing the property owner to noise pollution and potential health risks. Current information suggests the models should not be used for siting decisions unless known errors and tolerances are applied to the results.

Our formal presentation and paper on this topic (Simple guidelines for siting wind turbines to prevent health risks) is an abbreviated version of this essay. The formal paper was presented to the Institute of Noise Control Engineers (INCE) at its July Noise-Con 2008 conference in Detroit, MI. A copy of

the paper is included at the end of this document. The formal paper covered the community noise studies performed in response to complaints, research on health issues related to wind turbine noise, critiques of noise studies performed by consultants working for the wind developer, and research/technical papers on wind turbine sound immissions and related topics. The formal paper also reviewed sound studies conducted by consultants for governments, the wind turbine owner, or the local residents for a number of sites with known health or annoyance problems. The purpose was to determine if a set of simple guidelines using dBA and dBC sound levels can serve as the ‘safe’ siting guidelines for noise and its effects on communities and people. The papers considered in our review included, but were not limited to, those listed in Tables 1-4 on pages 2 through 4 of the Noise-Con document.

This essay expands upon the Noise–Con paper and includes information to support the findings and recommended criteria. We are proposing very specific, yet reasonably simple to implement and assess criteria for audible and non-audible sound on adjacent properties and also present a sample noise ordinance and the procedures needed for pre-construction sound test, computer model requirements and follow-up tests (including those for assessing compliance).

The purpose of this expanded paper is to outline a rational, evidence-based set of criteria for industrial wind turbine siting in rural communities, using:

1) A review of the European and other wind turbine siting criteria and existing studies of the prevalence of noise problems after construction;
2) Primary review of sound studies done in a variety of locations in response to wind turbine noise complaints (Table 1);
3) Review of publications on health issues for those living in close proximity to wind turbines (Table 2);
4) Review of critiques of pre-construction developer noise impact statements (Table 3); and
5) Review of technical papers on noise propagation and qualities from wind turbines (Table 4).

The Tables are on pages 2-4 of the formal paper. We also cite standard international criteria for community noise levels and allowances for low-frequency noise.

The specific sections are:

1. Introduction (This section)
2. Results of Literature Review and Sound Studies
3. Development of Siting Criteria
4. Proposed Sound Limits
5. How to Include the Recommended Criteria in Local or State Noise Ordinances
6. Elements of a Wind Energy System Licensing Ordinance
7. Measurement Procedures (Appendix to Ordinance)
8. The Noise-Con 2008 paper “Simple guidelines for siting wind turbines to prevent health risks” with revisions not in the paper included in the conference’s Proceedings.

The construction of large WT (industrial wind turbines) projects in the U.S. is a relatively recent phenomenon, with most projects built after 2000. Other countries, especially in Europe, have been using wind energy systems (WES) since the early 1990’s or earlier. These earlier installations generally used turbines of less than 1 MW capacity with hub heights under 61 m (200 feet). Now, many of these earlier turbines reaching the end of their useful life, are being replaced with the
larger 1.5 to 3 MW units. Thus, the concepts and recommendations in this article, developed for the 1.5 MW and larger turbines being built in the U.S, may also be applicable abroad.

II. Results of Literature Review and Sound Studies

In the U.K. there are currently about 133 operating WT developments. Many of these have been in operation for over 10 years. The Acoustic Ecology Institute\(^2\) (AEI) reported that a Special Report for the British government titled “Wind Energy Noise Impacts,”\(^3\) found that about 20% of the wind farms in the U.K. generated most of the noise complaints. Another study commissioned by British government, from the consulting firm Hayes, McKensie, reported that only five of 126 wind farms in the U.K. reported problems with the noise phenomenon known as aerodynamic modulation.\(^4\)

Thus, experience in the U. K. shows that not all WT projects lead to community complaints. AEI posed an important question: “What are the factors in those wind farms that may be problematic, and how can we avoid replicating these situations elsewhere?”

As experienced industrial noise consultants ourselves, we would have expected the wind industry, given the U.K. experience, to have attempted to answer this question, conducting extensive research -- using credible independent research institutions -- before embarking on wind power development in the U.S. The wind industry was aware, or should have been aware, that 20% of British wind energy projects provoked complaints about noise and/or vibration, even in a country with more stringent noise limits than in the U.S.

The wind industry complies with stricter noise limits in the U.K. and other countries than it does in the U.S., for example:\(^5\):

- Australia: higher of 35 dBA or \(L_{90} + 5\) dBA
- Denmark: 40 dBA
- France: \(L_{90} + 3\) dBA (night) and \(L_{90} + 5\) dBA (day)
- Germany: 40 dBA
- Holland: 40 dBA
- United Kingdom: 40 dBA (day) and 43 dBA or \(L_{90} + 5\) dBA (night)
- Illinois: Octave frequency band limits of about 50 dBA (day) and about 46 dBA (night)
- Wisconsin: 50 dBA
- Michigan: 55 dBA

Industry representatives on state governmental committees have worked to establish sound limits and setbacks that are lenient and favor the industry. In Michigan, for example, the State Task Force (working under the Department of Labor and Economic Growth) recommended in its “Siting Guidelines for Wind Energy Systems” that the limits be set at 55 dBA or \(L_{90} + 5\) dBA, whichever is higher. In Wisconsin, the State Task Force has recommended 50 dBA.

When Wisconsin's Town of Union wind turbine committee made an open records request to find out the scientific basis for the sound levels and setbacks in the state's draft model ordinance, it found that no scientific or medical data was used at all. Review of the meeting minutes provided

\(^2\) AEI is a 501(c)3 non-profit organization based in Santa Fe, New Mexico, USA. The article is available at [http://www.acousticecology.org/srwind.html](http://www.acousticecology.org/srwind.html)


\(^5\) © 2008 G. W. Kamperman and R. R. James

Prepared for Goodhue, MN Hearing
under the request showed that the limits had been set by Task Force members representing the wind industry.\(^6\) This may explain why state level committees or task forces have drafted ordinances with upper limits of 50 dBA or higher instead of the much lower limits applied to similar projects in other countries. There is no independent, scientific or medical support for claims that locating 400+ foot tall wind turbines as close as 1000 feet (or less) to non-participating properties will not create noise disturbances, economic losses or other risks.\(^7\) But, there is considerable independent research supporting that this will result in public health risks and other negative impacts on people and property.

To illustrate the way a typical WT developer responds to a question raised by a community committee about noise and health the following example is presented and discussed:

<table>
<thead>
<tr>
<th>Q: 19. What sound standards will EcoEnergy ensure that the turbines will be within, based on the setbacks EcoEnergy plans to implement, and what scientific and peer reviewed data do you have to ensure and support there will be no health and safety issues to persons within your setbacks?</th>
<th>Answer: As mentioned, turbines are sited to have maximum sound level of 45dBA. These sound levels are well below levels causing physical harm. Medical books on sound indicate sound levels above 80-90dBA cause physical (health) effects. The possible effects to a person’s health due to “annoyance” are impossible to study in a scientific way, as these are often mostly psychosomatic, and are not caused by wind turbines as much as the individuals’ obsession with a new item in their environment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>From EcoEnergy’s “Response to the Town of Union Health &amp; Safety Research Questionnaire”</td>
<td>By Curt Bjurlin, M.S., Wes Slaymaker, P.E., Rick Gungel, P.E., EcoEnergy, L.L.C., submitted to Town of Union, Wisconsin and Mr. Kendall Schneider, on behalf of the Town of Union</td>
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A serious question was asked and it deserves a responsible answer. The committee, charged with fact-finding, sought answers they presumed would be based on independent, peer-reviewed studies. Instead, the industry response was spurious and misleading, and did not address the question. It stated that the turbines will be located so as to produce maximum sound levels of 45 dBA, the tone and context implying that 45 dBA is fully compatible with the quiet rural community setting. No acknowledgement is made of the dramatic change this will be for the noise environment of nearby families. No mention is made of how the WT, once in operation, will raise evening and nighttime background sound levels from the existing background levels of 20 to 30 dBA to 45 dBA. There is no disclosure of the considerable low frequency content of the WT sound; in fact, there are often claims to the contrary. They fail to warn that the home construction techniques used for modern wood frame homes result in walls and roofs that cannot block out WT low frequencies.

There is no mention of the nighttime sound level recommendations set by the World Health Organization (WHO) in its reports, *Guidelines for Community Noise* \(^8\) and “Report on the third...”

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\(^7\) It is worth noting that the 2007-06-29 version of the Vestas Mechanical Operating and Maintenance Manual for the model V90 – 3.0 MW VCRS 60 Hz turbine includes this warning for technicians and operators:

**“2. Stay and Traffic by the Turbine**

| Do not stay within a radius of 400m (1300ft) from the turbine unless it is necessary. If you have to inspect an operating turbine from the ground, do not stay under the rotor plane but observe the rotor from the front. Make sure that children do not stay by or play nearby the turbine. ...” |

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\(^8\) Available at http://www.who.int/docstore/peh/noise/guidelines2.html.
meeting on night noise guidelines. In these documents WHO recommends that sound levels during nighttime and late evening hours should be less than 30 dBA during sleeping periods to protect children's health. They noted that a child's autonomic nervous system is 10 to 15 dB more sensitive to noise than is an adult. Even for adults, health effects are first noted in some studies when the sound levels exceed 32 dBA L\textsubscript{max}. These sounds are 10-20 dBA lower than the sound levels needed to cause awakening.

For sounds that contain a strong low frequency component, which is typical of wind turbines, WHO says that the limits may need to be even lower than 30 dBA to avoid health risks. Further, they recommend that the criteria use dBC frequency weighting instead of dBA for sources with low frequency content. When WT sound levels are 45 dBA outside a home, we may find that the interior sound levels will drop to the 30 dBA level recommended for sleeping areas but low frequency noise only decreased 6-7 dBC from outside to inside. That could create a sleep problem because the low frequency content of the noise can penetrate the home’s walls and roof with little reduction. An example demonstrating how WT sound is affected by walls and windows is provided later in this document.

The wind turbine developers in the excerpt above do not disclose that the International Standards Organization (ISO) in ISO 1996-1971 recommends 25 dBA as the maximum night-time limit for rural communities. As can be seen in the table below, sound levels of 40 dBA and above are only appropriate in suburban communities during the day and urban communities during day and night. There are no communities where 45 dBA is considered acceptable at night.

<table>
<thead>
<tr>
<th>District Type</th>
<th>Daytime Limit</th>
<th>Evening Limit 7-11pm</th>
<th>Night Limit 11pm-7am</th>
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<tbody>
<tr>
<td>Rural</td>
<td>35dB</td>
<td>30dB</td>
<td>25dB</td>
</tr>
<tr>
<td>Suburban</td>
<td>40dB</td>
<td>35dB</td>
<td>30dB</td>
</tr>
<tr>
<td>Urban residential</td>
<td>45dB</td>
<td>40dB</td>
<td>35dB</td>
</tr>
<tr>
<td>Urban mixed</td>
<td>50dB</td>
<td>45dB</td>
<td>40dB</td>
</tr>
</tbody>
</table>

Further, the wind industry claims, “These sound levels are well below levels causing physical harm. Medical books on sound indicate sound levels above 80-90 dBA cause physical (health) effects.” Concern about sound levels in the 80-90 dBA range is for hearing health (your ears) and not the health-related issues of sleep disturbance and other symptoms associated with prolonged exposure to low levels of noise with low frequency and amplitude modulation such as the sound emitted by modern wind turbines. This type of response is a non-answer. It is an overt attempt to mislead while giving the appearance of providing a legitimate response.

Furthermore, the statement, “The possible effects to a person's health due to ‘annoyance’ are impossible to study in a scientific way, as these are often mostly psychosomatic, and are not caused by wind turbines as much as the individuals' obsession with a new item in their environment,” is both inaccurate and misleading. It ignores the work of researchers such as Pedersen, Harry, Phipps, and Pierpont on wind turbine effects specifically, and the numerous medical research studies reviewed by Frey and Hadden. The studies belie the claims of the wind industry. This “failure to locate” published

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9 Available at: [http://www.euro.who.int/Noise/activities/20040721_1](http://www.euro.who.int/Noise/activities/20040721_1) References found in Report on third meeting at pages 13 and others
studies that are readily available on the internet as to make some interpret the claim of “no medical research” as a conscious decision to not look for it. Those companies that do acknowledge the existence of medical research take the position that it is not credible for one or another reason and thus can be ignored.

Making statements outside their area of competence, wind industry advocates, without medical qualifications, label complaints of health effects as “psychosomatic” in a pejorative manner that implies the complaints can be discounted because they are not “really medical” conditions. Such a response cannot be considered to be based in fact. It is, at best, an opinion. It ignores the work of many researchers, including the World Health Organizations, on the effect of sounds during nighttime hours that result in sleep disturbance and other disorders with physical, not just psychological, pathologies.10,11 Many people find it difficult to articulate what has changed. They know something is different from before the wind turbines were operating and they may express it as feeling uncomfortable, uneasy, sleepless, or some other symptom, without being able to explain why it is happening.

Our review of the studies listed in Tables 1-4 of our Noise-Con paper show that some residents living as far as 3 km (1.86 mi) from a wind farm complain of sleep disturbance from the noise. Many residents living 1/10 of this distance (300 m or 984 ft) from wind farms experience major sleep disruption and other serious medical problems from nighttime wind turbine noise. The peculiar acoustic characteristics of wind turbine noise immissions12 cause the sounds at the receiving properties to be more annoying and troublesome than the more familiar noise from traffic and industrial factories. Limits used for these other community noise sources are not appropriate for siting modern industrial wind turbines. The residents who are annoyed by wind turbine noise complain of the repetitive, approximately once-per-second (1 Hz) “swoosh-boom-swoosh-boom” sound of the turbine blades and of “low frequency” noise. It is not clear to us whether the complaints about “low frequency” noise are about the audible low frequency part of the “swoosh-boom” sound, the once-per-second amplitude modulation (amplitude modulation means that the sound varies in loudness and other characteristics in a rhythmic pattern) of the “swoosh-boom” sound, or some combination of the two.

Figure 1 of our Noise Con paper, reproduced as Figure 1, below, shows the data from one of the complaint sites plotted against the sound immission spectra for a modern 2.5 MWatt wind turbine; A home in the United States at 2km distance, Young’s threshold of perception for the 10% most sensitive population (ISO 0266); and a spectrum obtained for a rural community during a three hour, 20 minute test from 11:45 pm until 3:05 am on a windless June evening near Ubly, Michigan. This is a quiet rural community located in central Huron County (also called Michigan’s Thumb). It is worth noting that this sound measurement sample demonstrates how quiet a rural community can be when located at a distance from industry, highways, and airport related noise emitters.

The line representing the threshold of perception is the focus of this graph. The remaining graphs show sound pressure levels (dB) at each of the frequency ranges from the lowest inaudible sounds at the left, to sounds that “rumble” (20Hz to about 200 Hz) and then those in the range of communication (200Hz through about 4000Hz) through high pitched sounds (up to 10,000 Hz). At


11 According to Online Etymology Dictionary, psychosomatic means “pertaining to the relation between mind and body, ... applied from 1938 to physical disorders with psychological causes.”

12 Emissions refer to acoustic energy from the viewpoint of the sound emitter, while immissions refer to acoustic energy from the viewpoint of the receiver.
each frequency where the graphs of sound pressures are above (exceed) the graph showing perception the wind turbine sounds would be perceptible or audible. The more the wind turbine sound exceeds the perception curve the more pronounced it will be. When it exceeds the quiet rural background sound level (L_{A90}) it will not be masked or obscured by the rural soundscape.

The over-all sounds from each of the frequency bands are summed and presented on the right hand side of the graph. These are presented with corrections for A-weighting (dBA) and C-weighting (dBC). These show that if only dBA criteria are used to assess and limit wind turbine sound the low frequency content of the wind turbines emissions are not revealed. Note that in many cases the values for dBC are almost 20 dBA higher than the dBA values. This is the basis for the WHO warning that when low frequency sound content is present outside a home dBA is not an appropriate method of describing predicted noise impacts, sound limits, or criteria.

Our review of the studies listed in Tables 1-4 in the Noise-Con paper at the end of this document, provided answers to a number of significant questions we had, as acoustical engineers, regarding the development of siting guidelines for industrial-scale wind turbines. They are provided below for easy of reading and continuity:

**Do international, national, or local community noise standards for siting wind turbines near dwellings address the low frequency portion of the wind turbines’ sound immissions?** No. State and local governments are in the process of establishing wind farm noise limits and/or wind turbine setbacks from nearby residents, but the standards incorrectly assume that limits based on dBA levels are sufficient to protect the residents.
Do wind farm developers have noise limit criteria and/or wind turbine setback criteria that apply to nearby dwellings? Yes. But the industry-recommended wind turbine noise levels (typically 50-55 dBA) are too high for the quiet nature of the rural communities and may be unsafe for the nearest residents. An additional concern is that some of the methods for pre-construction computer modeling may predict sound levels that are too low. These two factors combined can lead to post-construction complaints and health risks.

An example of a condition that complies with

Are all residents living near wind farms equally likely to be affected by wind turbine noise? No. Children, people with certain pre-existing medical conditions, and the elderly are likely to be the most susceptible. Some people are unaffected while nearby neighbors develop serious health problems caused by exposure to the same wind turbine noise.

How does wind turbine noise impact nearby residents? Wind turbine-associated symptoms include sleep disturbance, headache, ringing in the ears, dizziness, nausea, irritability, and problems with memory, concentration, and problem solving, as described in the first paper in this volume.

What are the technical options for reducing wind turbine noise immission at residences? There are only two options: 1) increase the distance between the source and receiver, or 2) reduce the source sound power emission. Either solution is incompatible with the objective of the wind farm developer, which is to maximize the wind power electrical generation within the land available.

Is wind turbine noise at a residence much more annoying than traffic noise? Yes. Researchers have found that, “Wind turbine noise was … found to cause annoyance at sound pressure levels lower than those known to be annoying for other community noise sources, such as road traffic. …Living in a clearly rural area in comparison with a suburban area increases the risk of annoyance with wind turbine noise.” In other papers by Pedersen wind turbine noise was perceived by about 85% of respondents to the study at sound levels as low as 35.0–37.5 dBA. Currently, this increased sensitivity is believed to be due to the presence of amplitude modulation in the wind turbine’s sound emissions which limits the masking effect of other ambient sounds and the low frequency content which is associated with the sounds inside homes and other buildings.

Amplitude modulation is a continuing change in the sound level in synchronization with the turning of the wind turbine’s blades. An example of amplitude modulation is shown in the figure 2 below. This figure shows the constantly varying dBA sound level in the graph at the top. The sound level varies from a low of 40 dBA to a high of 45 dBA repeating every 1.3 seconds continuously when the turbine is operating. The turbine is located approximately 1200 feet from the farmhouse. The photo shows the turbine that was dominant during this test.

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Figure 2 Amplitude Modulation at a farmhouse (Study sponsored by CCCRE, Calumet, Wisconsin)

It is worth noting that this measurement averages about 43 dBA (Leq) which is very close to the sound level predicted for a single turbine at 1000 feet in Figure 1 (solid red line with solid triangle markers). The lower graph shows the frequency spectrum at approximately 9:49 PM at a low point in the amplitude modulation. (The frequency chart’s cursor is the vertical line at the upper graph’s midpoint.) Note the dominance of sound energy in the lower frequency range. This was also present in the model’s predictions in Figure 1.

It is not hard to understand why many people in this community feel that they have been forced to accept noise pollution as a side effect of the wind project. Even though the 40 to 45 dBA sound levels in this example may comply with the 50 dBA limits adopted by the host county from the Wisconsin Model Ordinance the impact on the people near the wind project are subjected to noise pollution. This example demonstrates why criteria set at 50 dBA or higher do not protect the health and economic welfare of people living in the host communities. Adopting criteria such as those recommended later in this essay can prevent these situations from occurring.

**Low frequency noise is a problem inside buildings**

When low frequency sound is present outside homes and other occupied structures, it is often more an indoor problem than an outdoor one. This is very true for wind turbine sounds.

**Why do wind turbine noise immissions of only 35 dBA disturb sleep at night?** Affected residents complain of the middle- to high-frequency, repetitive swooshing sounds of the rotating turbine blades at a constant rate of about 1 Hz, plus low frequency noise. The amplitude modulation of the “swooshing” sound changes continuously. Residents also describe a thump or low frequency banging sound that varies in amplitude up to 10 dBA in the short interval between the swooshing sounds. This may be a result of sounds from multiple wind turbines with similar spectral content combining to increase and decrease the sound over and above the effects of modulation. [Note: These effects (e.g. phasing and coherence effects) are not normally considered in predictive models.] It may also be a result of turbulence of the air and wind on wind turbine operations when the blades are not at an optimum angle for noise emissions and/or power generation. It is also a result of sounds penetrating homes and other buildings at night and at other times where quiet is needed. When low frequency sound is present outside homes and other occupied structures, it is
often more likely to be an indoor problem than an outdoor one. This is very true for wind turbine sounds.

![Wind Turbine Interior Noise Spectra](image)

**Figure 3-A Single Wind Turbine Sound Inside Home @ 1000 Feet**

The usual assumption about wall and window attenuation being 15 dBA or more, which is valid for most sources of community noise, may not be sufficiently protective given the relatively high amplitude of the wind turbines’ low frequency immission spectra. Figures 2 and 3 demonstrate the basis for this concern.

To demonstrate the effects of outdoor low frequency content from wind turbines we prepared Figure 1 showing the effect of a single turbine (propagation model based on sound power level test data) at 1000 feet and then in Figure 4 projected the impact of ten (10) similar turbines at one (1) mile. We applied the façade sound isolation data from the Canada Research Council to the wind turbine example used in our Noise-Con 2008 paper and shown in Figure 1 above. The graphs each show the outdoor sound pressure levels predicted for the distance of 1000 feet and one mile as the upper graph line respectively. The curve showing the threshold of human perception for sounds at each 1/3 octave band center is also plotted. When the graphs representing wind turbine sound have data points above this threshold curve the sounds will be perceptible to at least 10% of the population (which includes most children).
In addition to the top graph line representing the sounds outside the home there are two other graph lines for the sounds inside the home. One curve represents the condition of no open windows and the other represents one open window.

With just one turbine at 1,000 feet there is a significant amount of low frequency noise above hearing threshold within rooms having exterior walls without windows or very well sealed windows. Even with the windows closed the sound pressure levels in the 63 Hz to 200 Hz one-octave bands still exceed the perception curve, in many cases by more than 10 dB. Note the perceptible sound between 50 and 200 Hz with a wall resonance frequency at 125 Hz (2 X 4 studs on 16 inch centers) for the “windows closed” condition. This would be perceived as a constant low rumble, which would be present inside homes whenever the turbines are operating.

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15 The typical wood stud exterior used in modern home construction is vinyl siding over 1/2 inch OSB or rigid fiberglass board applied to 2 X 4 studs with the stud space filled with thermal and 1/2 inch gypsum board applied on the exposed interior side. This has a mass of about 3-4 lbs/sq ft and low 26 STC.

16 The basis for these predictions includes reports on aircraft sound insulation for dwellings and façade sound isolation data from the Canada Research Council.

17 “On the sound insulation of wood stud exterior walls” by J. S. Bradley and J. S. Birta, institute for Research in Construction, National Research Council, Montreal Road, Ottawa K1A 0R6, Canada, published: J.Acoust. Soc. Am. 110 (6), December 2001
walls and roof provide a reduction of 15 dBA or more. But, that would be misleading because it ignores the effects of low frequency sound.

We next increased the number of 2.5 Mw turbines from one to ten and moved the receiver one mile from the closest turbine. We assumed the acoustic center for the ten turbines to be 2km (1-1/4 miles) from the receiver. These results are presented in Figure 4. We were surprised to find that the one mile low frequency results are only 6.3 dB below the 1,000 foot one turbine example.

There is one other characteristic of wind turbine sound that increases the sleep disturbance potential above that of other long-term noise sources. The amplitude modulation of the sound emissions from the wind turbines create a repetitive rise and fall in sound levels synchronized to the blade rotation speed. Many common weather conditions increase the magnitude of amplitude modulation. Most of these occur at night. The graph in Figure 5 shows this effect in the first floor bedroom of a farm home in the U.K. The home is located 930 meters (3,050 feet) from the nearest turbine. The conditions documented by an independent acoustical consultant show the sound level varying over 9 dBA range from 28 to 37 dBA. The pattern repeats approximately every second often for hours at a time. For many people, especially seniors, children and those with pre-existing medical conditions, this represents a major challenge to restful sleep.

Figure 5- Amplitude modulation in a home 930 meters (3000 feet) from the nearest turbine.\(^\text{19}\)

This may explain why some residents as far as two (2) miles from a wind farm find the wind turbines sounds highly annoying. It also demonstrates the primary reason why relying on dBA

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\(^{18}\) Dan Hoffmeyer, Birger Plovsing: “Low Frequency Noise from Large Wind Turbines, Measurements of Sound Insulation of Facades.” Journal no. AV 1097/08, Client: Danish Energy Authority, Amaliegade 44, 1256 Copenhagen

\(^{19}\) This chart used with permission of Mike Stigwood, MIOA, FRSH, MAS Environmental, U.K. and the Davis family.
alone will not work for community noise criteria. It is the low frequency phenomena associated with wind turbine emissions that makes the dBC test criteria an important part of the proposed criteria\(^{20}\).

III. Development of Siting Criteria

Basis For Using LA\(_{90}\) To Determine Pre-Construction Long-Term Background Sound

We began our research into guidelines for proper siting by reviewing guidelines used in other countries to limit WT sound emissions. A recent compendium of these standards was presented in the report “Wind Turbine Facilities Noise Issues.”\(^{21}\) We found common ground in many of them. Some set explicit not-to-exceed sound level limits, for example, in Germany, 40 dBA nighttime in residential areas and 35 dBA nighttime in rural and other noise-sensitive areas. Other countries use the existing background sound levels for each community as the basis for establishing the sound level limits for the WES project. This second method has the advantage of adjusting the allowable limits for various background soundscapes. It makes use of a standard method for assessing background sound levels by measuring over a specified period of observation to determine the sound level exceeded 90\% of the time (LA\(_{90}\)) during the night. The night is important because it is the most likely time for sleep disturbance. Then, using the background sound level as the base, the WES project is allowed to increase it by 5 dBA. It is this second method (LA\(_{90}\) + 5 dBA) that was adopted for the criteria in this document. It has the advantage of adjusting the criteria for each community without the need for tables of allowable limits for different community types. The focus is only on the nighttime criteria. This is because the WES will operate 24 hours a day and the nighttime limits will be the controlling limits whether or not there are other limits for daytime.

*Wind turbine noise is more annoying than other noises and needs lower limits*

Since many rural communities are very quiet, it is possible that some will have LA\(_{90}\) values of 25 dBA or lower. This may seem extreme when compared to limits usually imposed on other sources of community noise. However, wind turbine sounds are not comparable to the more common noise sources of vehicles, aircraft, rail, and industry. Several studies have shown that annoyance to wind turbine sounds begins at levels as low as 30 dBA.\(^{22}\) This is especially true in quiet rural communities that have not had previous experience with industrial noise sources. This increased sensitivity may be due to the periodic ‘swoosh’ from the blades in the quiet rural soundscape, or it may be more complex. In either case, it is a legitimate response to wind turbine sound documented in peer-reviewed research.

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\(^{22}\) Eja Pedersen, “Human response to wind turbine noise: perception, annoyance and moderating factors.” Dissertation, Occupational and Environmental Medicine, Department of Public Health and Community Medicine, Gothenburg University, Goteborg, Sweden, 2007, and

Van den Berg F, Pedersen E, Bouma J, and Bakker R, Wind Farm Perception, Final Report Project no. 044628, University of Gothenburg and Medical Center Groningen, Netherlands June 3, 2008
Noise criteria need to take into account low frequency noise

In the table to the right are a series of observations and recommendations by the World Health Organization (WHO) supporting the need for stricter limits when there is substantial low frequency content in outdoor sound. Our review of other studies, and our own measurements, has demonstrated that wind turbine sound includes considerable low frequency content. We include a dBC limit in our guidelines to address the WHO recommendation that when low frequency sound may be present, criteria based on measurements using a C-weighting filter on the sound level meter (dBC) are needed in addition to dBA criteria.

IV. Proposed Sound Limits

The simple fact that so many residents complain of low frequency noise from wind turbines is clear evidence that the single A-weighted (dBA) noise descriptor used in most jurisdictions for siting turbines is not adequate. The only other simple audio frequency weighting that is standardized and available on sound level meters is C-weighting or dBC. A standard sound level meter set to measure dBA is increasingly less sensitive to low frequency below 500 Hz (one octave above middle-C). The same sound level meter set to measure dBC is equally sensitive to all frequencies above 32 Hz (lowest note on grand piano). It is generally accepted that dBC readings are more predictive of perceptual loudness than dBA readings if low frequency sounds are significant.

We are proposing to use the commonly accepted dBA criteria that is based on the pre-existing background sound levels allowing the wind turbine development to increase this by 5 dB (e.g. L_{A90A} +5) by the audible sounds from wind turbines. According to the New York State Energy Research & Development Authority:

- “… A change in sound level of 5 dB will typically result in a noticeable community response; and
- “… A 10 dB increase is subjectively heard as an approximate doubling in loudness, and almost always causes an adverse community response.”

To address the lower frequencies that are not considered in A-weighted measurements we are proposing to add limits based on dBC that follow the same scheme as used for dBA limits. The Proposed Sound Limits are presented in the text box at the end of this section.

For the current industrial grade wind turbines in the 1.5 to 3 MWatt (or over) range, the addition of the dBC requirement may result in an increased distance between wind turbines and the nearby

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residents. For the conditions shown in Figure 1, the distances would need to be increased significantly. This would result in setbacks in the range of 1 km or greater for the current generation of wind turbines if they are to be located in rural areas with little or no low frequency sound from man-made noise sources and where the $L_{A90}$ background sound levels are 30 dBA or lower. In areas with higher background sound levels, turbines could be located somewhat closer, but still at a distance greater than the 305 m (1000 ft.) or smaller setbacks commonly seen in U.S. based wind turbine standards set by many states and used for wind turbine developments.

Following are some additional Questions and Answers that summarize the major points of this discussion relevant to criteria.

**What are the typical wind farm noise immission criteria or standards?** Limits are not consistent and may vary even within a particular country. Examples are listed above in the section on Results of Literature and Sound Studies.

**What is a reasonable wind farm sound immission limit to protect the health of residences?** We are proposing a not-to-exceed immission limit of 35 $L_{Aeq}$ and a site-specific limit of $L_{A90} + 5$ dBA at the closest property line, whichever is exceeded first. We also propose the use of C-weighted criteria to address complaints of wind turbine low frequency noise. For the C-weighted criteria, we propose a site-specific limit of $L_{C90} + 5$ dBC. We also require that the site-specific $L_{Ceq}$ (dBC) sound level at a receiving property line not exceed the pre-existing $L_{A90}$ dB background sound level + 5dB by more than 20 dB. In other words, the dBC operating immission limit (as $L_{Ceq}$) at the receiving property line should not be more than 20 dB above the measured dBA (as $L_{A90}$) pre-construction long-term background sound level + 5dB. This criterion prevents an Immission Spectra Imbalance that often leads to complaints about rumble or other low frequency problems. We also include a not-to-exceed immission limit of 55 and 60 $L_{Ceq}$ at the receiving property line. Use of the multiple metrics and weightings will address the audible and inaudible low frequency portions of wind turbine sound emissions. Exceedances of any of the limits establish non-compliance.

**Why should the dBC immission limit not be permitted to be more than 20 dB above the background measured $L_{A90} + 5$ dB?** The World Health Organization and others have determined that if a noise has a measured difference between dBC and dBA more than 20 dB, the noise is highly likely to create an annoyance because of the low frequency component.

**Isn’t $L_{A90}$ the minimum background noise level?** Not exactly. This is the sound level that represents the quietest 10% of the time. It is often considered to be the sound level that represents the sounds one hears late in the evening or at night when there are no near-by or short term sounds present. It is very important to establish this “long term background” noise environment at the property line for a potentially impacted residence ($L_{A90}$) during the quietest sleeping hours of the night, between 10 p.m. and 4 a.m. Why? Because nighttime sleep disturbance has generated the majority of wind farm noise complaints throughout the world those conditions should guide the design of wind projects. ANSI standards define the “long term background sound” as excluding all short term sounds from the test sample using carefully selected sampling times and conditions using ten (10) minute long samples. This means that nature sounds not present during all seasons and wind noise are not to be included in the measurement. Following the procedures in ANSI S12.9, Part 3 for long term background sound the $L_{A90}$ and $L_{C90}$ can be measured with one or more 10-minute

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26 Ibid
measurements during any night when the atmosphere is classified as stable with a light wind from the area of the proposed wind farm. The basis for the immission limits for the proposed wind farm would then be the Nighttime Immission Limits, which we propose to be the minimum ten (10) minute nighttime $L_{A90}$ and $L_{C90}$ plus 5 dB, a test for Spectra Imbalance, and not-to-exceed limits for the period of 10 p.m. to 7 a.m. Daytime Limits (7 a.m. to 10 p.m.) could be set using daytime measurements, but unless the wind utility only operates during the day, the nighttime limit will always be the limiting sound level. Thus, daytime limits are not normally needed.

A nearby industrial scale wind utility meeting these noise immission criteria would occasionally be audible to the residents during nighttime and daytime. However, it would be unlikely for it to be an indoor problem.

The method used for establishing the background sound level at a proposed wind farm in many of the studies in Table 1, does not meet the requirements set by ANSI S12.9 Part 3 for outdoor measurements and determination of long-term background sound levels. Instead, they use unattended noise monitors to record hundreds of 10-minute or one-hour un-observed measurements that include the short term sounds from varying community and wind conditions over a period of days or weeks. The results for daytime and nighttime are usually combined to determine the average wind noise at the microphone as a function of wind velocity measured at a height of ten (10) meters. This provides an enormous amount of data, but the results have little relationship to wind turbine sound immissions or to potential for turbine noise impacts on nearby residents. They also do not comply with ANSI standards for methodology or quality and as such are not suitable for use in measurements that will be used to assess compliance with other standards and guidelines. This exhaustive exercise often only demonstrates how much ‘pseudo-noise’ is generated by instruments located in a windy environment that exceeds the capability of the instrument’s wind screen to protect the microphone. In many cases, this unqualified data is used to support a claim that the wind noise masks the turbines’ sound immissions.

The major complaints of residents living near wind farms is sleep disruption at night when there is little or no wind near ground level and the wind turbines located at a much higher elevation are turning and generating near or at maximum power and maximum noise emission. There is usually more surface wind and turbulence during daytime caused by solar radiation. Thus, the use of averaged data involving one or more 24-hour periods is of little value in predicting conditions that will result in people who cannot sleep in their homes during the night because of loud intrusive wind turbine noise.

The methodology used to predict the sound propagation from the turbines into the community also fails to represent the conditions of maximum turbine noise impact on nearby residents. This should be expected given the limitations of models based on ISO 9613-227. They also do not consider the effects of a frequent nighttime condition when winds at the ground are calm and the winds at the hub are at or above nominal operating speed. This condition is often referred to as a “stable” atmosphere. During this condition, the wind turbines can be producing the maximum or near maximum power while the wind at ground level is calm and the background noise level is low. The Michigan rural night test data in the earlier figure shows how quiet a night can be in the absence of wind at the ground. This common condition is known to directly cause chronic sleep

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27 The ISO 9613-2 sound propagation model formulas have known errors of 3 dB even when the conditions being modeled are a perfect match to the limiting conditions specified in the standard. Wind turbines operate far outside the limits for wind speed, height of the noise source above the ground, and other factors identified in the standard thus increasing the likelihood for error above the specified 3 dB. In addition, there are known measurement errors in the IEC61400-11 test that add another 2 dB of uncertainty to the model’s predictions.
disruption. Further, the studies report average sound levels and do not disclose the effects of amplitude modulation or low frequency sound which makes the turbine’s sound more objectionable and likely to cause sleep problems.

**Are there additional noise data to be recorded for a pre-wind turbine noise survey near selected dwellings?** Yes. The precision measuring sound level meter(s) need to be programmed to include measurement of $L_{A_{eq}}$, $L_{A_{10}}$, $L_{A_{90}}$, $L_{C_{eq}}$, $L_{C_{10}}$, and $L_{C_{90}}$, with starting time and date for each 10-minute sample. The $L_{10}$ results will be used to validate the $L_{90}$ data. For example, on a quiet night one might expect $L_{10}$ and $L_{90}$ to show similar results within 5 to 10 dB between $L_{10}$ and $L_{90}$ for each weighting scale. On a windy night or one with nearby short term noise sources the difference between $L_{10}$ and $L_{90}$ may be more than 20 dB. There is also often a need to obtain a time-averaged, one-third octave band analysis over the frequency range from 6.3 Hz to 10 kHz during the same ten minute sample. The frequency analysis is very helpful for identifying and correcting for extraneous sounds such as interfering insect noise. An integrating averaging sound level meter meeting ANSI or IEC Type 1 standards has the capability to perform all of the above acoustic measurements simultaneously and store the results internally. There is also a requirement for measurement of the wind velocity near the sound measurement microphone continuously throughout each 10-minute recorded noise sample. The 10-minute maximum wind speed near the microphone must be less than 2 m/s (4.5 mph) during measurements of background noise ($L_{90}$), and the maximum wind speed for noise measurements during turbine operation must be less than 4 m/s (9 mph). Measurements should be observed (without contaminating the data) and notes identifying short-term noises should be taken for these tests.

**Is there a need to record weather data during the background noise recording survey?** One weather monitor is required at the proposed wind farm on the side nearest the residents. The weather station sensors are at the standard 10 meter height above ground. It is critical that the weather be recorded every 10 minutes, synchronized with the clocks in the sound level recorders without ambiguity, at the start and end time of each 10 minute period. The weather station should record wind speed and direction, temperature, humidity and rain.

**Why do Canada and some other countries base the permitted wind turbine noise immission limits on the operational wind velocity at the 10m height wind speed instead of a maximum dBA or $L_{90} + 5$ dBA immission level?** First, it appears that the wind turbine industry will take advantage of every opportunity to elevate the maximum permitted noise immission level to reduce the setback distance from the nearby dwellings. Including wind as a masking source in the criteria is one method for elevating the permissible limits. The background noise level does indeed increase with surface wind speed. When this happens, it can be argued that the increased wind noise provides some masking of wind turbine noise. However, this is not true if the surface winds are calm. After sunset, when the ground cools (e.g. in the middle of the night), the lower level atmosphere can separate from the higher-level atmosphere. Then, the winds at the ground will be calm while wind at the turbine hub is very strong. Under this condition, the wind velocity at a 10-meter high wind monitoring station (such as those often used for weather reporting) may be $\frac{1}{4}$ to $\frac{1}{2}$ the speed of the wind at the hub, yet drop to calm at ground level. The result is that no ground level wind noise is present to mask the sound of the wind turbines, which can be operating at or close to full capacity.

This condition is one of the major causes of wind turbine related noise complaints for residents within 3 km (1.86 miles) of a wind farm. When the turbines are producing high sound levels, it is quiet outside the surrounding homes. The PhD thesis of G.P. van den Berg, *The Sounds of High*
Winds, is very enlightening on this issue (Table 3). See also the letter by John Harrison in Ontario “On Wind Turbine Guidelines.28”

What sound monitor measurements would be needed for enforcement of the wind turbine sound ordinance? A similar set of sound tests using the ten (10) minute series of measurements would be repeated, with and without the operation of the wind turbines, at the location where noise was measured before construction, which is closest to the resident registering the wind turbine noise complaint. If the nighttime background (L90) noise level (turbines off) was found to be slightly higher than the measured background prior to the wind farm installation, then the results with the turbines operating must be corrected using standard acoustical engineering methods to determine compliance with the pre-turbine established sound limits.

Who should conduct the sound measurements? An independent acoustics expert should be retained who reports to the County Board or other responsible governing body. This independent acoustics expert should be responsible for all the acoustic measurements including setup and calibration of instruments and interpretation of recorded results. He or she should perform all pre-turbine background noise measurements and interpretation of results to establish the nighttime (and daytime, if applicable) industrial wind turbine sound immission limits, and to monitor compliance.

At present, the acoustical consultants are retained by, and work directly for, the wind farm developers. This presents a serious problem with conflict of interest on the part of the consultants. The wind farm developer would like to show that a significant amount of wind noise is present to mask the sounds of the wind turbine immissions. The community is looking for authentic results showing that the wind turbine noise will be only barely perceptible, and then only occasionally, during the night or daytime.

Is frequency analysis required either during the pre-construction background noise survey or for compliance measurements? Normally one-third octave or narrower band analysis would only be required if there is a complaint of tones immission from the wind farm. Although only standardized dBA and dBC measurements are required to meet the proposed criteria, the addition of one-third octave band analysis is often useful to validate the dBA and dBC results.

The following summarizes the criteria necessary when siting wind turbines to minimize the risk of adverse impacts from noise on the adjacent community29. For those not familiar with acoustical annotation the table and its formulas may seem overly complex, but the criteria are defined in this manner to be as unambiguous as possible. They will be clear for those who are familiar with acoustical terminology. Definitions are provided in a later section of this essay.

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29 The authors have based these criteria, procedures, and language on their current understanding of wind turbine sound emissions, land-use compatibility, and the effects of sound on health. However, use of the following, in part or total, by any party is strictly voluntary and the user assumes all risks. Please seek professional assistance in applying the recommendations of this document to any specific community or WES development.
NOISE CRITERIA FOR SITING WIND TURBINES TO PREVENT HEALTH RISKS

1. Establishing Long-Term Background Noise Level
   a. Instrumentation: ANSI or IEC Type 1 Precision Integrating Sound Level Meter plus meteorological instruments to measure wind velocity, temperature and humidity near the sound measuring microphone. Measurement procedures must meet ANSI S12.9, Part 3 except as noted in Section 4. below.
   b. Measurement location(s): Nearest property line(s) from proposed wind turbines representative of all non-participating residential property within 2.0 miles.
   c. Time of measurements and prevailing weather: The atmosphere must be classified as stable with no vertical heat flow to cause air mixing. Stable conditions occur in the evening and middle of the night with a clear sky and very little wind near the surface. Sound measurements are only valid when the measured wind speed at the microphone is less than 2 m/s (4.5 mph).
   d. Long-Term Background sound measurements: All data recording shall be a series of contiguous ten (10) minute measurements. The measurement objective is to determine the quietest ten minute period at each location of interest. Nighttime test periods are preferred unless daytime conditions are quieter. The following data shall be recorded simultaneously for each ten (10) minute measurement period: dBA data includes L_{A90}, L_{A110}, L_{Aeq} and dBC data includes L_{C90}, L_{C10}, and L_{Ceq}. Record the maximum wind speed at the microphone during the ten minutes, a single measurement of temperature and humidity at the microphone for each new location or each hour whichever is oftener shall also be recorded. A ten (10) minute measurement contains valid data provided: Both L_{C10} minus L_{A90} and L_{C10} minus L_{C90} are not greater than 10 dB and the maximum wind speed at the microphone is less than 2 m/s during the same ten (10) minute period as the acoustic data.

2. Wind Turbine Sound Immission Limits
   No wind turbine or group of turbines shall be located so as to cause wind turbine sound immission at any location on non-participating property containing a residence in excess of the limits in the following table:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Condition</th>
<th>dBA</th>
<th>dBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Immission above pre-construction background:</td>
<td>L_{Aeq} = L_{A90} + 5</td>
<td>L_{Ceq} = L_{C90} +5</td>
</tr>
<tr>
<td>B</td>
<td>Maximum immission:</td>
<td>35 L_{Aeq}</td>
<td>55 L_{Ceq} for quiet rural environment</td>
</tr>
<tr>
<td>C</td>
<td>Immission spectra imbalance</td>
<td>L_{Ceq} (immission) minus (L_{A90} (background) +5) ≤ 20 dB</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Prominent tone penalty:</td>
<td>5 dB</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

   **Notes**
   1. Each Test is independent and exceedances of any test establishes non-compliance. Sound “immission” is the wind turbine noise emission as received at a property.
   2. A “Quiet rural environment” is a location >2 miles from a major transportation artery without high traffic volume during otherwise quiet periods of the day or night.
   3. Prominent tone as defined in IEC 61400-11. This Standard is not to be used for any other purpose.

   1 Procedures provided in Section 7. Measurement Procedures (ANSI 12.9 Part 3 with Amendments) of the most recent version of “The How To Guide To Siting Wind Turbines To Prevent Health Risks From Sound” by Kamperman and James and the apply to this table.

3. Wind Farm Noise Compliance Testing
   All of the measurements outlined above in 1. Establishing Nighttime Background Noise Level must be repeated to determine compliance with 2. Wind Turbine Sound Immission Limits. The compliance test location is to be the pre-turbine background noise measurement location nearest to the home of the complainant in line with the wind farm and nearer to the wind farm. The time of day for the testing and the wind farm operating conditions plus wind speed and direction must replicate the conditions that generated the complaint. Procedures of ANSI S12.9- Part 3 apply except as noted in Section 4. The effect of instrumentation limits for wind and other factors must be recognized and followed.
4. **ANSI S12.9 Part 3 Selected Options and Requirement Amendments**

For measurements taken to assess the preceding criteria specific options provided for in ANSI S12.9-Part 3 (2008) shall be followed along with any additional requirements included below:

5.2 Background Sound: Use definition (1): ‘long-term’

5.2 long-term background sound: The L90 excludes short term background sounds

5.3 basic measurement period: Ten (10) minutes L50(10 min)

5.6 Sound Measuring Instrument: Type 1 Precision meeting ANSI S1.43 or IEC 61672-1. The sound level meter shall cover the frequency range from 6.3 Hz to 20k Hz and simultaneously measure dBA L90 and dBC L90. The instrument must also be capable of accurately measuring low-level background sounds down to 20 dBA.

6.5 Windscreen: Required

6.6(a) An anemometer accurate to ± 10% at 2m/s to full-scale accuracy. The anemometer shall be located 1.5 to 2 meters above the ground and orientated to record maximum wind velocity. The maximum wind velocity, wind direction, temperature and humidity shall be recorded for each ten (10) minute sound measurement period observed within 5 m. of the measuring microphone.

7.1 Long-term background sound

7.2 Data collection Methods: Second method with observed samples to avoid contamination by short term sounds (purpose: to avoid loss of statistical data)

8. Source(s) Data Collection: All requirements in ANSI S12.18 Method #2, Precision to the extent possible while still permitting testing of the conditions that lead to complaints. The meteorological requirements in ANSI S12.18 may not be applicable for some complaint tests. For sound measurements in response to a complaint, the compliance sound measurements should be made under conditions that replicate the conditions that caused the complaint without exceeding instrument and windscreen limits and tolerances.

8.1(b) Measuring microphone with windscreen shall be located 1.2m to 1.8m (1.5 preferred) above the ground and greater than 8 m. from large sound reflecting surface.

8.3(a) All meteorological observations required at both (not either) microphone and nearest 10 m. weather reporting station.

8.3(b) For a ten (10) minute background sound measurement to be valid the wind velocity shall be less than 2m/s (4.5 mph) measured less than 5 m. from the microphone. Compliance sound measurements shall be taken when winds are less than 4m/s at the microphone.

8.3(c) In addition to the required acoustic calibration checks, the sound measuring instrument internal noise floor, including microphone, must also be checked at the end of each series of ten minute measurements and no less frequently than once per day. Insert the microphone into the acoustic calibrator with the calibrator signal off. Record the observed dBA and dBC reading on the sound level meter to determine an approximation of the instrument self noise. Perform this test before leaving the background measurement location. The calibrator-covered microphone must demonstrate the results of this test are at least 5 dB below the immediately previous ten (10) minute acoustic test results, for the acoustic background data to be valid. This test is necessary to detect undesired increase in the microphone and sound level meter internal self-noise. As a precaution sound measuring instrumentation should be removed from any air conditioned space at least an hour before use. Nighttime measurements are often performed very near the meteorological dew point. Minor moisture condensation inside a microphone or sound level meter can increase the instrument self noise and void the measured background data.

8.4 The remaining sections, starting at 8.4 in ANSI S12.9 Part 3 Standard do not apply.
V. How to Include the Recommended Criteria in Ordinances and/or Community Noise Limits

The following two sections present the definitions, technical requirements, and complaint resolution processes that support the recommended criteria. Following the formal elements is a section discussing the measurement procedures and requirements for enforcement of these criteria. For the purpose of the following sections the government authority will be referred to as the Local Government Authority (LGA) as a place marker for State, County, Township or other authorized authority. The abbreviation ‘WES’ is used for industrial scale wind energy system.

The authors have based these criteria, procedures, and language on their current understanding of wind turbine sound emissions, land-use compatibility, and the effects of sound on health. However, use of the following, in part or total, by any party is strictly voluntary and the user assumes all risks. Please seek professional assistance in applying the recommendations of this document to any specific community or WES development.

VI. ELEMENTS OF A WIND ENERGY SYSTEMS LICENSING ORDINANCE FOR SOUND

I. Purpose and Intent.

Based upon the findings stated above, it is the intended purpose of the LGA to regulate Wind Energy Systems to promote the health, safety, and general welfare of the citizens of the Town and to establish reasonable and uniform regulations for the operation thereof so as to control potentially dangerous effects of these Systems on the community.

II. Definitions.

The following terms have the meanings indicated:

“Aerodynamic Sound” means a noise that is caused by the flow of air over and past the blades of a WES.

“Ambient Sound” Ambient sound encompasses all sound present in a given environment, being usually a composite of sounds from many sources near and far. It includes intermittent noise events, such as, from aircraft flying over, dogs barking, wind gusts, mobile farm or construction machinery, and the occasional vehicle traveling along a nearby road. The ambient also includes insect and other nearby sounds from birds and animals or people. The near-by and transient events are part of the ambient sound environment but are not to be considered part of the long-term background sound.

“American National Standards Institute (ANSI)” Standardized acoustical instrumentation and sound measurement protocol shall meet all the requirements of the following ANSI Standards:

ANSI S1.43 Integrating Averaging Sound Level Meters: Type-1 (or IEC 61672-1)
ANSI S1.11 Specification for Octave and One-third Octave-Band Filters (or IEC 61260)
ANSI S1.40 Verification Procedures for Sound Calibrators
ANSI S12.9 Part 3 Procedures for Measurement of Environmental Sound
ANSI S12.18 Measurement of Outdoor Sound Pressure Level
IEC 61400-11 Wind turbine generator systems –Part 11: Acoustic noise measurements

“Anemometer” means a device for measuring the speed and direction of the wind.
"Applicant" means the individual or business entity that seeks to secure a license under this section of the Town municipal code.

"A-Weighted Sound Level (dBA)" A measure of over-all sound pressure level designed to reflect the response of the human ear, which does not respond equally to all frequencies. It is used to describe sound in a manner representative of the human ear’s response. It reduces the effects of the low with respect to the frequencies centered around 1000 Hz. The resultant sound level is said to be “A-weighted” and the units are “dBA.” Sound level meters have an A-weighting network for measuring A-weighted sound levels (dBA) meeting the characteristics and weighting specified in ANSI Specifications for Integrating Averaging Sound Level Meters, S1.43-1997 for Type 1 instruments and be capable of accurate readings (corrections for internal noise and microphone response permitted) at 20 dBA or lower. In this document dBA means $L_{Aeq}$ unless specified otherwise.

"Background Sound ($L_{90}$)” refers to the sound level present at least 90% of the time. Background sounds are those heard during lulls in the ambient sound environment. That is, when transient sounds from flora, fauna, and wind are not present. Background sound levels vary during different times of the day and night. Because WES operates 24/7 the background sound levels of interest are those during the quieter periods which are often the evening and night. Sounds from the WES of interest, near-by birds and animals or people must be excluded from the background sound test data. Nearby electrical noise from streetlights, transformers and cycling AC units and pumps etc must also be excluded from the background sound test data.

Background sound level (dBA and dBC (as $L_{90}$)) is the sound level present 90% of the time during a period of observation that is representative of the quiet time for the soundscape under evaluation and with duration of ten (10) continuous minutes. Several contiguous ten (10) minute tests may be performed in one hour to determine the statistical stability of the sound environment. Measurement periods such as at dusk when bird and insect activity is high or the early morning hours when the ‘dawn chorus’ is present are not acceptable measurement times. Longer term sound level averaging tests, such as 24 hours or multiple days are not at all appropriate since the purpose is to define the quiet time background sound level. It is defined by the $L_{A90}$ and $L_{C90}$ descriptors. It may be considered as the quietest one (1) minute during a ten (10) minute test. $L_{A90}$ results are valid only when $L_{A10}$ results are no more than 10 dB above $L_{A90}$ for the same period. $L_{C10}$ less $L_{C90}$ are not to exceed 10 dB to be valid.

The background noise environment consists of a multitude of distant sources of sound. When a new nearby source is introduced the new background noise level would be increased. The addition of a new source with a noise level 10 below the existing background would increase the new background 0.4 dB. If the new source has the same noise level as the existing background then the new background is increased 3.0 dB. Lastly, if the new source is 3.3 dB above the existing background then the new background would have increased 5 dB. For example, to meet the requirement of $L_{90A} + 5\text{ dB} = 31\text{ dBA}$ if the existing quiet nighttime background sound level is 26 dBA, the maximum wind turbine noise immission contribution independent of the background cannot exceed 29.3 dBA $L_{eq}$ at a dwelling. When adding decibels, a 26 dBA background combined with 29.3 dBA from the turbines (without background) results in 31 dBA.

Further, background $L_{90}$ sound levels documenting the pre-construction baseline conditions should be determined when the ten (10) minute maximum wind speed is less than 2 m/s (4.5 mph) near ground level/microphone location 1.5 m height.

"Blade Passage Frequency" (BPF) means the frequency at which the blades of a turbine pass a particular point during each revolution (e.g. lowest point or highest point in rotation) in terms of
events per second. A three bladed turbine rotating at 28 rpm would have a BPF of 1.4 Hz. [E.g. ((3 blades times 28rpm)/60 seconds per minute = 1.4 Hz BPF)]

“C-Weighted Sound Level (dBC)” Similar in concept to the A-Weighted sound Level (dBA) but C-weighting does not de-emphasize the frequencies below 1k Hz as A-weighting does. It is used for measurements that must include the contribution of low frequencies in a single number representing the entire frequency spectrum. Sound level meters have a C-weighting network for measuring C-weighted sound levels (dBC) meeting the characteristics and weighting specified in ANSI S1.43-1997 Specifications for Integrating Averaging Sound Level Meters for Type 1 instruments. In this document dBC means $L_{eq}$ unless specified otherwise.

“Decibel (dB)” A dimensionless unit which denotes the ratio between two quantities that are proportional to power, energy or intensity. One of these quantities is a designated reference by which all other quantities of identical units are divided. The sound pressure level ($L_{p}$) in decibels is equal to 10 times the logarithm (to the base 10) of the ratio between the pressure squared divided by the reference pressure squared. The reference pressure used in acoustics is 20 MicroPascals.

“Emission” Sound energy that is emitted by a noise source (wind farm) is transmitted to a receiver (dwelling) where it is immitted (see “immission”).

“Frequency” The number of oscillations or cycles per unit of time. Acoustical frequency is usually expressed in units of Hertz (Hz) where one Hz is equal to one cycle per second.

“Height” means the total distance measured from the grade of the property as existed prior to the construction of the wind energy system, facility, tower, turbine, or related facility at the base to its highest point.

“Hertz (Hz)” Frequency of sound expressed by cycles per second.

“Immission” Noise immitted at a receiver (dwelling) is transmitted from noise source (wind turbine) that emitted sound energy (see “emission”).

“Immission spectra imbalance” The spectra are not in balance when the C-weighted sound level is more than 20 dB greater than the A-weighted sound level. For the purposes of this requirement, the A-weighted sound level is defined as the long-term background sound level ($L_{A,90}$) +5 dBA. The C-weighted sound level is defined as the $L_{eq}$ measured during the operation of the wind turbine operated so as to result in its highest sound output. A Complaint test provided later in this document is based on the immission spectra imbalance criteria.

“Infra-Sound” sound with energy in the frequency range of 0-20 Hz is considered to be infra-sound. It is normally considered to not be audible for most people unless in relatively high amplitude. However, there is a wide range between the most sensitive and least sensitive people to perception of sound and perception is not limited to stimulus of the auditory senses. The most significant exterior noise induced dwelling vibration occurs in the frequency range between 5 Hz and 50 Hz. Moreover, levels below the threshold of audibility can still cause measurable resonances inside dwelling interiors. Conditions that support or magnify resonance may also exist in human body cavities and organs under certain conditions. Although no specific test for infrasound is provided in this document, the test for immission spectra imbalance will limit low frequency sound and thus, indirectly limit infrasound. See low-frequency noise (LFN) for more information.

“Low Frequency Noise (LFN)” refers to sounds with energy in the lower frequency range of 20 to 200 Hz. LFN is deemed to be excessive when the difference between a C-weighted sound level and an A-weighted sound level is greater than 20 decibels at any measurement point outside a residence or
other occupied structure. The criteria for this condition is the “Immission Spectra Imbalance” entry in the Table of Not-To-Exceed Property Line Sound Immission Limits.”

“Measurement Point (MP)” means location where sound measurements are taken such that no significant obstruction blocks sound from the site. The Measurement Point should be located so as to not be near large objects such as buildings and in the line-of-sight to the nearest turbines. Proximity to large buildings or other structures should be twice the largest dimension of the structure, if possible. Measurement Points should be at quiet locations remote from street lights, transformers, street traffic, flowing water and other local noise sources.

“Measurement Wind Speed” For measurements conducted to establish the background noise levels (LA90 10 min, LC90 10 min, and etc.) the maximum wind speed, sampled within 5m of the microphone and at its height, shall be less than 2 m/s (4.5 mph) for valid background measurements. For valid wind farm noises measurements conducted to establish the post-construction sound level the maximum wind speed, sampled within 5m of the microphone and at its height, shall be less than 4m/s (9 mph). The wind speed at the WES blade height shall be at or above the nominal rated wind speed and operating in its highest sound output mode. For purposes of enforcement, the wind speed and direction at the WES blade height shall be selected to reproduce the conditions leading to the enforcement action while also restricting maximum wind speeds at the microphone to less than 4 m/s (9 mph).

For purposes of models used to predict the sound levels and sound pressure levels of the WES to be submitted with the Application, the wind speed shall be the speed that will result in the worst-case LAeq and LCeq sound levels at the nearest non-participating properties to the WES. If there may be more than one set of nearby sensitive receptors, models for each such condition shall be evaluated and the results shall be included in the Application.

“Mechanical Noise” means sound produced as a byproduct of the operation of the mechanical components of a WES(s) such as the gearbox, generator and transformers.

“Noise” means any unwanted sound. Not all noise needs to be excessively loud to represent an annoyance or interference.

“Project Boundary” means the external property boundaries of parcels owned by or leased by the WES developers. It is represented on a plot plan view by a continuous line encompassing all WES(s) and related equipment associated with the WES project.

“Property Line” means the recognized and mapped property parcel boundary line.

“Qualified Independent Acoustical Consultant” Qualifications for persons conducting baseline and other measurements and reviews related to the application for a WES or for enforcement actions against an operating WES include, at a minimum, demonstration of competence in the specialty of community noise testing. An example is a person with Full Membership in the Institute of Noise Control Engineers (INCE). There are scientists and engineers in other professional fields that have been called upon by their local community for help in the development of a WES Noise Ordinance. Many of these scientists and engineers have recently spent hundreds of hours learning many important aspects of noise related to the introduction of WES into their communities. Then with field measurement experience with background data and wind turbine noise emission, they have become qualified independent acoustical consultants for WES siting. Certifications such as Professional Engineer (P.E.) do not test for competence in acoustical principles and measurement and are thus not, without further qualification, appropriate for work under this document. The Independent Qualified Acoustical Consultant can have no financial or other connection to a WES developer or related company.
“Sensitive Receptor” means places or structures intended for human habitation, whether inhabited or not, public parks, state and federal wildlife areas, the manicured areas of recreational establishments designed for public use, including but not limited to golf courses, camp grounds and other nonagricultural state or federal licensed businesses. These areas are more likely to be sensitive to the exposure of the noise, shadow or flicker, etc. generated by a WES or WESF. These areas include, but are not limited to: schools, daycare centers, elder care facilities, hospitals, places of seated assemblage, non-agricultural businesses and residences.

“Sound” A fluctuation of air pressure which is propagated as a wave through air

“Sound Power” The total sound energy radiated by a source per unit time. The unit of measurement is the watt. Abbreviated as Lw. This information is determined for the WES manufacturer under laboratory conditions specified by IEC 61400-11 and provided to the local developer for use in computer model construction. There is known measurement error in this test procedure that must be disclosed and accounted for in the computer models. Even with the measurement error correction it cannot be assumed that the reported Lw values represent the highest sound output for all operating conditions. They reflect the operating conditions required to meet the IEC 61400-11 requirements. The lowest frequency is 50 Hz for acoustic power (Lw) requirement (at present) in IEC 61400-11. This Ordinance requires wind turbine certified acoustic power (Lw) levels at rated load for the total frequency range from 6.3 Hz to 10k Hz in one-third octave frequency bands tabulated to the nearest 1 dB. The frequency range of 6.3 Hz to 10k Hz shall be used throughout this Ordinance for all sound level modeling, measuring and reporting.

“Sound Pressure” The instantaneous difference between the actual pressure produced by a sound wave and the average or barometric pressure at a given point in space.

“Sound Pressure Level (SPL)” 20 times the logarithm, to the base 10, of the ratio of the pressure of the sound measured to the reference pressure, which is 20 microneutons per square meter. In equation form, sound pressure level in units of decibels is expressed as SPL (dB) = 20 log p/pr.

“Spectrum” The description of a sound wave's resolution into its components of frequency and amplitude. The WES manufacturer is required to supply a one-third octave band frequency spectrum of the wind turbine sound emission at 90% of rated power. The published sound spectrum is often presented as A-weighted values but C-weighted values are preferred. This information is used to construct a model of the wind farm’s sound immission levels at locations of interest in and around the WES. The frequency range of interest for wind turbine noise is approximately 6 Hz to 10k Hz.

“Statistical Noise Levels” Sounds that vary in level over time, such as road traffic noise and most community noise, are commonly described in terms of the statistical exceedance levels LNA, where LNA is the A-weighted sound level exceeded for N% of a given measurement period. For example, L10 is the noise level exceeded for 10% of the time. Of particular relevance, are: LA10 and LC10 the noise level exceed for 10% of the ten (10) minute interval. This is commonly referred to as the average maximum noise level. LLA0 and LCG0 are the A-weighted and C-weighted sound levels exceeded for 90% of the ten (10) minute sample period. The L00 noise level is defined by ANSI as the long-term background sound level (i.e. the sounds one hears in the absence of the noise source under consideration and without short term or near-by sounds from other sources), or simply the “background level.” Leq is the A or C-weighted equivalent noise level (the “average” noise level). It is defined as the steady sound level that contains the same amount of acoustical energy as the corresponding time-varying sound.
“Tonal sound or tonality” Tonal audibility. A sound for which the sound pressure is a simple sinusoidal function of the time, and characterized by its singleness of pitch. Tonal sound can be simple or complex.

"Wind Energy Systems (WES)" means equipment that converts and then transfers energy from the wind into usable forms of electrical energy.

"Wind Turbine" or "Turbine" (WT) means an industrial scale mechanical device which captures the kinetic energy of the wind and converts it into electricity. The primary components of a wind turbine are the blade assembly, electrical generator and tower.

III. APPLICATION PROCEDURE FOR WIND ENERGY SYSTEMS AND TECHNICAL REQUIREMENTS FOR LICENSING

This ordinance is intended to promote the safety and health of the community through criteria limiting sound emissions during operation of Wind Energy Systems. It is recognized that the requirements herein are neither exclusive, nor exhaustive. In instances where a health or safety concern is known to the wind project developer or identified by other means with regard to any application for a Wind Energy System, additional and/or more restrictive conditions may be included in the license to address such concerns. All rights are reserved to impose additional restrictions as circumstances warrant. Such additional or more restrictive conditions may include, without limitation (a) greater setbacks, (b) more restrictive noise limitations, or (c) limits restricting operation during night time periods or for any other conditions deemed reasonable to protect the community.

A. Application

Any Person desiring to secure a Wind Energy Systems license shall file an application form provided by the LGA Clerk, together with two additional copies of the application with the LGA Clerk.

B. Information to be submitted with Application

1. Information regarding the:

- Make and model of all turbines potentially used in this project,
- Sound Power Levels (Lw) for each 1/3 octave band from 6.3 Hz to 10,000 Hz, and
- A sound propagation model predicting the sound levels emitted into the community computed using at minimum 1/1 octave band sound power levels to compute the L_{Ceq} and L_{Aeq} levels to generate L_{Aeq} and L_{Ceq} contours in 5 dB increments overlaying an aerial view and property survey map from the WES property out to a distance to include all residential property within two (2) miles of the WES Property. Appropriate corrections for model algorithm error, IEC61400-11 test measurement accuracy, and directivity patterns of for each model of WT shall be disclosed and accounted for in the model(s). Predictions shall be made at all property lines within and outward for two (2) miles from the project boundary for the wind speed, direction and operating mode that would result in the worst case WT nighttime sound emissions.

The prediction model shall assume that the winds at hub height are sufficient for the highest sound emission operating mode. The projection shall include a description of all assumptions made in the model’s construction and algorithms. If the model does not consider the effects of wind direction, geography of the terrain, and/or the effects of reinforcement from coherent sounds or tones from
the turbines all these items should be identified and all other means used to adjust the model’s output to account for these factors. The results shall be displayed as a contour map of the predicted levels as over-all \( L_{Aeq} \) and \( L_{Ceq} \) contours out to 2 miles from the WES property, and shall also include a table showing the 1/3 or 1/1 octave band sound pressure as \( L_{Ceq} \) levels for the nearest property line(s) for sensitive receptor sites (including residences) within the model’s boundaries. The predicted values must include the over-all sound levels and 1/1 or 1/3 octave band sound pressure levels from 6 Hz to 10 kHz in data tables that include the location of each receiving point by GPS location or other repeatable means.

C. Preconstruction Background Noise Survey

1. The Town reserves the right to require the preparation of (a) a preconstruction noise survey for each proposed Wind Turbine location conducted per procedures provided in the section on Measurement Procedures showing long-term background \( L_{A90} \) and \( L_{C90} \) sound levels. This must be completed and accepted prior to approval of the final layout and issuance of project permits.

   a. If any proposed wind farm project locates a WES within two miles of a sensitive receptor these studies are mandatory. The preconstruction baseline studies shall be conducted by an Independent Qualified Acoustical Consultant selected and hired by the LGA.

   b. The applicant shall be responsible for paying the consultant’s fees and costs associated with conducting the study. These fees and cost shall be negotiated with the consultant and determined prior to any work being done on the study. The applicant shall be required to set aside 100% of these fees in an escrow account managed by the LGA, before the study is commenced by the consultant. Payment for this study does not require the WES developer’s acceptance of the study’s results.

   c. If the review shows that the predicted \( L_{Aeq} \) and \( L_{Ceq} \) sound levels exceed any of the criteria specified in the Table of Not-To-Exceed Property Line Sound Immission Limits then the application cannot be approved.

2. The LGA will refer the application to the LGA engineer (if qualified in acoustics) or an independent qualified acoustical consultant for further review and comparison of the long-term background sound levels against the predicted \( L_{Aeq} \) and \( L_{Ceq} \) sound levels reported for the model using the criteria in the Table of Not-To-Exceed Property Line Sound Immission Limits. The reasonably necessary costs associated with such a review shall be the responsibility of the applicant, in accord with the terms of this ordinance.

D. Post Construction Noise Measurement Requirements

1. Sound Regulations Compliance: A WES shall be considered in violation of the conditional use permit unless the applicant demonstrates that the project complies with all sound level limits using the procedures specified in this ordinance. Sound levels in excess of the limits established in this ordinance shall be grounds for the LGA to order immediate shut down of all non-compliant WT units.

2. Post-Construction Sound Measurements: Within twelve months of the date when the project is fully operational, and within four weeks of the anniversary date of the pre-construction background noise measurements, repeat the existing sound environment measurements taken before the project approval. Post-construction sound level measurements shall be taken both with all WES’s running and with all WES’s off. At the discretion of the Town, the Pre-construction background sound levels (\( L_{A90} \) and \( L_{C90} \)) can be substituted for the “all WES off” tests if a random sampling of 10% of the pre-construction study sites shows that background \( L_{90A} \) and \( L_{90C} \) conditions have increased less than 3 dB from those measured under the pre-
construction nighttime conditions. The post-construction measurements will be reported to the
LGA (available for public review) using the same format as used for the preconstruction sound
studies. Post-construction noise studies shall be conducted by a firm chosen and hired by the
LGA. Costs of these studies are to be reimbursed by the Licensee in a similar manner to that
described above. The wind farm developer’s may ask to have its own consultant observe the
publicly retained consultant at the convenience of the latter. The WES Licensee shall provide all
technical information and wind farm data required by the qualified independent acoustical
consultant before, during, and/or after any acoustical studies required by this document and for
acoustical measurements.

3. Sound Limits

1. Establishing Long-Term Background Sound Level

a. Instrumentation: ANSI or IEC Type 1 Precision Integrating Sound Level Meter plus
meteorological instruments to measure wind velocity, temperature and humidity near the
sound measuring microphone. Measurement procedures must meet ANSI S12.9, Part 3 and
Measurement Procedures Appendix to Ordinance following next Section.

b. Measurement location(s): Nearest property line(s) from proposed wind turbines
representative of all non-participating residential property within 2.0 miles.

c. Time of measurements and prevailing weather: The atmosphere must be classified as
stable with no vertical heat flow to cause air mixing. Stable conditions occur in the
evening and middle of the night with a clear sky and very little wind near the surface. Sound
measurements are only valid when the measured maximum wind speed at the
microphone must be less than 2 m/s (4.5 mph).

d. Long-Term Background sound measurements: All data recording shall be a series of
contiguous ten (10) minute measurements. The measurement objective is to determine
the quietest ten minute period at each location of interest. Nighttime test periods are
preferred unless daytime conditions are quieter. The following data shall be recorded
simultaneously for each ten (10) minute measurement period: dBA data includes LA90, LA10, LAeq and dBC data includes LC90, LC10, and LCeq. The maximum wind speed at the
microphone during the ten minutes, a single measurement of temperature and humidity
at the microphone for each new location or each hour whichever is oftener shall also be
recorded. A ten (10) minute measurement contains valid data provided: Both LA10 minus
LA90 and LC10 minus LC90 are not greater than 10 dB and the maximum wind speed at the
microphone is less than 2 m/s during the same ten (10) minute period as the acoustic
data.

2. Wind Turbine Sound Immission Limits

No wind turbine or group of turbines shall be located so as to cause wind turbine sound
immission at any location on non-participating property containing a residence in
excess of the limits in the following table:
### Table of Not-To-Exceed Property Line Sound Immission Limits

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Condition</th>
<th>dBA</th>
<th>dBc</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Immission above pre-construction background:</td>
<td>$L_{A_{eq}} = L_{A_{90}} + 5$</td>
<td>$L_{C_{eq}} = L_{C_{90}} + 5$</td>
</tr>
<tr>
<td>B</td>
<td>Maximum immission:</td>
<td>35 $L_{A_{eq}}$</td>
<td>55 $L_{C_{eq}}$ for quiet(^2) rural environment</td>
</tr>
<tr>
<td>C</td>
<td>Immission spectra imbalance (C - A ≤ 20dB)</td>
<td>$L_{C_{eq}}$ (immission) minus ($L_{A_{90}}$ (background) +5 dB) ≤ 20 dB</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Prominent tone penalty:</td>
<td>5 dB</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

**Notes**

1. Each Test is independent and exceedances of any test establishes non-compliance. Sound “immission” is the wind turbine sound emission as received at a property.

2. A “quiet rural environment” is a location 2 miles from a major transportation artery without high traffic volume during otherwise quiet periods of the day or night.

3. Prominent tone as defined in IEC 61400-11. This Standard is not to be used for any other purpose.

\(1\) Required Procedures provided in VIII Reference Standards including ANSI 12.9 Part 3 as Amended

### 3. Wind Farm Noise Compliance Testing

All of the measurements outlined above in 1. Establishing Long Term Background Noise Level must be repeated to determine compliance with 2. Wind Turbine Sound Immission Limits. The compliance test location is to be the pre-turbine background noise measurement location nearest to the home of the complainant in line with the wind farm and nearer to the wind farm. The time of day for the testing and the wind farm operating conditions plus wind speed and direction must replicate the conditions that generated the complaint. Procedures of ANSI S12.9- Part 3 apply as amended in the Appendix to Ordinance. The effect of instrumentation limits for wind and other factors must be recognized and followed.

### 3. Operations

The WES/WT is non-compliant and must be shut down immediately if it exceeds any of the limits in the **Table of Not-To-Exceed Property Line Sound Immission Limits**.

### 4. Complaint Resolution

1. The owner/operator of the WES shall respond within five (5) business days after notified of a noise complaint by any property owner within the project boundary and a one-mile radius beyond the project boundary.

2. The tests shall be performed by a qualified independent acoustical consultant acceptable to the complainant and the local agency charged with enforcement of this ordinance.

3. Testing shall commence within ten (10) working days of the request. If testing cannot be initiated within ten (10) days, the WES(s) in question shall be shut down until the testing can be started.

4. A copy of the test results shall be sent to the property owner, and the LGA’s Planning or Zoning department within thirty (30) days of test completion.

5. If a Complaint is made, the presumption shall be that it is reasonable. The LGA shall undertake an investigation of the alleged operational violation by a qualified individual mutually acceptable to the LGA.
5. Reimbursement of Fees and Costs.

Licensee/operator/owner agrees to reimburse the LGA’s reasonable fees and costs incurred in the preparation, negotiation, administration and enforcement of this Ordinance, including, without limitation, the LGA’s attorneys’ fees, engineering and/or consultant fees, LGA meeting and hearing fees and the costs of public notices. If requested by the LGA the funds shall be placed in an escrow account under the management of the LGA. The preceding fees are payable within thirty (30) days of invoice. Unpaid invoices shall bear interest at the rate of 1% per month until paid. The LGA may recover all reasonable costs of collection, including attorneys’ fees.

VII. MEASUREMENT PROCEDURES

SUPPLEMENT TO WIND ENERGY SYSTEMS LICENSING ORDINANCE FOR SOUND

I. Introduction

The potential impact of sound and sound-induced building vibration associated with the operation of wind powered electric generators is often a primary concern for citizens living near proposed wind energy systems (WES(s)). This is especially true of projects located near homes, residential neighborhoods, businesses, schools, and hospitals in quiet residential and rural communities. Determining the likely sound and vibration impacts is a highly technical undertaking and requires a serious effort in order to collect reliable and meaningful data for both the public and decision makers.

This protocol is based in part on criteria published in American National Standards S12.9—Part 3 Quantities and Procedures for Description and Measurement of Environmental Sound, and S12.18 and for the measurement of sound pressure level outdoors.

The purpose is to first, establish a consistent and scientifically sound procedure for evaluating existing background levels of audible and low frequency sound in a WES project area, and second to use the information provided by the Applicant in its Application showing the predicted overall sound levels in terms of $L_{Aeq}$ and $L_{Ceq}$ and 1/3 or 1/1 octave bands as part of the required information submitted with the application.

The overall values shall be presented as overlays to the applicant’s iso-level plot plan graphics and, for 1/1 or 1/3 octave data, in tabular form with location information sufficient to permit comparison of the baseline results to the predicted levels. This comparison will use the level limits of the ordinance to determine the likely impact operation of a new wind energy system project will have on the existing community soundscape. If the comparison demonstrates that the WES project will not exceed any of the level limits the project will be considered to be within allowable limits for safety and health. If the Applicant submits only partial information required for this comparison
the application cannot be approved. In all cases the burden to establish the operation as meeting safety and health limits will be on the Applicant.

Next, it covers requirements for the sound propagation model to be supplied with the application.

Finally, if the project is approved, this section covers the study needed to compare the post-build sound levels to the predictions and the baseline study. The level limits in the ordinance apply to the post-build study. In addition, if there have been any complaints about WES sound or low frequency noise emissions or wind turbine noise induced dwelling vibration by any resident of an occupied dwelling that property will be included in the post-build study for evaluation against the rules for sound level limits and compliance.

The characteristics of the proposed WES project and the features of the surrounding environment will influence the design of the sound and vibration study. Site layout, types of WES(s) selected and the existence of other significant local audible and low frequency sound sources and sensitive receptors should be taken into consideration when designing a sound study. The work will be performed by a qualified independent acoustical consultant for both the pre-construction background and post-construction sound studies as described in the body of the ordinance.

II. Instrumentation

All instruments and other tools used to measure audible, inaudible and low frequency sound shall meet the requirements for ANSI or IEC Type 1 Integrating Averaging Sound Level Meter Standards. The principle standard reference for this document is ANSI 12.9/Part 3 with important additional specific requirements for the measuring instrumentation and measurement protocol.

III. Measurement of Pre-Construction Sound Environment (Base-line)

An assessment of the proposed WES project areas existing sound environment is necessary in order to predict the likely impact resulting from a proposed project. The following guidelines must be used in developing a reasonable estimate of an area's existing background sound environment. All testing is to be performed by an independent qualified acoustical consultant approved by the LGA as provided in the body of the ordinance. The WES applicant may file objections detailing any concerns it may have with the LGA's selection. These concerns will be addressed in the study. Objections must be filed prior to the start of the noise study. All measurements are to be conducted with ANSI or IEC Type 1 certified and calibrated test equipment per reference specification at the end of this section. Test results will be reported to the LGA or its appointed representative.

Sites with No Existing Wind Energy Systems (Base-line Sound Study)

Sound level measurements shall be taken as follows:

The results of the model showing the predicted worst case $L_{Aeq}$ and $L_{Ceq}$ sound emissions of the proposed WES project will be overlaid on a map (or separate $L_{Aeq}$ and $L_{Ceq}$ maps) of the project area. An example (right) shows an approximately two (2) mile square section with iso-level contour lines prepared by the
applicant, sensitive receptors (homes) and locations selected for the baseline sound tests whichever are the controlling metric. The test points shall be located at the property line bounding the property of the turbine’s host closest to the wind turbine. Additional sites may be added if appropriate. A grid comprised of one (1) mile boundaries (each grid cell is one (1) square mile) should be used to assist in identifying between two (2) to ten (10) measurement points per cell. The grid shall extend to a minimum of two (2) miles beyond the perimeter of the project boundary. This may be extended to more than two (2) miles at the discretion of the LGA. The measurement points shall be selected to represent the noise sensitive receptor sites based on the anticipated sound propagation from the combined WT in the project. Usually, this will be the closest WT. If there is more than one WT near-by then more than one test site may be required.

The intent is to anticipate the locations along the bounding property line that will receive the highest sound immissions. The site that will most likely be negatively affected by the WES project’s sound emissions should be given first priority in testing. These sites may include sites adjacent to occupied dwellings or other noise sensitive receptor sites. Sites shall be selected to represent the locations where the background soundscapes reflect the quietest locations of the sensitive receptor sites. Background sound levels (and 1/3 octave band sound pressure levels if required) shall be obtained according to the definitions and procedures provided in the ordinance and recognized acoustical testing practice and standards.

All properties within the proposed WES project boundaries will be considered for this study.

One test shall be conducted during the period defined by the months of April through November with the preferred time being the months of June through August. These months are normally associated with more contact with the outdoors and when homes may have open windows during the evening and night. Unless directed otherwise by the LGA the season chosen for testing will represent the background soundscapes for other seasons. At the discretion of the LGA, tests may be scheduled for other seasons.

All measurement points (MPs) shall be located with assistance from the LGA staff and property owner(s) and positioned such that no significant obstruction (building, trees, etc.) blocks sound and vibration from the nearest proposed WES site.

Duration of measurements shall be a minimum of ten (10) continuous minutes for all criteria at each location. The duration must include at least six (6) minutes that are not affected by transient sounds from near-by and non-nature sources. Multiple ten (10) minute samples over longer periods such as 30 minutes or one (1) hour may be used to improve the reliability of the LA90 and LC90 values. The ten (10) minute sample with the lowest valid L90 values will be used to define the background sound.

The tests at each site selected for this study shall be taken during the expected ‘quietest period of the day or night’ as appropriate for the site. For the purpose of determining background sound characteristics the preferred testing time is from 10pm until 4 am. If circumstances indicated that a different time of the day should be sampled the test may be conducted at the alternate time if approved by the Town.

Sound level measurements shall be made on a weekday of a non-holiday week. Weekend measurements may also be taken at selected sites where there are weekend activities that may be affected by WT sound.

Measurements must be taken with the microphone at 1.2 to 1.5 meters above the ground and at least 15 feet from any reflective surface following ANSI 12.9 Part 3 protocol including selected options and other requirements outlined later in this Section.
Reporting

1. For each Measurement Point and for each qualified measurement period, provide each of the following measurements:
   a. LAeq, LA10, and LA90 and
   b. LCeq, LC10, and LC90

2. A narrative description of any intermittent sounds registered during each measurement. This may be augmented with video and audio recordings.

3. A narrative description of the steady sounds that form the background soundscape. This may be augmented with video and audio recordings.

4. Wind speed and direction at the microphone (Measurement Point), humidity and temperature at time of measurement will be included in the documentation. Corresponding information from the nearest 10 meter weather reporting station shall also be obtained.

Measurements taken only when wind speeds are less than 2m/s (4.5 mph) at the microphone location will be considered valid for this study. A windscreen of the type recommended by the monitoring instrument’s manufacturer must be used for all data collection.

5. Provide a map and/or diagram clearly showing (Using plot plan provided by LGA or Applicant):
   - The layout of the project area, including topography, the project boundary lines, and property lines.
   - The locations of the Measurement Points.
   - The distance between any Measurement Points and the nearest WT(s).
   - The location of significant local non-WES sound and vibration sources.
   - The distance between all MPs and significant local sound sources. And,
   - The location of all sensitive receptors including but not limited to: schools, day-care centers, hospitals, residences, residential neighborhoods, places of worship, and elderly care facilities.

Sites with Existing Wind Energy Systems

Two complete sets of sound level measurements must be taken as defined below:

1. One set of measurements with the wind generator(s) off unless the LGA elects to substitute the sound data collected for the background sound study. Wind speeds must be suitable for background sound tests as specified elsewhere in this ordinance.

2. One set of measurements with the wind generator(s) running with wind speed at hub height sufficient to meet nominal rated power output or higher and less than 2 m/s below at the microphone location. Conditions should reflect the worst case sound emissions from the WES project. This will normally involve tests taken during the evening or night when winds are calm (less than 2m/sec) at the ground surface yet, at hub height, sufficient to power the turbines.

Sound level measurements and meteorological conditions at the microphone shall be taken and documented as discussed above.

Sound level Estimate for Proposed Wind Energy Systems (when adding more WT to existing project)

In order to estimate the sound impact of the proposed WES project on the existing environment an estimate of the sound produced by the proposed WES(s) under worst-case conditions for
producing sound emissions must be provided. This study may be conducted by a firm chosen by the WES operator with oversight provided by the LGA.

The qualifications of the firm should be presented along with details of the procedure that will be used, software applications, and any limitations to the software or prediction methods as required elsewhere in this ordinance for models.

Provide the manufacturer's sound power level ($L_{Aw}$) and ($L_{Cw}$) characteristics for the proposed WES(s) operating at full load utilizing the methodology in IEC 61400-11 Wind Turbine Noise Standard. Provide one-third octave band sound power level information from 6.3 Hz to 10k Hz. Furnish the data using no frequency weighting. A-weighted data is optional. Provide sound pressure levels predicted for the WES(s) in combination and at full operation and at maximum sound power output for all areas where the predictions indicate $L_{Aeq}$ levels of 30 dBA and above. The same area shall be used for reporting the predicted $L_{Ceq}$ levels. Contour lines shall be in increments of 5 dB.

Present tables with the predicted sound levels for the proposed WES(s) as $L_{Aeq}$ and $L_{Ceq}$ and at all octave band centers (8 Hz to 10k Hz) for distances of 500, 1000, 1500, 2000, 2500 and 5000 feet from the center of the area with the highest density of WES(s). For projects with multiple WES(s), the combined sound level impact for all WES(s) operating at full load must be estimated.

The above tables must include the impact (increased dBA and dBC ($L_{eq}$) above baseline $L_{B}$ background sound levels) of the WES operations on all residential and other noise sensitive receiving locations within the project boundary. To the extent possible, the tables should include the sites tested (or likely to be tested) in the background study.

Provide a contour map of the expected sound level from the new WES(s), using 5dB $L_{Aeq}$ and $L_{Ceq}$ increments created by the proposed WES(s) extending out to a distance of two (2) miles from the project boundary, or other distance necessary, to show the 25 $L_{Aeq}$ and 50 $L_{Ceq}$ boundaries.

Provide a description of the impact of the proposed sound from the WES project on the existing environment. The results should anticipate the receptor sites that will be most negatively impacted by the WES project and to the extent possible provide data for each MP that are likely to be selected in the background sound study (note the sensitive receptor MPs):

1. Report expected changes to existing sound levels for $L_{Aeq}$ and $L_{A90}$
2. Report expected changes to existing sound levels for $L_{Ceq}$ and $L_{C90}$
3. Report the expected changes to existing sound pressure levels for each of the 1/1 or 1/3 octave bands in tabular form from 8 Hz to 10k Hz.
4. Report all assumptions made in arriving at the estimate of impact, any limitations that might cause the sound levels to exceed the values of the estimate, and any conclusions reached regarding the potential effects on people living near the project area. If the effects of coherence, worst case weather, or operating conditions are not reflected in the model a discussion of how these factors could increase the predicted values is required.
5. Include an estimate of the number of hours of operation expected from the proposed WES(s) and under what conditions the WES(s) would be expected to run. Any differences from the information filed with the Application should be addressed.
IV. Post-Construction Measurements

Post Construction Measurements should be conducted by a qualified noise consultant selected by and under the direction of the LGA. The requirements of this Appendix for Sites with Existing Wind Energy Systems shall apply.

1. Within twelve months of the date when the project is fully operational, preferably within two weeks of the anniversary date of the pre-construction background sound measurements, repeat the measurements. Post-construction sound level measurements shall be taken both with all WES(s) running and with all WES(s) off except as provided in this ordinance.

2. Report post-construction measurements to the LGA using the same format as used for the background sound study.

VIII. REFERENCE Standards and ANSI S12.9 Part 3 with Required Amendments


This standard is the second in a series of parts concerning description and measurement of outdoor environmental sound. The standard describes recommended procedures for measurement of short-term, time-average environmental sound outdoors at one or more locations in a community for environmental assessment or planning for compatible land uses and for other purposes such as demonstrating compliance with a regulation. These measurements are distinguished by the requirement to have an observer present. Sound may be produced by one or more separate, distributed sources of sound such as a highway, factory, or airport. Methods are given to correct the measured levels for the influence of background sound.

Wind Turbine Siting Acoustical Measurements

ANSI S12.9 Part 3 Selected Options and Requirement Amendments

For the purposes of this ordinance specific options provided in ANSI S12.9-Part 3 (2008) shall apply with the additional following requirements to Sections in ANSI S12.9/Part 3:

5.2 background sound: Use definition (1) ‘long-term’
5.2 long-term background sound: The L90 excludes short term background sounds
5.3 basic measurement period: Ten (10) minutes L90(10 min)
5.6 Sound Measuring Instrument: Type 1 Integrating Meter meeting ANSI S1.43 or IEC 61672-1. The sound level meter shall cover the frequency range from 6.3 Hz to 20k Hz and simultaneously measure dBA LN and dBC LN. The instrument must also be capable of accurately measuring low-level background sounds down to 20 dBA.
6.5 Windscreen: Required
6.6(a) An anemometer accurate to ± 10% at 2m/s. to full scale accuracy. The anemometer shall be located 1.5 to 2m above the ground and orientated to record maximum wind velocity. The maximum wind velocity, wind direction, temperature and humidity shall be recorded for each ten (10) minute sound measurement period observed within 5 m. of the measuring microphone.
7.1 Long-term background sound
7.2 Data collection Methods: Second method with observed samples to avoid contamination by short term sounds (purpose: to avoid loss of statistical data)
8 Source(s) Data Collection: All requirements in ANSI S12.18 Method #2 precision to the extent possible while still permitting testing of the conditions that lead to complaints. The
meteorological requirements in ANSI S12.18 may not be applicable for some complaints. For sound measurements in response to a complaint, the compliance sound measurements should be made under conditions that replicate the conditions that caused the complaint without exceeding instrument and windscreen limits and tolerances.

8.1(b) Measuring microphone with windscreen shall be located 1.2m to 1.8m (1.5m preferred) above the ground and greater than 8m from large sound reflecting surface.

8.3(a) All meteorological observations required at both (not either) microphone and nearest 10m weather reporting station.

8.3(b) For a 10 minute background sound measurement to be valid the wind velocity shall be less then 2m/s (4.5 mph) measured less than 5m from the microphone. Compliance sound measurements shall be taken when winds shall be less than 4m/s at the microphone.

8.3(c) In addition to the required acoustic calibration checks, the sound measuring instrument internal noise floor, including microphone, must also be checked at the end of each series of ten minute measurements and no less frequently than once per day. Insert the microphone into the acoustic calibrator with the calibrator signal off. Record the observed dBA and dBC reading on the sound level meter to determine an approximation of the instrument self noise. Perform this test before leaving the background measurement location. This calibrator-covered microphone must demonstrate the results of this test are at least 5 dB below the immediately previous ten-minute acoustic test results, for the acoustic background data to be valid. This test is necessary to detect undesired increase in the microphone and sound level meter internal self-noise. As a precaution sound measuring instrumentation should be removed from any air-conditioned space at least an hour before use. Nighttime measurements are often performed very near the meteorological dew point. Minor moisture condensation inside a microphone or sound level meter can increase the instrument self noise and void the measured background data.

8.4 The remaining sections starting at 8.4 in ANSI S12.9 Part 3 Standard do not apply.


This American National Standard describes procedures for the measurement of sound pressure levels in the outdoor environment, considering the effects of the ground, the effects of refraction due to wind and temperature gradients, and the effects due to turbulence. This standard is focused on measurement of sound pressure levels produced by specific sources outdoors. The measured sound pressure levels can be used to calculate sound pressure levels at other distances from the source or to extrapolate to other environmental conditions or to assess compliance with regulation. This standard describes two methods to measure sound pressure levels outdoors. METHOD No. 1: general method; outlines conditions for routine measurements. METHOD No. 2: precision method; describes strict conditions for more accurate measurements. This standard assumes the measurement of A-weighted sound pressure level or time-averaged sound pressure level or octave, 1/3-octave or narrow-band sound pressure level, but does not preclude determination of other sound descriptors.


This Standard describes instruments for the measurement of frequency-weighted and time-average sound pressure levels. Optionally, sound exposure levels may be measured. This standard is consistent with the relevant requirements of ANSI S1.4-1983(R 1997) American National Standard Specification for Sound Level Meters, but specifies additional characteristics that are necessary to
measure the time-average sound pressure level of steady, intermittent, fluctuating, and impulsive sounds.

**ANSI S1.11-2004 American National Standard 'Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters'**

This standard provides performance requirements for analog, sampled-data, and digital implementations of band-pass filters that comprise a filter set or spectrum analyzer for acoustical measurements. It supersedes ANSI S1.11-1986 (R1998) American National Standard Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters, and is a counterpart to International Standard IEC 61260:1995 Electroacoustics - Octave-Band and Fractional-Octave-Band Filters. Significant changes from ANSI S1.11-1986 have been adopted in order to conform to most of the specifications of IEC 61260:1995. This standard differs from IEC 61260:1995 in three ways: (1) the test methods of IEC 61260 clauses 5 is moved to an informative annex, (2) the term 'band number,' not present in IEC 61260, is used as in ANSI S1.11-1986, (3) references to American National Standards are incorporated, and (4) minor editorial and style differences are incorporated.

**ANSI S1.40-2006 American National Standard Specifications and Verification Procedures for Sound Calibrators**

IEC 61400-11

Second edition 2002-12, Amendment 1 2006-05

IEC 61400-11

Second edition 2002-12, Amendment 1 2006-0

**Wind turbine generator systems –Part 11: Acoustic noise measurement techniques**

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions by wind turbine generator systems. The standard has been prepared with the anticipation that it would be applied by:

- the wind turbine manufacturer striving to meet well defined acoustic emission performance requirements and/or a possible declaration system;
- the wind turbine purchaser in specifying such performance requirements;
- the wind turbine operator who may be required to verify that stated, or required, acoustic performance specifications are met for new or refurbished units;
- the wind turbine planner or regulator who must be able to accurately and fairly define acoustical emission characteristics of a wind turbine in response to environmental regulations or permit requirements for new or modified installations.

This standard provides guidance in the measurement, analysis and reporting of complex acoustic emissions from wind turbine generator systems. The standard will benefit those parties involved in the manufacture, installation, planning and permitting, operation, utilization, and regulation of wind turbines. The measurement and analysis techniques recommended in this document should be applied by all parties to insure that continuing development and operation of wind turbines is carried out in an atmosphere of consistent and accurate communication relative to environmental concerns. This standard presents measurement and reporting procedures expected to provide accurate results that can be replicated by others.

End of Measurement Procedure
Industrial scale wind turbines are a familiar part of the landscape in Europe, U.K. and other parts of the world. In the U.S., however, similar industrial scale wind energy developments are just beginning operation. The presence of industrial wind projects will increase dramatically over the next few years given the push by the Federal and state governments to promote renewable energy sources through tax incentives and other forms of economic and political support. States and local governments in the U.S. are promoting what appear to be lenient rules for how industrial wind farms can be located in communities, which are predominantly rural and often very quiet. Studies already completed and currently in progress describe significant health effects associated with living in the vicinity of industrial grade wind turbines. This paper reviews sound studies conducted by consultants for governments, the wind turbine owner, or the local residents for a number of sites with known health or annoyance problems. The purpose is to determine if a set of simple guidelines using dBA and dBC sound levels can serve as the ‘safe’ siting guidelines. Findings of the review and recommendations for sound limits will be presented. A discussion of how the proposed limits would have affected the existing sites where people have demonstrated pathologies apparently related to wind turbine sound will also be presented.

Background

A relatively new source of community noise is spreading rapidly across the rural U.S. countryside. Industrial grade wind turbines, a common sight in many European countries, are now being promoted by Federal and state governments as the way to minimize coal powered electrical energy and its effects on global warming. But, the initial developments using the newer 1.5 to 3 MWatt wind turbines here in the U.S. has also led to numerous complaints from
residents who find themselves no longer in the quiet rural communities they were living in before the wind turbine developments went on-line. Questions have been raised about whether the current siting guidelines being used in the U.S. are sufficiently protective for the people living closest to the developments. Research being conducted into the health issues using data from established wind turbine developments is beginning to appear that supports the possibility there is a basis for the health concerns. Other research into the computer modeling and other methods used for determining the layout of the industrial wind turbine developments and the distances from residents in the adjacent communities are showing that the output of the models should not be considered accurate enough to be used as the sole basis for making the siting decisions.

The authors have reviewed a number of noise studies conducted in response to community complaints for wind energy systems sited in Europe, Canada, and the U.S. to determine if additional criteria are needed for establishing safe limits for industrial wind turbine sound immissions in rural communities. In several cases, the residents who filed the complaints have been included in studies by medical researchers who are investigating the potential health risks associated with living near industrial grade wind turbines 365 days a year. These studies were also reviewed by the authors to help in identifying what factors need to be considered in setting criteria for ‘safe’ sound limits at receiving properties. Due to concerns about medical privacy, details of these studies are not discussed in this paper. Current standards used in the U.S. and in most other parts of the world rely on not-to-exceed dBA sound levels, such as 50 dBA, or on not-to-exceed limits based on the pre-construction background sound level plus an adder (e.g. L_{90A} + 5 dBA).

Our review covered the community noise studies performed in response to complaints, research on health issues related to wind turbine noise, critiques of noise studies performed by consultants working for the wind developer, and research/technical papers on wind turbine sound immissions and related topics. The papers are listed in Tables 1-4.

**Table 1-List of Studies Related to Complaints**

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### Table 2- List of Studies related to Health

<table>
<thead>
<tr>
<th>Study</th>
<th>Source</th>
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<tr>
<td>Nina Pierpont, “Wind Turbine Syndrome – Abstract” from draft article and personal conversations. <a href="http://www.ninapierpont.com">www.ninapierpont.com</a></td>
<td></td>
</tr>
<tr>
<td>Barbara J. Frey and Peter J. Hadden, “Noise Radiation from Wind Turbines Installed Near Homes, Effects on Health” (2007)</td>
<td></td>
</tr>
<tr>
<td>Robin Phipps, “In the Matter of Moturimu Wind Farm Application, Palmerston North, Australia,” March 2007</td>
<td></td>
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<tr>
<td>WHO European Centre for Environment and Health, Bonn Office, “Report on the third meeting on night noise guidelines,” April 2005</td>
<td></td>
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### Table 3-List of Studies that review Siting Impact Statements

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<tr>
<th>Study</th>
<th>Source</th>
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### Table 4-List of Research and Technical papers included in review process

<table>
<thead>
<tr>
<th>Study</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Julian T. and Jane Davis, “Living with aerodynamic modulation, low frequency vibration</td>
<td></td>
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</table>
Discussion

After reviewing the materials in the tables; we have arrived at our current understanding of wind turbine noise and its impact on the host community and its residents. The review showed that some residents living as far as 3 km (two (2) miles) from a wind farm complain of sleep disturbance from the noise. Many residents living one-tenth this distance (300 m. or 1000 feet) from a wind farm are experiencing major sleep disruption and other serious medical problems from nighttime wind turbine noise. The peculiar acoustic characteristics of wind turbine noise immissions cause the sounds heard at the receiving properties to be more annoying and troublesome than the more familiar noise from traffic and industrial factories. Limits used for these other community noise sources do not appear to be appropriate for siting industrial wind turbines. The residents who are annoyed by wind turbine noise complain of the approximately one (1) second repetitive swoosh-boom-swoosh-boom sound of the turbine blades and “low frequency” noise. It is not apparent to these authors whether the complaints that refer to “low frequency” noise are about the audible low frequency part of the swoosh-boom sound, the one hertz amplitude modulation of the swoosh-boom sound, or some combination of both acoustic phenomena.

To assist in understanding the issues at hand, the authors developed the ‘conceptual’ graph for industrial wind turbine sound shown in Figure 1. This graph shows the data from one of the complaint sites plotted against the sound immission spectra for a modern 2.5 MWatt wind turbine; Young’s threshold of perception for the 10% most sensitive population (ISO 0266); and a spectrum obtained for a rural community during a three hour, 20 minute test from 11:45 pm until 3:05 am on a windless June evening in near Ubly, Michigan a quiet rural community located in central Huron County. (Also called: Michigan’s “Thumb.”) It is worth noting that this rural community demonstrates how quiet a rural community can be when located at a distance from industry, highways, and airport related noise emitters.

During our review we posed a number of questions to ourselves related to what we were learning. The questions (italics) and our answers are:

Do National or International or local community Noise Standards for siting wind turbines near dwellings address the low frequency portion of the wind turbine’s sound immissions?32 No! State and Local governments are in the process of establishing wind farm noise limits and/or wind turbine

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32 Emissions refer to acoustic energy from the ‘viewpoint’ of the sound emitter, while immissions refer to acoustic energy from the viewpoint of the receiver.
setbacks from nearby residents, but the standards incorrectly presume that limits based on dBA levels are sufficient to protect the residents.

Do wind farm developers have noise limit criteria and/or wind turbine setback criteria that apply to nearby residents? Yes! But the Wind Industry recommended residential wind turbine noise levels (typically 50-55 dBA) are too high for the quiet nature of the rural communities and may be unsafe for the nearest residents. An additional concern is that some of the methods for implementing pre-construction computer models may predict sound levels that are too low. These two factors combined can lead to post-construction complaints and health risks.

Are all residents living near wind farms equally affected by wind turbine noise? No, children, people with pre-existing medical conditions, especially sleep disorders, and the elderly are generally the most susceptible. Some people are unaffected while some nearby neighbors develop serious health effects caused by exposure to the same wind turbine noise.

How does wind turbine noise impact nearby residents? Initially, the most common problem is chronic sleep deprivation during nighttime. According to the medical research documents, this may develop into far more serious physical and psychological problems.

What are the technical options for reducing wind turbine noise immission at residences? There are only two options: 1) increase the distance between source and receiver, and/or 2) reduce the source sound power immission. Either solution is incompatible with the objective of the wind farm developer to maximize the wind power electrical generation within the land available.

![Wind Turbine Noise Spectra](image)

**Figure 1—Generalized Sound Spectra vs. perception and rural community L90A background 1/3 octave SPL**

Is wind turbine noise at a residence much more annoying than traffic noise? Yes, researchers have found that “Wind turbine noise was perceived by about 85% of the respondents even when the calculated A-weighted SPL were as low as 35.0–37.5 dB. This could be due to the presence of...
amplitude modulation in the noise, making it easy to detect and difficult to mask by ambient noise.” [JASA 116(6), December 2004, pgs 3460-3470, “Perception and annoyance due to wind turbine noise-a dose-relationship” Eja Pedersen and Kerstin Persson Waye, Dept of Environmental Medicine, Goteborg University, Sweden]

Why do wind turbine noise immissions of only 35 dBA disturb sleep at night? This issue is now being studied by the medical profession. The affected residents complain of the middle to high frequency swooshing sounds of the rotating turbine blades at a constant repetitive rate of about 1 hertz plus low frequency noise. The amplitude modulation of the swooshing sound changes continuously. The short time interval between the blade’s swooshing sounds described by residents as sometimes having a thump or low frequency banging sound that varies in amplitude up to 10 dBA. This may be a result of phase changes between turbine emissions, turbulence, or an operational mode. The assumptions about wall and window attenuation being 15 dBA or more may not be sufficiently protective considering the relatively high amplitude of the wind turbine’s low frequency immission spectra.

What are the typical wind farm noise immission criteria or standards? Limits are not consistent and may vary even within a particular country. Example criteria include: Australia-the lower of 35 dBA or L90 + 5 dBA, Denmark-40 dBA, France L90 + 3 (night) and L90 + 5 (day), Germany-40 dBA, Holland-40 dBA, United Kingdom-40 dBA (day) and 43 dBA (night) or L90 + 5 dBA, Illinois-55 dBA (day) and 51 dBA (night), Wisconsin-50 dBA and Michigan-55 dBA. Note: Illinois statewide limits are expressed only in nine contiguous octave frequency bands and no mention of A-weighting for the hourly L eq limits. Typically, wind turbine noise just meeting the octave band limits would read 5 dB below the energy sum of the nine octave bands after applying A-weighting. So the Illinois limits are approximately 50 dBA (daytime 7 AM to 10 PM) and 46 dBA at night, assuming a wind farm is a Class C Property Line Noise Source.

What is a reasonable wind farm sound immission limit to protect the health of residences? We are proposing an immission limit of 35 dBA or L90A + 5 dBA whichever is lower and also a C-weighted criteria to address the impacted resident’s complaints of wind turbine low frequency noise: For the proposed criteria the dBC sound level at a receiving property shall not exceed L90A + 20dB. In other words, the dBC operating immission limit shall not be more than 20 dB above the measured dBA (L90A) pre-construction nighttime background sound level. A maximum not-to-exceed limit of 50 dBC is also proposed.

Why should the dBC immission limit not be permitted to be more than 20 dB above the background measured L90A? The World Health Organization and others have determined a sound emitter’s noise that results in a difference between the dBC and dBA value greater than 20 dB will be an annoying low frequency issue.

Is not L90A the minimum dBA background noise level? This is not exactly correct. The L90 is the statistical descriptor representing the quietest 10% of the time. It may be understood as the sounds one hears when there are no nearby or short-term sounds from man-made or natural sources. It excludes sounds that are not part of the soundscape during all seasons. It is very important to establish the statistical average background noise environment outside a potentially impacted residence during the quietest (10 pm to 4 am) sleeping hours of the night. This nighttime sleep disturbance has generated the majority of the wind farm noise complaints throughout the world. The basis for a community’s wind turbine sound immission limits would be the minimum 10 minute nighttime L90A plus 5 dB for the time period of 10 pm to 7 am. This would become the Nighttime Immission Limits for the proposed wind farm. This can be accomplished with one or several ten (10) minute measurements during any night when the

Prepared for Goodhue, MN Hearing
atmosphere is classified stable with a light wind from the area of the proposed wind farm. The Daytime Limits (7 am to 7 pm) could be set 10 dB above the minimum nighttime L90A measured noise, but the nighttime criteria will always be the limiting sound levels.

A nearby wind farm meeting these noise immission criteria will be clearly audible to the residents occasionally during nighttime and daytime. Compliance with this noise standard would be determined by repeating the initial nighttime minimum nighttime L90A tests and adding the dBC (LeqC) noise measurement with the turbines on and off. If the nighttime background noise level (turbines off) was found to be slightly higher than the measured background prior to the wind farm installation, then the results with the turbines on must be corrected to determine compliance with the pre-turbine established sound limits.

The common method used for establishing the background sound level at a proposed wind farm used in many of the studies in Table 1 was to use unattended noise monitors to record hundreds of ten (10) minute measurements to obtain a statistically significant sample over varying wind conditions or a period of weeks. The measured results for daytime and nighttime are combined to determine the statically average wind noise as a function of wind velocity measured at a height of ten (10) meters. This provides an enormous amount of data but the results have little relationship to the wind turbine sound immission or turbine noise impact in nearby residents. The purpose of this exhaustive exercise often only demonstrates how much noise is generated by the wind. In some cases it appears that the data is used to ‘prove’ that the wind noise masks the turbine’s sound immissions.

The most glaring failure of this argument occurs during the frequent nighttime condition of a stable atmosphere. Then, the wind turbines operate at full or near full power and noise output while the wind at ground level is calm and the background noise level is low. This is the condition of maximum turbine noise impact on nearby residents. It is the condition which most directly causes chronic sleep disruption. Furthermore, the measurement methodology is usually faulty, as much of the wind noise measured by unattended sound monitors is the pseudo-wind noise generated by failure of the microphone’s windscreen. This results in totally erroneous background sound levels being used for permitting and siting decisions. (See studies in Table 3, esp. Van den Berg)

Are there additional noise data to be recorded for a pre-wind turbine noise survey near selected dwellings? Yes, The measuring sound level meter(s) need document the LAeq , LA10 , L90 and LCeq , LC10 , L90 sound levels plus start time & date for each 10 minute sample. The L10 results will be utilized to help validate that conditions were appropriate for measuring the L90 long term background sound levels. For example, on a quiet night one would expect L10 to be less than 10 dB higher than the L90 long-term background sound level. On a windy night or day the difference may be more than 20 dB. There is a requirement for measurement of the wind velocity near the sound measurement microphone continuously throughout each ten (10) minute recorded noise sample. The ten (10) minute average of the wind speed near the microphone shall not exceed 2 m/s (4.5 mph) and the maximum wind speed for operational tests shall not exceed 4 m/s (9 mph). It is strongly recommended that observed samples be used for these tests.

Is there a need to record weather data during the background noise recording survey? One weather monitor is required at the proposed wind farm on the side nearest the residents. The weather station sensors are at standard ten (10) meter height above ground. It is critical the weather be recorded every ten (10) minutes synchronized with the clocks in the sound level recorders without ambiguity in the start and end time of each ten (10) minute period. The weather station should record wind speed and direction, temperature, humidity and rain.
Why do Canada and some other countries base the permitted wind turbine noise immission limits on the operational wind velocity at the 10m height wind speed instead of a maximum dBA or $L_{A90} + 5$ dBA immission level? First, it appears that the wind turbine industry will take advantage of every opportunity to elevate the maximum permitted noise immission level to reduce the setback distance from the nearby dwellings. Including wind as a masking source in the criteria is one method for elevating the permissible limits. Indeed the background noise level does increase with surface wind speed. When it does occur, it can be argued that the increased wind noise provides some masking of the wind farm turbine noise emission. However, in the middle of the night when the atmosphere is defined as stable (no vertical flow from surface heat radiation) the layers of the lower atmosphere can separate and permit wind velocities at the turbine hubs to be 2 to 4 times the wind velocity at the 10m high wind monitor but remain near calm at ground level. The result is the wind turbines can be operating at or close to full capacity while it is very quiet outside the nearby dwellings.

This is the heart of the wind turbine noise “problem” for residents within 3 km (approx. two miles) of a wind farm. When the turbines are producing the sound from operation it is quietest outside the surrounding homes. The PhD thesis of P.G. van den Berg “The Sounds of High Winds” is very enlightening on this issue. See also the letter by John Harrison in Ontario “On Wind Turbine Guidelines.”

What sound monitor measurements would be needed for enforcement of the wind turbine sound ordinance? A similar sound and wind 10 minute series of measurements would be repeated at the pre-wind farm location nearest the resident registering the wind turbine noise complaint, with and without the operation of the wind turbines. An independent acoustics expert should be retained who reports to the County Board or other responsible governing body. This independent acoustics expert shall be responsible for all the acoustic measurements including instrumentation setup, calibration and interpretation of recorded results. An independent acoustical consultant shall also perform all pre-turbine background noise measurements and interpretation of results to establish the Nighttime (and Daytime if applicable) industrial wind turbine sound immission limits. At present the acoustical consultants are retained by, and work directly for, the wind farm developer.

This presents a serious problem with conflict of interest on the part of the consultant. The wind farm developer would like to show the significant amount of wind noise that is present to mask the sounds of the wind turbine immissions. The wind farm impacted community would like to know that wind turbine noise will be only barely perceptible and then only occasionally during the night or daytime.

Is frequency analysis required either during pre-wind farm background survey or for compliance measurements? Normally one-third octave or narrower band analysis would only be required if there is a complaint of tones immission from the wind farm.

Proposed Sound Limits
The simple fact that so many residents complain of low frequency noise from wind turbines is clear evidence that the single A-weighted (dBA) noise descriptor used in most jurisdictions for siting turbines is not adequate. The only other simple audio frequency weighting that is standardized and available on all sound level meters is C-weighting or dBC. A standard sound level meter set to measure dBA is increasingly less sensitive to low frequency below 500 Hz (one octave above middle-C). The same sound level meter set to measure dBC is equally sensitive to all frequencies above 32 Hz (lowest note on grand piano). It is well accepted that dBC readings
are more predictive of perceptual loudness than dBA readings if low frequency sounds are significant.

We are proposing to use the commonly accepted dBA criteria that is based on the pre-existing background sound levels plus a 5 dB allowance for the wind turbine’s immissions (e.g. $L_{90A} +5$) for the audible sounds from wind turbines. In addition, to address the lower frequencies that are not considered in A-weighted measurements we are proposing to add limits based on dBC. The Proposed Sound Limits are presented in the text box at the end of this paper.

For the current industrial grade wind turbines in the 1.5 to 3 MWatt range, the addition of the dBC requirement will result in an increased distance between wind turbines and the nearby residents. For the generalized graphs shown in Figure 1, the distances would need to be approximately double the current distance. This will result in setbacks in the range of 1 km or greater for the current generation of wind turbines if they are to be located in rural areas where the $L_{90A}$ background sound levels are 30 dBA or lower. When no man-made sounds are audible they can even be under 20 dBA. In areas with higher background sound levels, turbines could be located somewhat closer, but still at a distance greater than the 305 m (1000 ft.) or less setbacks commonly seen in U.S. based wind turbine standards set by many states and used for wind turbine developments.
1. Establishing Long-Term Background Noise Level
   a. Instrumentation: ANSI or IEC Type 1 Precision Integrating Sound Level Meter plus meteorological instruments to measure wind velocity, temperature and humidity near the sound measuring microphone. Measurement procedures must meet ANSI S12.9, Part 3.
   b. Measurement location(s): Nearest property line(s) from proposed wind turbines representative of all non-participating residential property within 2.0 miles.
   c. Time of measurements and prevailing weather: The atmosphere must be classified as stable with no vertical heat flow to cause air mixing. Stable conditions occur in the evening and middle of the night with a clear sky and very little wind near the surface. Sound measurements are only valid when the measured wind speed at the microphone does not exceed 2 m/s (4.5 mph).
   d. Long-Term Background sound measurements: All data recording shall be a series of contiguous ten (10) minute measurements. The measurement objective is to determine the quietest ten minute period at each location of interest. Nighttime test periods are preferred unless daytime conditions are quieter. The following data shall be recorded simultaneously for each ten (10) minute measurement period: dBA data includes Lₐ₁₀, Lₐ₁₂, Lₐₑₙq and dBC data includes LC₉₀, Lₐ₁₀, and Lₐₑₙq. The maximum wind speed at the microphone during the ten minutes, a single measurement of temperature and humidity at the microphone for each new location or each hour whichever is oftener shall also be recorded. A ten (10) minute measurement contains valid data provided: Both Lₐ₁₀ minus Lₐₑₙq and Lₐ₁₀ minus Lₐₑₙq are not greater than 10 dB and the maximum wind speed at the microphone did not exceed 2 m/s during the same ten (10) minute period as the acoustic data.

2. Wind Turbine Sound Immission Limits
   No wind turbine or group of turbines shall be located so as to cause wind turbine sound immission at any location on non-participating property containing a residence in excess of the limits in the following table:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Condition</th>
<th>dBA</th>
<th>dBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Immission above pre-construction background:</td>
<td>( L_{AEQ} = L_{A90} + 5 )</td>
<td>( L_{CEQ} = L_{C90} + 5 )</td>
</tr>
<tr>
<td>B</td>
<td>Maximum immission:</td>
<td>35 ( L_{AEQ} )</td>
<td>55 ( L_{CEQ} ) for quiet rural environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 ( L_{CEQ} ) for rural-suburban environment</td>
</tr>
<tr>
<td>C</td>
<td>Immission spectra imbalance:</td>
<td>( L_{CEQ} ) (immission) minus ( L_{A90} ) (background)+5 ( \leq 20 ) dB</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Prominent tone penalty:</td>
<td>5 dB</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

Notes
1. Each Test is independent and exceedances of any test establishes non-compliance Sound “immission” is the wind turbine noise emission as received at a property
2. A “Quiet rural environment” is a location 2 miles from a state road or other major transportation artery without high traffic volume during otherwise quiet periods of the day or night.
3. Prominent tone as defined in IEC 61400-11. This Standard is not to be used for any other purpose.

1 Procedures provided in Section 7. Measurement Procedures (Appendix to Ordinance) of the most recent version of “The How To Guide To Siting Wind Turbines To Prevent Health Risks From Sound” by Kamperman and James apply to this table.

3. Wind Farm Noise Compliance Testing
   All of the measurements outlined above in 1. Establishing the Long-Term Background Noise Level must be repeated to determine compliance with 2. Wind Turbine Sound Immission Limits. The compliance test location is to be the pre-turbine background noise measurement location nearest to the home of the complainant in line with the wind farm and nearer to the wind farm. The time of day for the testing and the wind farm operating conditions plus wind speed and direction must replicate the conditions that generated the complaint. Procedures of ANSI S12.9-Part 3 apply as amended. instrumentation limits for wind and other factors must be recognized and followed.

The authors have based these criteria, procedures, and language on their current understanding of wind turbine sound emissions, land-use compatibility, and the effects of sound on health. However, use of the following, in part or total, by any party is strictly voluntary and the user assumes all risks. Please seek professional assistance in applying the recommendations of this document to any specific community or WES development.
Testimony of Rick James, INCE

Exhibit RJ-03
wind-turbine noise
what audiologists should know
Wind-Turbine NOISE
What Audiologists Should Know

BY JERRY PUNCH, RICHARD JAMES, AND DAN PABST

Noise from modern wind turbines is not known to cause hearing loss, but the low-frequency noise and vibration emitted by wind turbines may have adverse health effects on humans and may become an important community noise concern.
Most of us would agree that the modern wind turbine is a desirable alternative for producing electrical energy. One of the most highly touted ways to meet a federal mandate that 20 percent of all energy must come from renewable sources by 2020 is to install large numbers of utility-scale wind turbines. Evidence has been mounting over the past decade, however, that these utility-scale wind turbines produce significant levels of low-frequency noise and vibration that can be highly disturbing to nearby residents.

None of these unwanted emissions, whether audible or inaudible, are believed to cause hearing loss, but they are widely known to cause sleep disturbances. Inaudible components can induce resonant vibration in solids, liquids, and gases—including the ground, houses, and other building structures, spaces within those structures, and bodily tissues and cavities—that is potentially harmful to humans. The most extreme of these low-frequency (infrasonic) emissions, at frequencies under about 16 Hz, can easily penetrate homes. Some residents perceive the energy as sound, others experience it as vibration, and others are not aware of it at all. Research is beginning to show that, in addition to sleep disturbances, these emissions may have other deleterious consequences on health. It is for these reasons that wind turbines are becoming an important community health issue, especially when hosted in quiet rural communities that have no prior experience with industrial noise or urban hum.

The people most susceptible to disturbances caused by wind turbines may be a small percentage of the total exposed population, but for them the introduction of wind turbines in their communities is not something to which they can easily become acclimated. Instead, they become annoyed, uncomfortable, distressed, or ill. This problem is increasing as newer utility-scale wind turbines capable of generating 1.5-5 MWatts of electricity or more replace the older turbines used over the past 30 years, which produced less than 1 MWatt of power. These large wind turbines can have hub heights that span the length of a football field and blade lengths that span half that distance. The increased size of these multi-MWatt turbines, especially the blades, has been associated with complaints of adverse health effects (AHES) that cannot be explained by auditory responses alone.

For this article, we reviewed the English-language, peer-reviewed literature from around the world on the topic of wind-turbine noise and vibration and their effects on humans. In addition, we used popular search engines to locate relevant online trade journals, books, reference sources, government regulations, and acoustic and vibration standards. We also consulted professional engineers and psychoacousticians regarding their unpublished ideas and research.

Sources of Wind-Turbine Noise and Vibration

Physically, a modern wind turbine consists of a tower; a rotor (or hub); a set of rotating blades—usually three, located upwind to the tower; and a nacelle, which is an enclosure containing a gearbox, a generator, and

![Major components of a modern wind turbine.](image-url)
computerized controls that monitor and regulate operations (FIGURE 1). Wind speed can be much greater at hub level than at ground level, so taller wind towers are used to take advantage of these higher wind speeds. Calculators are available for predicting wind speed at hub height, based on wind speeds at 10 meter weather towers, which can easily be measured directly.

Mechanical equipment inside the nacelle generates some noise, but at quieter levels than older turbines. This mechanical sound is usually considered of secondary importance in discussions of annoyance from today’s turbines. The main cause of annoyance is an aerodynamic source created by interaction of the turning blades with the wind. With optimal wind conditions, this aerodynamic noise is steady and commonly described as an airplane overhead that never leaves.

When wind conditions are not optimal, such as during turbulence caused by a storm, the steady sounds are augmented by fluctuating aerodynamic sounds. Under steady wind conditions, this interaction generates a broadband whooshing sound that repeats itself about once a second and is clearly audible. Many people who live near the wind turbine find this condition to be very disturbing.

The whooshing sound comes from variations of air turbulence from hub to blade tip and the inability of the turbine to keep the blades adjusted at an optimal angle as wind direction varies. The audible portion of the whoosh is around 300 Hz, which can easily penetrate walls of homes and other buildings. In addition, the rotating blades create energy at frequencies as low as 1–2 Hz (the blade-passage frequency), with overtones of up to about 20 Hz. Although some of this low-frequency energy is audible to some people with sensitive hearing, the energy is mostly vibratory to people who react negatively to it.

Adverse Health Effects of Wind-Turbine Noise

Hubbard and Shepherd (1990), in a technical paper written for the National Aeronautics and Space Administration (NASA), were the first to report in depth on the noise and vibration from wind turbines. Most of the relevant research since that time has been conducted by European investigators, as commercial-grade (utility-scale) wind turbines have existed in Europe for many decades. Unfortunately, the research and development done by wind-turbine manufacturers is proprietary and typically has not been shared with the public, but reports of the distressing effects on people living near utility-scale wind turbines in various parts of the world are becoming more common.

Studies carried out in Denmark, The Netherlands, and Germany (Wolsink and Sprengers, 1993; Wolsink et al, 1993), a Danish study (Pedersen and Nielsen, 1994), and two Swedish studies (Pedersen and Persson Waye, 2004, 2007) collectively indicate that wind turbines differ from other sources of community noise in several respects. These investigators confirm the findings of earlier research that amplitude-modulated sound is more easily perceived and more annoying than constant-level sounds (Bradley, 1994; Bengtsson et al, 2004) and that sounds that are unpredictable and uncontrollable are more annoying than other sounds (Geeen and McCown, 1984; Hatfield et al, 2002).

Annoyance from wind-turbine noise has been difficult to characterize by the use of such psychoacoustic parameters as sharpness, loudness, roughness, or modulation (Persson Waye and Öhrström, 2002). The extremely low-frequency nature of wind-turbine noise, in combination with the fluctuating blade sounds, also means that the noise is not easily masked by other environmental sounds.

Pedersen et al (2009), in a survey conducted in The Netherlands on 725 respondents, found that noise from
wind turbines is more annoying than transportation or industrial noises at comparable levels, measured in dBA. They noted that annoyance from turbine sounds at 35 dBA corresponds to the annoyance reported for other common community-noise sources at 45 dBA. Higher visibility of the turbines was associated with higher levels of annoyance, and annoyance was greater when attitudes toward the visual impact of the turbines on the landscape were negative. However, the height of wind turbines means that they are also most clearly visible to the people closest to them and those who also receive the highest sound levels. Thus, proximity of the receiver to wind turbines makes it difficult to determine whether annoyance to the noise is independent of annoyance to the visual impact. Pedersen et al. (2009) also found that annoyance was substantially lower in people who benefitted economically from having wind turbines located on their property.

Among audiologists and acousticians, it has been understood for many decades that sufficiently intense and prolonged exposure to environmental noise can cause hearing impairment, annoyance, or both. In essence, the view has been what you can hear can hurt you. In the case of wind turbines, it seems that what you can’t hear can also hurt you. Again, there is no evidence that noise generated by wind turbines, even the largest utility-scale turbines, causes hearing loss. But there is increasingly clear evidence that audible and low-frequency acoustic energy from these turbines is sufficiently intense to cause extreme annoyance and inability to sleep, or disturbed sleep, in individuals living near them.

Jung and colleagues (2008), in a Korean study, concluded that low-frequency noise in the frequency range above 30 Hz can lead to psychological complaints and that infrasound in the frequency range of 5–8 Hz can cause complaints due to rattling doors and windows in homes.

The energy generated by large wind turbines can be especially disturbing to the vestibular systems of some people, as well as cause other troubling sensations of the head, chest, or other parts of the body. Dr. Nina Pierpont (2009), in her definitive natural experiment on the subject, refers to these effects as Wind-Turbine Syndrome (WTS). TABLE 1 lists the symptoms that, in various combinations, characterize WTS. Although hearing impairment is not one of the symptoms of WTS, audiologists whose patients report these symptoms should ask them if they live near a wind turbine.

It is well known that sleep deprivation has serious consequences, and we know that noncontinuous sounds and nighttime sounds are less tolerable than continuous and daytime sounds. Somewhat related effects, such as cardiac arrhythmias, stress, hypertension, and headaches have also been attributed to noise or vibration from wind turbines, and some researchers are referring to these effects as Vibroacoustic Disease, or VAD (Castelo Branco, 1999; Castelo Branco and Alves-Pereira, 2004). VAD is described as occurring in persons who are exposed to high-level (>90 dB SPL) infra- and low-frequency noise (ILFN), under 500 Hz, for periods of 10 years or more. It is believed to be a systemic pathology characterized by direct tissue damage to a variety of bodily organs and may involve abnormal proliferation of extracellular matrices.

Alves-Pereira and Castelo Branco (2007) reported on a family who lived near wind turbines and showed signs of VAD. The sound levels in the home were less than 60 dB SPL in each 1/3–octave band below 100 Hz. We have measured unweighted sound levels ranging from 60 to 70 dB Leq (averaged over 1 minute) in these low-frequency bands in Ontario homes of people reporting AHEs from wind turbines. A spectral analysis of sounds emitted at a Michigan site revealed that unweighted peak levels at frequencies under 5 Hz exceeded 90 dB SPL (Wade Bray, pers. comm., 2009).

### Table 1. Core Symptoms of Wind-Turbine Syndrome

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Sleep disturbance</td>
</tr>
<tr>
<td>2</td>
<td>Headache</td>
</tr>
<tr>
<td>3</td>
<td>Visceral Vibratory Vestibular Disturbance (VVVD)</td>
</tr>
<tr>
<td>4</td>
<td>Dizziness, vertigo, unsteadiness</td>
</tr>
<tr>
<td>5</td>
<td>Tinnitus</td>
</tr>
<tr>
<td>6</td>
<td>Ear pressure or pain</td>
</tr>
<tr>
<td>7</td>
<td>External auditory canal sensation</td>
</tr>
<tr>
<td>8</td>
<td>Memory and concentration deficits</td>
</tr>
<tr>
<td>9</td>
<td>Irritability, anger</td>
</tr>
<tr>
<td>10</td>
<td>Fatigue, loss of motivation</td>
</tr>
</tbody>
</table>

Source: Pierpont, 2009
Similar observations have been made in studies of people who live near busy highways and airports, which also expose people to low-frequency sounds, both outdoors and in their homes. Evidence is insufficient to substantiate that typical exposures to wind-turbine noise, even in residents who live nearby, can lead to VAD, but early indications are that there are some more-vulnerable people who may be susceptible. Because ILFN is not yet recognized as a disease agent, it is not covered by legislation, permissible exposure levels have not yet been established, and dose-response relationships are unknown (Alves-Pereira, 2007).

As distinguished from VAD, Pierpont’s (2009) use of the term Wind-Turbine Syndrome appears to emphasize a constellation of symptoms due to stimulation, or overstimulation, of the vestibular organs of balance due to ILFN from wind turbines (see Table 1). One of the most distinctive symptoms he lists in the constellation of symptoms comprising WTS is Visceral Vibration Vestibular Disturbance (VVVD), which she defines as “a sensation of internal quivering, vibration, or pulsation accompanied by agitation, anxiety, alarm, irritability, rapid heartbeat, nausea, and sleep disturbance” (p. 270).

Drawing on the recent work of Balaban and colleagues (i.e., Balaban and Yates, 2004), Pierpont describes the close association between the vestibular system and its neural connections to brain nuclei involved with balance processing, autonomic and somatic sensory inflow and outflow, the fear and anxiety associated with vertigo or a sudden feeling of postural instability, and aversive learning. These neurological relationships give credence to Pierpont’s linkage of the symptoms of VVVD to the vestibular system.

Todd et al (2008) demonstrated that the resonant frequency of the human vestibular system is 100 Hz, concluding that the mechano-receptive hair cells of the vestibular structures of the inner ear are remarkably sensitive to low-frequency vibration and that this sensitivity to vibration exceeds that of the cochlea. Not only is 100 Hz the frequency of the peak response of the vestibular system to vibration, but it is also a frequency at which a substantial amount of acoustic energy is produced by wind turbines. Symptoms of both VAD and VVVD can presumably occur in the presence of ILFN as a result of disruptions of normal paths or structures that mediate the fine coordination between living tissue deformation and activation of signal transducers; these disruptions can lead to aberrant mechano-electrical coupling that can, in turn, lead to conditions such as heart arrhythmias (Ingber, 2008). Ultimately, further research will be needed to sort out the commonalities and differences among the symptoms variously described in the literature as VAD, VVVD, and WTS.

Dr. Geoff Leventhall, a British scientist, and his colleagues (Waye et al, 1997; Leventhall, 2003, 2004) have documented the detrimental effects of low-frequency noise exposure. They consider it to be a special environmental noise, particularly to sensitive people in their homes. Waye et al (1997) found that exposure to dynamically modulated low-frequency ventilation noise (20–200 Hz)—as opposed to midfrequency noise exposure—was more bothersome, less pleasant, impacted work performance more negatively, and led to lower social orientation.

Leventhall (2003), in reviewing the literature on the effects of exposure to low-frequency noise, found no evidence of hearing loss but substantial evidence of vibration of bodily structures (chest vibration), annoyance (especially in homes), perceptions of unpleasantness (pressure on the eardrum, unpleasant perception within the chest area, and a general feeling of vibration), sleep disturbance (reduced wakefulness), stress, reduced performance on demanding...
verbal tasks, and negative biological effects that included
quantitative measurements of EEG activity, blood pressure,
respiration, hormone production, and heart rate.

Regarding work performance, reviewed studies
indicated that dynamically modulated low-frequency
noise, even when inaudible to most individuals, is more
difficult to ignore than mid- or high-frequency noise and
that its imperviousness to habituation leads to reduced
available information-processing resources. Leventhall
hypothesized that low-frequency noise, therefore, may
impair work performance. More recently, as a consul-
tant on behalf of the British Wind Energy Association
(BWEA), the American Wind Energy Association (AWEA),
and the Canadian Wind Energy Association (CANWEA),
Leventhall (2006) changed his position, stating that
although wind turbines do produce significant levels
of low-frequency sound, they do not pose a threat to
humans—in effect reverting to the notion that what you
can’t hear can’t hurt you.

According to the World Health Organization guidelines
(WHO, 2007), observable effects of nighttime, outdoor
wind-turbine noise do not occur at levels of 30 dBA or
lower. Many rural communities have ambient, nighttime
sound levels that do not exceed 25 dBA. As outdoor sound
levels increase, the risk of AHEs also increases, with
the most vulnerable being the first to show its effects.
Vulnerable populations include elderly persons; children,
especially those younger than age six; and people with
pre-existing medical conditions, especially if sleep is
affected. For outdoor sound levels of 40 dBA or higher,
the WHO states that there is sufficient evidence to link
prolonged exposure to AHEs. While the WHO identifies
long-term, nighttime audible sounds over 40 dBA outside
one’s home as a cause of AHEs, the wind industry com-
monly promotes 50 dBA as a safe limit for nearby homes
and properties. Recently, a limit of 45 dBA has been pro-
posed for new wind projects in Canada (Keith et al, 2008).

Much of the answer as to why the wind industry
denies that noise is a serious problem with its wind tur-
bines is because holding the noise to 30 dBA at night has
serious economic consequences. The following quota-
tion by Upton Sinclair seems relevant here: “It is difficult
to get a man to understand something when his salary
depends upon his not understanding it” (Sinclair, 1935,

In recent years, the wind industry has denied the
validity of any noise complaints by people who live near
its utility-scale wind turbines. Residents who are leasing
their properties for the siting of turbines are generally so
pleased to receive the lease payments that they seldom
complain. In fact, they normally are required to sign a
leasing agreement, or gag clause, stating they will not
speak or write anything unfavorable about the turbines.
Consequently, complaints, and sometimes lawsuits, tend
to be initiated by individuals who live near property on
which wind turbines are sited, and not by those who are
leasing their own property. This situation pits neighbor
against neighbor, which leads to antagonistic divisions
within communities.

**Measurement of Wind-Turbine Noise**

It is important to point out that the continued use of the
A-weighting scale in sound-level meters is the basis for
misunderstandings that have led to acrimony between
advocates and opponents of locating wind turbines in
residential areas. The dBA scale grew out of the desire to
incorporate a function into the measurement of sound
pressure levels of environmental and industrial noise that
is the inverse of the minimum audibility curve (Fletcher
and Munson, 1933) at the 40-phon level. It is typically
used, though, to specify the levels of noises that are more
intense, where the audibility curve becomes considerably
flattened, obviating the need for A-weighting. It is man-
dated in various national and international standards for
measurements that are compared to damage-risk criteria
for hearing loss and other health effects. The A-weighted
scale in sound-level meters drastically reduces

![Utility-scale wind turbines located in Huron County, Michigan.](image)
sound-level readings in the lower frequencies, beginning at 1000 Hz, and reduces sounds at 20 Hz by 50 dB.

For wind-turbine noise, the A-weighting scale is especially ill-suited because of its devaluation of the effects of low-frequency noise. This is why it is important to make C-weighted measurements, as well as A-weighted measurements, when considering the impact of sound from wind turbines. Theoretically, linear-scale measurements would seem superior to C-scale measurements in wind-turbine applications, but linear-scale measurements lack standardization due to failure on the part of manufacturers of sound-level meters to agree on such factors as low-frequency cutoff and response tolerance limits. The Z-scale, or zero-frequency weighting, was introduced in 2003 by the International Electro-technical Commission (IEC) in its Standard 61672 to replace the flat, or linear, weighting used by manufacturers in the past.

**State of Michigan Siting Guidelines**
Michigan’s siting guidelines (State of Michigan, 2008) will be used as an example of guidelines that deal only in a limited way with sound. These guidelines refer to earlier, now outdated, WHO and Environmental Protection Agency (EPA) guidelines to support a noise criterion that SPLs cannot exceed 55 dBA at the adjacent property line. This level is allowed to be exceeded during severe weather or power outages, and when the ambient sound level is greater than 55 dBA, the turbine noise can exceed that higher background sound level by 5 dB. These levels are about 30 dB above the nighttime levels of most rural communities. When utility-scale turbines were installed in Huron County, Michigan, in May 2008, the WHO’s 2007 guidelines that call for nighttime, outside levels not to exceed 30 dBA were already in place. Based on measurements made by the authors, these turbines produce 40–45 dBA sound levels at the perimeter of a 1,000 ft radius under typical weather conditions, and the additive effects of multiple turbines produce higher levels. Many of the turbines have been located close enough to homes to produce very noticeable noise and vibration.

Kamperman and James (2009) have offered recommendations for change in the State of Michigan guidelines (2008) for wind turbines. Some of the more pertinent details of the Michigan siting guidelines are shown in the left-hand column of **Table 2**. The state of Michigan permits sound levels that do not exceed 55 dBA or L90 + 5 dBA, whichever is greater, measured at the property line closest to the wind-energy system. These guidelines make no provisions to limit low-frequency sounds from wind-turbine operations.

In consideration of the current WHO guidelines (2007), measurements made by the authors in Huron County, Michigan, indicate that the current Michigan guidelines do not appear adequate to protect the public from the nuisances and known health risks of wind-turbine noise. In fact, these guidelines appear to be especially lenient

### Table 2. Current and Proposed Wind-Turbine Siting Guidelines

<table>
<thead>
<tr>
<th>Current Michigan Guidelines*</th>
<th>Alternative Proposed Guidelines**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound level cannot exceed 55 dBA or L90 + 5 dBA, whichever is greater.</td>
<td>Operating LAeq is not to exceed the background LA90 + 5 dBA, where LA90 is measured during a preconstruction noise study at the quietest time of night. Similar dBc limits should also be applied.</td>
</tr>
<tr>
<td>Limits apply to sound levels measured at homes (as stated in Huron County Ordinance).</td>
<td>Limits apply to sound levels measured at property lines, except that turbine sounds cannot exceed 35 dBA at any home.</td>
</tr>
<tr>
<td>No provisions are made for limiting low-frequency sounds from wind-turbine operations.</td>
<td>L(Ceq-LA90 cannot exceed 20 dB at receiving property, e.g., L(Ceq [from turbines] minus [LA90 [background] + 5]) &lt; 20 dB, and is not to exceed 55 L(Ceq for properties within one mile of major heavily trafficked roads).</td>
</tr>
</tbody>
</table>

*Source: State of Michigan, 2008

**Source: Kamperman and James, 2009
People living near wind turbines may experience sleep disturbance.

Leq during turbine operation and the quietest A-weighted pre-operation background sound levels, plus 5 dB, to no more than 20 dB at the property line. This level should not exceed 55 dB Leq on the C scale, or 60 dB Leq for properties within one mile of major heavily trafficked roads, which sets a higher tolerance for communities that tend to experience slightly noisier conditions.

Implementation of the recommendations of Kamperman and James would result in siting wind turbines differently than what is currently planned for future wind-turbine projects in Michigan. This change would result in sound levels at nearby properties that are much less noticeable, and much less likely to cause sleep deprivation, annoyance, and related health risks. These sound-level measurements should be made by independent acoustical engineers or knowledgeable audiologists who follow ANSI guidelines (1993, 1994) to ensure fair and accurate readings, and not by representatives of the wind industry.

People living within a mile of one or more wind turbines, and especially those living within a half mile, have frequent sleep disturbance leading to sleep deprivation, and sleep disturbances are common in people who live up to about 1.25 miles away. This is the setback distance at which a group of turbines would need to be in order not to be a nighttime noise disturbance (Kamperman and James, 2009). It is also the setback distance used in several other countries that have substantial experience with wind turbines, and is the distance at which Pierpont (2009) found very few people reporting AHEs.

A study conducted by van den Berg (2003) in The Netherlands demonstrated that daytime levels cannot be used to predict nighttime levels and that residents within 1900 mile (1.18 mile) of a wind-turbine project expressed annoyance from the noise. Pierpont (2009) recommends baseline minimum setbacks of 2 kilometers (1.24 mile) from residences and other buildings such as hospitals, schools, and nursing homes, and longer setbacks in mountainous terrain and when necessary to meet the noise criteria developed by Kamperman and James (2009).

In a panel review report, the American Wind Energy Association (AWEA) and Canadian Wind Energy Association (CANWEA) have objected to setbacks that exceed 1 mile (Colby et al, 2009). A coalition of independent medical and acoustical experts, the Society for Wind Vigilance (2010), has provided a recent rebuttal to that report. The society has described the panel review as a typical product of industry-funded white papers, being neither authoritative nor convincing. The society accepts as a medical fact that sleep disturbance, physiological stress, and psychological distress can result from exposure to wind-turbine noise.

Wind turbines have different effects on different people. Some of these effects are somewhat predictable based on financial compensation, legal restrictions on free speech included in the lease contracts with hosting landowners, and distance of the residence from wind projects, but they are sometimes totally unpredictable. Planning for wind projects needs to be directed not only toward benefitting society at large but also toward protecting the individuals living near them. We believe that the state of Michigan, and other states that have adopted similar siting guidelines for wind turbines, are not acting in the best interest of all their citizens and need to revise their siting guidelines to protect the public from possible health risks and loss of property values, as well as reduce complaints about noise annoyance.

Wind-utility developers proposing new projects to a potential host community are often asked if their projects will cause the same negative community responses that are heard from people living in the footprint of operating projects. They often respond that they will use a different
type of wind turbine or that reports of complaints refer to older-style turbines that they do not use. In our opinion, these statements should usually be viewed as diversionary.

Finally, it is important to note that there is little difference in noise generated across makes and models of modern utility-scale, upwind wind turbines once their power outputs are normalized. Kamperman (pers. comm., 2009), after analyzing data from a project funded by the Danish Energy Authority (Søndergaard and Madsen, 2008), has indicated that when the A-weighted sound levels are converted to unweighted levels, the low-frequency energy from industrial wind turbines increases inversely with frequency at a rate of approximately 3 dB per octave to below 10 Hz (the lowest reported frequency). Kamperman has concluded that the amount of noise generated at low frequencies increases by 3–5 dB for every MW of electrical power generated. Because turbines are getting larger, this means that future noise problems are likely to get worse if siting guidelines are not changed.

Conclusion

Our purpose in this article has been to provide audiologists with a better understanding of the types of noise generated by wind turbines, some basic considerations underlying sound-level measurements of wind-turbine noise, and the adverse health effects on people who live near these turbines. In future years, we expect that audiologists will be called upon to make noise measurements in communities that have acquired wind turbines, or are considering them. Some of us, along with members of the medical profession, will be asked to provide legal testimony regarding our opinions on the effects of such noise on people. Many of us will likely see clinical patients who are experiencing some of the adverse health effects described in this article.

As a professional community, audiologists should become involved not only in making these measurements to corroborate the complaints of residents living near wind-turbine projects but also in developing and shaping siting guidelines that minimize the potentially adverse health effects of the noise and vibration they generate. In these ways, we can promote public health interests without opposing the use of wind turbines as a desirable and viable alternative energy source.

Jerry Punch, PhD, Richard James, BME, and Dan Pabst, BS, are with the Department of Communicative Sciences and Disorders, Michigan State University, East Lansing, MI.
Portions of this work were presented at the Annual Convention of the American Speech-Language-Hearing Association (ASHA), November 2009, New Orleans, LA.

Acknowledgments. We wish to thank the many families and residents of Huron County, Michigan, with whom we spent many hours discussing a variety of issues related to their concerns about the noise and vibration from nearby wind turbines. Their involvement, and especially their compelling stories, provided information and encouragement that led us to the belief that this work should be shared with members of the audiology profession.

References


Testimony of Rick James, INCE

Exhibit RJ-04
Wind Energy Industry Acknowledgement of Adverse Health Effects

Part 1 Conclusion and Executive Summary


Prepared by
The Society for Wind Vigilance

January 2010*

In alphabetical order:

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* Appended January 18, 2009 to include document production details.
Note: the contents of this analysis have not been altered.
FORWARD

Wind Turbine Sound and Health Effects, An Expert Panel Review (A/CanWEA Panel Review) was prepared for and sponsored by the American Wind Energy Association (AWEA) and the Canadian Wind Energy Association (CanWEA).

In response, an analysis was conducted by The Society for Wind Vigilance of the A/CanWEA Panel Review. Details of the analysis are included in Table 1 of this document.

The summary and related points cover a broad spectrum of claims. For convenience the remainder of the analysis and critique is done in a tabulated format of point - counter point. The volume of material necessitated this approach and hopefully will enhance the clarity of the critique being put forward.

The method utilized was to excerpt each of the claims and place it in the context of authoritative and contrary information. In addition an effort has been made to identify the errors of omission as well as those of commission.

CONCLUSION

It is apparent from this analysis that the A/CanWEA Panel Review is neither authoritative nor convincing. The work is characterized by commission of unsupportable statements and the confirmation bias in the use of references. Many important references have been omitted and not considered in the discussion. Furthermore the authors have taken the position that the World Health Organization standards regarding community noise are irrelevant to their deliberation - a remarkable presumption.

There is no medical doubt that audible noise such as emitted by modern upwind industrial wind turbines sited close to human residences causes significant adverse health effects. These effects are mediated through sleep disturbance, physiological stress and psychological distress. This is settled medical science.

There are many peer-reviewed studies showing that infra and low frequency sound can cause adverse health effects, especially when dynamically modulated. Modern upwind industrial scale turbines of the types now being located in rural areas of North America require study. The extent to which infra and low frequency noise from wind turbines inside or outside homes causes direct adverse effects upon the human body remains an open question - there is no settled medical science on this issue as of yet.

Perhaps the most egregious conclusion is that no more research is required. That statement implies that the science is settled which quite simply is false. It also demonstrates a disdain for the scientific method itself.

There is but one conclusion: independent third party studies must be undertaken to establish the incidence and prevalence of adverse health effects relating to wind energy.

Wind Energy Industry Acknowledgement of Adverse Health Effects

Note any errors or omissions are unintentional
turbines. Beyond that a deeper understanding of the potential mechanisms for the impacts must be elucidated in order to define the mechanisms by which the sleep disturbance, stress and psychological distress occur.

In contrast to the statement of the A/CanWEA Panel Review, our view is that a great deal of research is required for the protection of people's health.

EXECUTIVE SUMMARY

The conclusions of the A/CanWEA Panel Review are not supported by its own contents nor does it have convergent validity with relevant literature.

The A/CanWEA Panel Review acknowledges that wind turbine noise may cause annoyance, stress and sleep disturbance and that as a result people may experience adverse physiological and psychological symptoms. It then ignores the serious consequences.

World Health Organization identifies annoyance and sleep disturbance as adverse health effects.¹

In 2009 the World Health Organization released a peer reviewed summary of research regarding the risks to human health from noise induced sleep disturbance. Some of the adverse health effects documented include fatigue, memory difficulties, concentration problems, mood disorders, cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders, impaired immune system function and a reported increased risk of mortality to name a few.²

Health Canada acknowledges the health consequences of stress and considers it a to be a risk factor in a great many diseases, such as heart disease, some types of bowel disease, herpes, mental illness and difficulty for diabetics to control blood sugar. It states severe stress can cause biochemical changes in the body, affecting the immune system, which leaves the body vulnerable to disease.³

Despite the acknowledgement that wind turbine noise may cause annoyance, stress and sleep disturbance the A/CanWEA Panel Review fails to offer any science based guidelines that would mitigate these health risks.

On the contrary the A/CanWEA Panel Review concludes by suggesting that the authoritative health based noise guidelines of the World Health Organization should be ignored and that wind turbine noise limits be based on public policy.⁴

¹ World Health Organization, Guidelines for Community Noise, 1999
http://www.euro.who.int/mediacentre/PR/2009/20091008_1
www.euro.who.int/document/e92845.pdf
Wind Energy Industry Acknowledgement of Adverse Health Effects

Note any errors or omissions are unintentional
The A/CanWEA Panel Review concludes by stating that it does not “advocate for funding further studies.”

Others do not agree.

In November 2009 the Japanese Ministry of Environment announced a four year study into the effects of wind farms on health.

In September 2009 members of the Maine Medical Association passed a resolution which among other things calls for independent study and authoritative guidelines.

Preliminary findings of a controlled study (Mars Hill, Maine) being conducted by Dr. Michael Nissenbaum to investigate potential negative health effects concludes that adults living within 1100 meters of industrial wind turbines suffer high incidences of chronic sleep disturbances and headaches, among other somatic complaints, and high incidences of dysphoric psychiatric symptomatology, compared to a control group living 5000-6000 meters away. This controlled study is a work in progress.

The A/CanWEA Panel Review can only be viewed for what it is. It is an industry association convened and sponsored attempt to deny the adverse health effects being reported.

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6 http://www.yomiuri.co.jp/dy/national/20091129TDY02309.htm
7 Maine Medical Association Resolution re Wind Energy and Public Health September 2009
8 http://windvigilance.com/mars_hill.aspx

Wind Energy Industry Acknowledgement of Adverse Health Effects

Note any errors or omissions are unintentional
SUMMARY OF FINDINGS

The A/CanWEA Panel Review:

- appears to value quantity over quality – it consists largely of filler material including 22 of 85 pages (26%) blank or title pages.
- is not a study: it is an incomplete literature review.
- was prepared for and sponsored by AWEA and CanWEA which raises questions about its objectivity.
- displays selective bias favouring the positions of AWEA and CanWEA in the presentation of the referenced material.
- displays selective bias favouring the positions of AWEA and CanWEA by omission of relevant references.
- displays a negative bias regarding references that do not favour the interest of the AWEA and CanWEA.
- misquotes references.
- contains incomplete risk assessments related to health.
- contains misleading statements.
- contains statements without appropriate supporting references.
- contains conclusions which are not supported by cited references.
- ignores the authoritative research and noise guidelines of the World Health Organization.
- contains pre-emptive stereotyping of those who have concerns about health risks associated with wind turbine facilities. Terms such as “detractors” and “opponents” are used. This pre-emptive stereotyping extends to concerned medical professionals who are calling for authoritative guidelines designed to protect human health. This pre-emptive stereotyping dismisses the claim that the panel is independent and unbiased.
Wind Energy Industry Acknowledgement of Adverse Health Effects

Part 2 Detailed Analysis


Prepared by
The Society for Wind Vigilance

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January 2010*

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John Harrison, PhD

* Appended January 18, 2009 to include document production details and pagination.
Note: the contents of this analysis have not been altered.
Table 1
Analysis

A/CanWEA Panel Review contents in non bold quotations

*The Society for Wind Vigilance* analysis in bold italicized

Note any errors or omissions are unintentional.

Notice to Reader

The analysis contained in this table is not intended be exhaustive and does not address all the inadequacies contained in the A/CanWEA Panel Review.

| Title Page | “Prepared for: American Wind Energy Association and Canadian Wind Energy Association”

*Industry trade associations convening and sponsoring a literature review cannot be considered independent or unbiased.*

*This approach is reminiscent of the now discredited “Tobacco Industry Research Committee” created in the 1950’s and sponsored by the tobacco industry.*


| ES1 | “Wind energy enjoys considerable public support, but it also has its detractors, who have publicized their concerns that the sounds emitted from wind turbines cause adverse health consequences.”

*The A/CanWEA Panel Review uses biased pre-emptive stereotyping by labelling individuals or groups who have concerns about the adverse effects from exposure to industrial wind turbines as “detractors”. The pre-emptive stereotyping attempts to invalidate legitimate concerns at the onset.*

*Detractor is defined as “somebody who disparages or devalues somebody or something”.*


*This pre-emptive stereotyping extends to concerned medical professionals such as members of the Maine Medical Association who have passed a resolution calling for independent research and the development of authoritative wind turbine guidelines designed to protect human health.*
**Table 1**

**Analysis**

A/CanWEA Panel Review contents in non bold quotations

The Society for Wind Vigilance analysis in bold italicized

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<table>
<thead>
<tr>
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<td><strong>This pre-emptive stereotyping dismisses the claim that the panel is independent and unbiased.</strong></td>
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</table>
| “Following review, analysis, and discussion of current knowledge, the panel reached consensus on the following conclusions:  
• There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.  
• The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.  
• The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel’s experience with sound exposures in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences.” |
| **The contents of the A/CanWEA Panel Review do not support these statements. See discussion on pages 5-1 and 5-2.** |

<table>
<thead>
<tr>
<th>2-1</th>
<th>Methodology</th>
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<tr>
<td><strong>2.1 Formation of Expert Panel</strong></td>
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<tr>
<td>“The American and Canadian wind energy associations, AWEA and CanWEA, assembled a distinguished panel of independent experts to address concerns that the sounds emitted from wind turbines cause adverse health consequences.”</td>
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<tr>
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<th>2.2 Review of Literature Directly Related to Wind Turbines</th>
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<tr>
<td>“The panel conducted a search of Pub Med under the heading “Wind Turbines and Health Effects” to research and address peer-reviewed literature. In addition, the panel conducted a search on “vibroacoustic disease.” The reference section identifies the peer and non-peer reviewed sources that were consulted by the panel.”</td>
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<td><strong>A/CanWEA Panel Review contents in non bold quotations</strong></td>
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</table>

The search criteria used in the report is very limited and limiting.

For example, additional searches should have included relevant headings such “wind turbines and adverse health effects”, “noise”, “annoyance”, “low frequency noise”, “stress”, “sleep disturbance” and “flicker” to name a few obvious omissions.

The A/CanWEA Panel Review is not comprehensive as it did not consider other environmental exposures associated with wind turbine operations such as safety, visual acceptability, electromagnetic pollution and visual interference or flicker.

The A/CanWEA Panel Review is an incomplete literature review.

2-2

“The reference section identifies the peer and non-peer reviewed sources that were consulted by the panel.”

The A/CanWEA Panel Review presents peer and non peer reviewed sources but displays selective bias regarding sources which do not support the conclusions of the report.

Many relevant and authoritative sources have not been cited or discussed in the A/CanWEA Panel Review.

See discussion regarding page 6-1.

2-1

2.3 Review of Potential Environmental Exposures

“The panel conducted a review of potential environmental exposures associated with wind turbine operations, with a focus on low frequency sound, infrasound, and vibration.”

The A/CanWEA Panel Review was not comprehensive as it ignored other environmental exposures associated with wind turbine operations such safety, visual acceptability, electromagnetic pollution and visual interference or flicker.

In summary the A/CanWEA Panel Review is an incomplete literature review.

3-12 to 3-14

3.3 Potential Adverse Effects of Exposure to Sound

The A/CanWEA Panel Review displays selective bias in citing noise limits from various references regarding potential adverse effects of exposure to sound (sections 3.3.1-3.3.5).
The A/CanWEA Panel Review cites selective noise limits which are consistently higher than the authoritative health based noise guidelines of the World Health Organization.

3.3.1 Speech Interference

“Levels below 45 dBA can be considered irrelevant with respect to speech interference.”

The A/CanWEA Panel Review displays selective bias by citing a level of 45dBA.

World Health Organization guidelines indicates a level of 35 LAeq[dB] to protect speech intelligibility and moderate annoyance, daytime and evening (Guidelines For Community Noise 1999)

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Note: an increase of 10 dBA is a 10-fold increase in acoustic energy.

3.3.2 Noise-Induced Hearing Loss

“Regulatory (OSHA, 1983) and advisory (NIOSH, 1998) authorities in the U.S. concur that risk of NIHL begins at about 85 dBA”

The A/CanWEA Panel Review displays selective bias by citing a level of 85dBA.

World Health Organization guidelines recommend a level of 70 LAeq [dB] to protect against hearing impairment in industrial, commercial, shopping and traffic areas, indoors and outdoors (Guidelines For Community Noise 1999)

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Note an increase of 10 dBA is a 10-fold increase in acoustic energy.

3.3.3 Task Interference

“Levels below 70 dBA do not result in task interference.”

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World Health Organization guidelines recommend a level of 35 LAeq [dB] to protect disturbance of information extraction (e.g. comprehension and reading acquisition). (Guidelines For Community Noise 1999)

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Note an increase of 10 dBA is a 10-fold increase in acoustic energy.

3.3.4 Annoyance

“It is important to note that although annoyance may be a frustrating experience for people, it is not considered an adverse health effect or disease of any kind.”

The A/CanWEA Panel Review displays selective bias by ignoring the adverse health effect of noise induced annoyance.

Health Canada states in their publication “It’s Your Health”:

“The most common effect of community noise is annoyance, which is considered an adverse health effect by the World Health Organization.”

http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/life-vie/community-urbain-eng.php#he

World Health Organization states:

“The range of health effects of noise is wide. They include pain and hearing fatigue, hearing impairment including tinnitus, annoyance...”

http://www.euro.who.int/Noise/activities/20021203_2

“Sleep disturbance and annoyance are the first effects of night noise and can lead to mental disorders.”
The effects of noise can even trigger premature illness and death.”

http://www.euro.who.int/mediacentre/PR/2009/20091008_1

W. David Colby, M.D., one of the authors or the A/CanWEA Panel Review, described the consequence of wind turbines induced annoyance when he publicly stated:

“We’re not denying that there are people annoyed and that maybe some of them are getting stressed out enough about being annoyed that they’re getting sick.”

W. David Colby, M.D, Sounding Board, 97.9 FM The Beach December 17, 2009

The A/CanWEA Panel Review ignores the serious risk to human health that annoyance and stress may cause.

According to Health Canada:

“...stress is considered to be a risk factor in a great many diseases, including:
• heart disease
• some types of bowel disease
• herpes
• mental illness
Stress also makes it hard for people with diabetes to control their blood sugar.
Stress is also a risk factor in alcohol and substance abuse, as well as weight loss and gain. Stress has even been identified as a possible risk factor in Alzheimer’s Disease. Severe stress can cause biochemical changes in the body, affecting the immune system, leaving your body vulnerable to disease.”


“Noise from airports, road traffic, and other sources (including wind turbines) may annoy some people, and, as described in Section 4.1, the louder the noise, the more people may become annoyed.”

The A/CanWEA Panel Review ignores the risk to human health from
"Noise from airports, road traffic, and other sources (including wind turbines).

**World Health Organization states:**

> "The effects of noise can even trigger premature illness and death. Night noise from aircraft can increase blood pressure, even if it does not wake people. Noise is likely to be more harmful when people are trying to fall asleep and awaken. Recent studies show that aircraft noise in the early morning is the most harmful in increasing the heart rate."

> "Nuisance at night can lead to an increase in medical visits and spending on sleeping pills, which affects families’ budgets and countries’ health expenditure."


3.3.5 Sleep Disturbance

"DNL is a 24-hour average that gives 10 dB extra weight to sounds occurring between 10p.m. and 7 a.m., on the assumption that during these sleep hours, levels above 35 dBA indoors may be disruptive."

**While the A/CanWEA Panel Review acknowledges “... levels above 35 dBA indoors may be disruptive”** it cites a 1974 document without citing WHO (1999).

**World Health Organization guidelines recommend a level of 30 LAeq [dB] indoors to protect against sleep disturbance and when the noise is composed of a large proportion of low-frequency sounds a still lower guideline value is recommended, because low frequency noise (e.g. from ventilation systems) can disturb rest and sleep even at low sound pressure levels. (Guidelines For Community Noise 1999)**

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

**Note an increase of 10 dBA is a 10-fold increase in acoustic energy.**

**World Health Organization “Night Noise Guidelines for Europe” 2009 states:**
“For the primary prevention of subclinical adverse health effects related to night noise in the population, it is recommended that the population should not be exposed to night noise levels greater than 40 dB of Lnight, outside during the part of the night when most people are in bed. The LOAEL of night noise, 40 dB Lnight, outside, can be considered a health-based limit value of the night noise guidelines (NNG) necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

The A/CanWEA Panel Review ignores the serious adverse health consequences from noise induced sleep disturbance.

**World Health Organization states:**

“Recent research clearly links exposure to night noise with harm to health. Noise can aggravate serious health problems, beyond damage to hearing, particularly through its effects on sleep and the relations between sleep and health.”


**World Health Organization “Night Noise Guidelines for Europe” 2009 states:**

“There is plenty of evidence that sleep is a biological necessity, and disturbed sleep is associated with a number of health problems. Studies of sleep disturbance in children and in shift workers clearly show the adverse effects.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

According to World Health Organization some of the documented health related consequences of sleep debt include poor
A/CanWEA Panel Review contents in non bold quotations

The Society for Wind Vigilance analysis in bold italicized

Note any errors or omissions are unintentional.

- performance at work, fatigue, memory difficulties, concentration problems, motor vehicle accidents, mood disorders (depression, anxiety), alcohol and other substance abuse, cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders, obesity, impaired immune system function and a reported increased risk of mortality.

  _World Health Organization “Night Noise Guidelines for Europe” 2009_

  (Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

3.3.6 Other Adverse Health Effects of Sound

The A/CanWEA Panel Review displays selective bias by attempting to understate the risk of noise induced chronic health problems such as hypertension and heart disease. The A/CanWEA Panel Review selectively quotes references, many of which are decades old to understate this risk.

World Health Organization states:

  “Recent research clearly links exposure to night noise with harm to health. Noise can aggravate serious health problems, beyond damage to hearing, particularly through its effects on sleep and the relations between sleep and health. When people are asleep, their ears, brains and bodies continue to react to sounds. Sleep disturbance and annoyance are the first effects of night noise and can lead to mental disorders.

  The effects of noise can even trigger premature illness and death. Night noise from aircraft can increase blood pressure, even if it does not wake people.”


World Health Organization “Night Noise Guidelines for Europe” 2009 states

  “Above 55 dB The situation is considered increasingly dangerous for public health. Adverse health effects occur...”
frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

The A/CanWEA Panel Review assumes people are inside their homes 24 hours a day with doors and windows shut. This is inaccurate.

Families are entitled to work, play and enjoy all areas of their property. Infants, children, adults and seniors risk being exposed to wind turbine outdoor noise levels much higher than the guidelines allow for noise receptors (homes).

Modern wind turbines emit 100 to 110 dBA Sound Power Level. Unweighted Sound Power Levels which are seldom reported are 120 dB or higher. Additional turbines result in higher combined sound pressure levels. Typically noise guidelines for wind turbines provide no protection for humans outside of their home. In Ontario it is allowable for multiple wind turbines to be sited within 50 meters (blade length plus 10 meters) of a non participant’s property line. As an example on a one hundred acre parcel of land it is possible for individuals to be exposed on their property to wind turbine sound pressure levels which may cause speech interference, task interference, annoyance and other adverse health effects of sound. (previously referenced above section 3.3)

The A/CanWEA Panel Review ignores this environmental exposure and the associated risks to human health.

In summary:

Wind turbines emit industrial noise pollution. Wind turbine “noise is a primary siting constraint”.


(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)
<table>
<thead>
<tr>
<th>A/CanWEA Panel Review Page Reference</th>
<th>Table 1 Analysis</th>
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<tbody>
<tr>
<td>The A/CanWEA Panel Review displays selective bias by understating the risk of adverse health effects from environmental noise.</td>
<td></td>
</tr>
<tr>
<td>The A/CanWEA Panel Review displays selective bias by consistently ignoring the recommendations and guidance of the World Health Organization on the issue of noise and health. (see discussion regarding World Health Organization page 4-13)</td>
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<tr>
<td>3-14</td>
<td>&quot;On the other hand, many people become accustomed to regular exposure to noise or other potential stressors, and are no longer annoyed.&quot;</td>
</tr>
<tr>
<td>This A/CanWEA Panel Review statement is false.</td>
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<tr>
<td>World Health Organization states</td>
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<tr>
<td>“During sleep the auditory system remains fully functional. Incoming sounds are processed and evaluated and although physiological changes continue to take place, sleep itself is protected because awakening is a relatively rare occurrence. Adaptation to a new noise or to a new sleeping environment (for instance in a sleep laboratory) is rapid, demonstrating this active protection. The physiological reactions do not adapt, as is shown by the heart rate reaction and the increase of average motility with sound level.”</td>
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<tr>
<td>World Health Organization “Night Noise Guidelines for Europe” 2009</td>
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<tr>
<td>(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)</td>
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<tr>
<td>3-17</td>
<td>3.4.3 Low-Frequency Sound and Infrasound</td>
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<tr>
<td>“No scientific studies have specifically evaluated health effects from exposure to low frequency sound from wind turbines.”</td>
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<tr>
<td>The absence of scientific studies does not imply that health effects from exposure to low frequency sound from wind turbines do not occur - it implies scientific uncertainty and the requirement for third party independent health studies.</td>
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</table>
There is no medical doubt that audible noise such as emitted by modern upwind industrial wind turbines sited close to human residences causes significant adverse health effects. These effects are mediated through sleep disturbance, physiological stress and psychological distress. This is settled medical science.

Sound energy in the infra and low frequency range may also be a factor for other adverse health effects. Although these sounds may be sub-audible to all but the most sensitive people, others may perceive it as internal body sensations. This is compounded indoors, because the sound pressure levels inside homes may be augmented by building resonance and harmonics. This can result in a larger percentage of the general population that may perceive the sound or vibration in their body or home, and stronger effects on those who responded without such augmentation. It can also result in perceptible audible noise to people who may not have perceived the sounds outdoors or in another building with different resonance characteristics.

The extent to which infra and low frequency noise from wind turbines inside or outside homes causes direct adverse effects upon the human body remains an open question - there is no settled medical science on this issue as yet.

“Natural sources of low frequency sound include wind, rivers, and waterfalls in both audible and non-audible frequencies. Other sources include road traffic, aircraft, and industrial machinery. The most common source of infrasound is vehicular (National Toxicology Program, 2001).”

This statement is misleading. There are references that wind turbine low frequency noise is unique.

Alberts, D. 2006. Primer for Addressing Wind Turbine Noise states:

“Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise.”

(Note: this reference is listed in Additional References but the citation was neglected in the main body of the A/CanWEA Panel Review)

Soysai, H., and O. Soysai. Wind farm noise and regulations in the
The Society for Wind Vigilance analysis in bold italicized

Note any errors or omissions are unintentional.

eastern United States. 2007 states:

“Sound generated by wind turbines has particular characteristics and it creates a different type of nuisance compared to usual urban, industrial, or commercial noise. The interaction of the blades with air turbulences around the towers creates low frequency and infrasound components, which modulate the broadband noise and create fluctuations of sound level. The lower frequency fluctuation of the noise is described as ‘swishing’ or ‘whooshing’ sound, creating an additional disturbance due to the periodic and rhythmic characteristic.”

(Note: this applies to the lower frequency fluctuation of sound of modern upwind industrial scale wind turbines. This reference is listed in Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

“The U.S. Food and Drug Administration (FDA) has approved the use of infrasound for therapeutic massage at 70 dB in the 8 to 14 Hz range (National Toxicology Program, 2001). In light of the FDA approval for this type of therapeutic use of infrasound, it is reasonable to conclude that exposure to infrasound in the 70 dB range is safe.”

This A/CanWEA Panel Review conclusion has no reference to support it.

A therapeutic device would likely have operating instructions and guidance.

The product website states:

“…it should not be used within six inches of a pacemaker, and should not be used on the calves where blood clots are suspected.”

“Therapy on the developing fetus has not been studied, we do not recommend applying it directly over the developing fetus.”

http://www.chinahealthways.com

3-15 3-16 3.4.1 Evaluation of Annoyance and Dose-Response Relationship of Wind Turbine Sound
“To date, three studies in Europe have specifically evaluated potential health effects of people living in proximity to wind turbines (Pedersen and Persson Waye, 2004; Pedersen and Persson Waye, 2007; Pedersen et al., 2009).”

This A/CanWEA Panel Review statement is misleading as none of the three studies cited were specifically designed to “specifically” evaluate potential adverse health effects. The studies were very specific in scope as noted below:

Project WINDFARMperception Visual and acoustic impact of wind turbine farms on residents Pedersen et al., 2008 states:

“The purpose of this study is to gain insight into the perception of a modern wind farm by residents living nearby such a farm. The objective of the WINDFARMperception project is:
- to provide knowledge on the perception of wind turbines by people living close to windfarms;
- to evaluate human responses to audio and visual exposures from wind turbines and to give insight in possibilities to mitigate the local impact of wind farms.”

Pedersen, E. and K. Persson Waye. 2007. Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments states:

“The objectives of this study were to evaluate the prevalence of perception and annoyance due to wind turbine noise among people living in the vicinity of one or more turbines, and to study relationships between noise and perception/annoyance with focus on differences between different living environments.”

Perception and annoyance due to wind turbine noise—a dose–response relationship Eja Pedersen and Kerstin Persson Waye 2004 states

“The aims of this study were to evaluate the prevalence of annoyance due to wind turbine noise and to study dose–response relationships. The intention was also to look at interrelationships between noise annoyance and sound characteristics, as well as the influence of subjective
variables such as attitude and noise sensitivity.”

The three studies cited documented high annoyance and sleep disturbance associated with wind turbines.

The A/CanWEA Panel Review fails to note that:

Project WINDFARMperception Visual and acoustic impact of wind turbine farms on residents Pedersen et al., 2008 concludes:

“With respect to other health effects associated with wind turbines:

- The risk for sleep interruption by noise was higher at levels of wind turbine sound above 45 dBA than at levels below 30 dBA.
- Annoyance with wind turbine noise was associated with psychological distress, stress difficulties to fall asleep and sleep interruption.”

The A/CanWEA Panel Review fails to note that:

Perception and annoyance due to wind turbine noise—a dose–response relationship Eja Pedersen and Kerstin Persson Waye 2004 states:

“At lower sound categories, no respondents were disturbed in their sleep by wind turbine noise, but 16% (n=520, 95%CI: 11%–20%!) of the 128 respondents living at sound exposure above 35.0 dBA stated that they were disturbed in their sleep by wind turbine noise.”

“Some of the respondents also stated that they were disturbed in their sleep by wind turbine noise, and the proportions seemed to increase with higher SPL. The number of respondents disturbed in their sleep, however, was too small for meaningful statistical analysis, but the probability of sleep disturbances due to wind turbine noise can not be neglected at this stage.”

The A/CanWEA Panel Review ignores that:

Regarding:

Pedersen, E. and K. Persson Waye. 2007. Wind turbine
noise, annoyance and self-reported health and wellbeing in different living environments:

Table 1, contained in the report, indicates the mean SPL for respondents was 33.4 dBA which is far lower than the wind turbine SPL that many families are being subjected to.

In an interview with A/CanWEA Panel Review author Dr. Robert McCunney states:

“... the existing peer-reviewed literature generally examined exposure to sounds from homes or residential areas that are about one kilometre away or further from wind turbines.”

Canwest News Service December 16, 2009

In North America many turbines have been sited less than 400 metres from homes. New set back guidelines in Ontario allow for multiple turbines within 550 meters of a home.

The A/CanWEA Panel Review displays selective bias by omitting to discuss the significance of the typical setback distances and sound power levels in the references cited.

The report found that:

“Annoyance was further associated with lowered sleep quality and negative emotions. This, together with reduced restoration possibilities may adversely affect health.”

The A/CanWEA Panel Review displays selective bias by omitting sleep disturbance, annoyance, stress, and negative emotions (adverse psychological effects) reported by the references used by the Panel.

“Although some people may be affected by annoyance, there is no scientific evidence that noise at levels created by wind turbines could cause health problems”

The A/CanWEA Panel Review displays selective bias by concluding with a citation from a 2003 reference when subsequent references by the same author, Eja Pedersen, state in 2004, 2007 and 2008:

“Some of the respondents also stated that they were
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**disturbed in their sleep by wind turbine noise, and the proportions seemed to increase with higher SPL. The number of respondents disturbed in their sleep, however, was too small for meaningful statistical analysis, but the probability of sleep disturbances due to wind turbine noise can not be neglected at this stage.”**

*Perception and annoyance due to wind turbine noise—a dose–response relationship Eja Pedersen and Kerstin Persson Waye 2004*

“One annoyance was further associated with lowered sleep quality and negative emotions. This, together with reduced restoration possibilities may adversely affect health.”

*Pedersen, E. and K. Persson Waye. 2007. Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments*

“With respect to other health effects associated with wind turbines:
- The risk for sleep interruption by noise was higher at levels of wind turbine sound above 45 dBA than at levels below 30 dBA.
- Annoyance with wind turbine noise was associated with psychological distress, stress difficulties to fall asleep and sleep interruption.”

*Project WINDFARMperception Visual and acoustic impact of wind turbine farms on residents Pedersen et al., 2008*

“Perhaps the main finding is that wind turbine sound is relatively annoying, more so than equally loud sound from aircraft or road traffic. A swishing character is perceived by most respondents, indicating that this is an important characteristic of wind turbine sound. Sound should therefore receive more attention in the planning of wind farms, and (more) sound mitigation measures must be considered.”

*The A/CanWEA Panel Review displays selective bias by omitting*
**Table 1**

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**this citation which recommends “additional sound mitigation measures be considered.”** The A/CanWEA Panel Review ignores this recommendation in section 4.6.3 Wind Turbine Siting Guidelines (see discussion regarding pages 4-13 to 4-15)

**There are other relevant findings in these three studies cited which the A/CanWEA Panel Review neglected to discuss or reference.**

<table>
<thead>
<tr>
<th>3-17</th>
<th>“According to a report of the National Research Council (NRC), low frequency sound is a concern for older wind turbines but not the modern type (National Research Council, 2007).”</th>
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<tbody>
<tr>
<td><strong>This statement contained in the A/CanWEA Panel Review is misquoted.</strong></td>
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<tr>
<td><strong>According to “Public Health Impacts of Wind Turbines” Prepared by: Minnesota Department of Health Environmental Health Division, 2009</strong></td>
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<tr>
<td>“The National Research Council of the National Academies (NRC, 2007) has reviewed impacts of wind energy projects on human health and well-being. The NRC begins by observing that wind projects, just as other projects, create benefits and burdens, and that concern about impacts is natural when the source is near one’s home. Further, the NRC notes that different people have different values and levels of sensitivity. Impacts noted by the NRC that may have the most effect on health include noise and low frequency vibration, and shadow flicker.”</td>
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<tr>
<td><strong>This citation states:</strong></td>
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<tr>
<td>“Broadband, tonal, and low-frequency noise have all been addressed to some degree in modern upwind horizontal wind turbines, and turbine technologies continue to improve in this regard.”</td>
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<tr>
<td><strong>The qualification that “Broadband, tonal, and low-frequency noise have all been addressed to some degree” suggests there are still low-frequency noise issues with modern turbines. This”</strong></td>
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qualification contradicts the A/CanWEA Panel Review statement.

“According to a report of the National Research Council (NRC), low frequency sound is a concern for older wind turbines but not the modern type (National Research Council, 2007).”

This is confirmed on page 4-1 of the A/CanWEA Panel Review where it is acknowledged that:

“The low frequency sound emitted by spinning wind turbines could possibly be annoying to some…”

The A/CanWEA Panel Review displays selective bias by omitting the following passages from the National Research Council draft cited:

“Low-frequency vibration and its effects on humans are not well understood. Sensitivity to such vibration resulting from wind-turbine noise is highly variable among humans. Although there are opposing views on the subject, it has recently been stated (Pierpont 2006) that “some people feel disturbing amounts of vibration or pulsation from wind turbines, and can count in their bodies, especially their chests, the beats of the blades passing the towers, even when they can’t hear or see them.” More needs to be understood regarding the effects of low-frequency noise on humans.”

“Guidelines for measuring noise produced by wind turbines are provided in the standard, IEC 61400-11: Acoustic Noise Measurement Techniques for Wind Turbines (IEC 2002), which specifies the instrumentation, methods, and locations for noise measurements. Wind-energy developers are required to meet local standards for acceptable sound levels; for example, in Germany, this level is 35 dB(A) for rural nighttime environments.”

“Noise-emission measurements potentially are subject to problems, however. A 1999 study involving noise-measurement laboratories from seven European countries found, in measuring noise emission from the same 500 kW wind turbine on a flat terrain, that while apparent sound power levels and wind speed dependence could be measured reasonably reliably, tonality measurements were...
much more variable (Kragh et al. 1999.) In addition, methods for assessing noise levels produced by wind turbines located in various terrains, such as mountainous regions, need further development.”

“Shadow flicker caused by wind turbines can be an annoyance, and its effects need to be considered during the design of a wind-energy project. In the United States, shadow flicker has not been identified as even a mild annoyance. In Northern Europe, because of the higher latitude and the lower angle of the sun, especially in winter, shadow flicker has, in some cases, been noted as a cause for concern.”

“Recent research studies regarding noise from wind-energy projects suggest that the industry standards (such as the IEC 61400-11 guidelines) for assessing and documenting noise levels emitted may not be adequate for nighttime conditions and projects in mountainous terrain. This work on understanding the effect of atmospheric stability conditions and on site-specific terrain conditions and their effects on noise needs to be accounted for in noise standards. In addition, studies on human sensitivity to very low frequencies are recommended. Computational tools have become available that not only compute shadow flicker in real time during turbine operation, but also convey information to the turbine-control system to allow shutdown if the shadow flicker at a particular location becomes particularly problematic. Hence, the development and implementation of a real-time system at a wind-energy project to take such actions when shadow flicker is indicated might be useful.”

4.1 Infrasound, Low-Frequency Sound, and Annoyance

“The infrasound emitted from wind turbines is at a level of 50 to 70 dB, sometimes higher, but well below the audible threshold. There is a consensus among acoustic experts that the infrasound from wind turbines is of no consequence to health.”

*The NASA Technical paper* “Wind Turbine Acoustics” *states:*

“People who are exposed to wind turbine noise inside buildings experience a much different acoustic environment*
than do those outside…. They may actually be more
disturbed by the noise inside their homes than the would be
outside.”

*The paper also states:*

“One of the common ways that a person might sense the
noise-induced excitation of a house is through structural
vibrations. This mode of observation is particularly
significant at low frequencies, below the threshold of normal
hearing.”

“The low frequency sound emitted by spinning wind turbines could
possibly be annoying to some when winds are unusually turbulent, but
there is no evidence that this level of sound could be harmful to health.”

**Public Health Impacts of Wind Turbines**
**Prepared by: Minnesota Department of Health**
**Environmental Health Division states:**

“Wind turbines generate a broad spectrum of low-intensity
noise. At typical setback distances higher frequencies are
attenuated. In addition, walls and windows of homes
attenuate high frequencies, but their effect on low
frequencies is limited.”

“The most common complaint in various studies of wind
turbine effects on people is annoyance or an impact on
quality of life. Sleeplessness and headache are the most
common health complaints and are highly correlated (but
not perfectly correlated) with annoyance complaints.
Complaints are more likely when turbines are visible or
when shadow flicker occurs.”

“Most available evidence suggests that reported health
effects are related to audible low frequency noise.
Complaints appear to rise with increasing outside noise
levels above 35 dB(A).”

*Alberts, D. 2006. Primer for Addressing Wind Turbine Noise states:*

“For broadband noise, such as wind turbines produce, the
low frequency components may travel further than the
higher frequency components. Since low-frequency noise is
particularly annoying to most people, it is important to specify limits for low frequency noise.”

“Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise. Light weight building home structures will not attenuate these frequencies components as well as higher frequency components.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Incorporating Low Frequency Noise Legislation for the Energy Industry in Alberta, Canada Authors: DeGagne, David C.; Lapka, Stephanie D states:

“Complaints related to LFN are often described by the affected party as a deep, heavy sound, like “humming,” sometimes with an accompanying vibration. In some cases, the direction of the source of the LFN will be unknown to the receptor. However, it is the complainant that is most able to detect the presence of the LFN, signifying a particular sensitivity of the individual to the sound while others in the same family may not be able to detect the sound at all. To make a proper determination for the presence of LFN, the data must be collected during a time when environmental conditions are representative of when the sound is annoying. Residents who are impacted by LFN may suffer from sleep disturbances, headaches, and in some cases chronic fatigue.”

“Unlike higher frequency noise issues, LFN is very difficult to suppress. Closing doors and windows in an attempt to diminish the effects sometimes makes it worse because of the propagation characteristics and the low-pass filtering effect of structures. Individuals often become irrational and anxious as attempts to control LFN fail, serving only to increase the individual’s awareness of the noise, accelerating the above symptoms.”

World Health Organization, Guidelines for Community Noise, 1999 states
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“Health effects due to low-frequency components in noise are estimated to be more severe than for community noises in general”

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

“If so, city dwelling would be impossible due to the similar levels of ambient sound levels normally present in urban environments. Nevertheless, a small number of people find city sound levels stressful.”

This A/CanWEA Panel Review conclusion does not appear to be based on scientific evidence. The conclusion there are no adverse health effects from noise on the basis that people are able live in cities ignores the ample evidence that environmental noise is a risk to human health.

World Health Organization states:

“Just like air pollution and toxic chemicals, noise is an environmental hazard to health. While almost everyone is exposed to too much noise, it has traditionally been dismissed as an inevitable fact of urban life and has not been targeted and controlled as much as other risks,” concludes Dr Rokho Kim of the WHO Regional Office for Europe, who managed the project to draw up the guidelines.

“We hope that the new guidelines will create a culture of noise awareness, and prompt governments and local authorities to invest effort and money in protecting health from this growing hazard, particularly in cities.”

http://www.euro.who.int/mediacentre/PR/2009/20091008_1

“Noise seriously harms human health and interferes with people’s daily activities at school, at work, at home and during leisure time. Traffic noise alone is harming the health of almost every third European. One in five Europeans is regularly exposed to sound levels at night that could significantly damage health.”

http://www.euro.who.int/Noise

4-3 “The main health effect of noise stress is disturbed sleep, which may
lead to other consequences.”

“There is no evidence that sound at the levels from wind turbines as heard in residences will cause direct physiological effects. A small number of sensitive people, however, may be stressed by the sound and suffer sleep disturbances.”

These A/CanWEA Panel Review statements are paradoxical. The statements acknowledge sleep disturbance(s) and stress may occur from wind turbine exposure. The second statement concludes there is no evidence direct physiological effects occur.

World Health Organization, Guidelines For Community Noise 1999 states:

Uninterrupted sleep is a prerequisite for good physiological and mental functioning, and the primary effects of sleep disturbance are: difficulty in falling asleep; awakenings and alterations of sleep stages or depth; increased blood pressure, heart rate and finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia; and increased body movements.

(Note this reference is listed in the References but this citation was neglected in the main body of the A/CanWEA Panel Review)

World Health Organization “Night Noise Guidelines for Europe” 2009 states:

“There is plenty of evidence that sleep is a biological necessity, and disturbed sleep is associated with a number of health problems.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

According to World Health Organization “Night Noise Guidelines for Europe” 2009:

Sleep documented health related consequences of sleep debt include poor performance at work, fatigue, memory difficulties, concentration problems, motor vehicle accidents, mood disorders.
(depression, anxiety), alcohol and other substance abuse, cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders, obesity, impaired immune system function and a reported increased risk of mortality among others.

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

The A/CanWEA Panel Review is silent on what scientific basis it came to the conclusion that only “A small number of sensitive people” may be “stressed by the sound and suffer sleep disturbances.”

The A/CanWEA Panel Review qualification that only a small number and only sensitive people will be adversely affected is not supported by any credible reference.

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<th>4-3 to 4-5</th>
<th>4.1.3 Other Aspects of Annoyance</th>
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<td>4.1.4 Nocebo Effect</td>
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<td>4.1.5 Somatoform Disorders</td>
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These sections of the A/CanWEA Panel Review are disturbing.

The A/CanWEA Panel Review acknowledges that wind turbine noise may cause annoyance, stress and sleep disturbance and that as a result people may experience adverse physiological and psychological symptoms.

One of the authors of the report W. David Colby, M.D. has stated:

“We’re not denying that there are people annoyed and that maybe some of them are getting stressed out enough about being annoyed that they’re getting sick.”

Sounding Board, 97.9 FM The Beach December 17, 2009

Despite these acknowledgements and without having studied victims the authors of the A/CanWEA Panel Review offer the Nocebo Effect and Somatoform Disorders as causal explanations for physiological and psychological symptoms being reported by clinicians such as Dr. Pierpont.

Without having studied victims, the A/CanWEA Panel Review
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<td><strong>speculates further that:</strong></td>
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<td>“Associated stress from annoyance, exacerbated by the rhetoric, fears, and negative publicity generated by the wind turbine controversy, may contribute to the reported symptoms described by some people living near rural wind turbines.”</td>
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<td><strong>There are people reporting adverse health effects from exposure to wind turbines. Families including children have abandoned their homes to protect their health. This cannot be denied.</strong></td>
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<td><strong>There are European peer review studies that have documented high annoyance and sleep disturbance in populations exposed to industrial wind turbines.</strong></td>
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<td><strong>A 2009 court decision requires a France industrial wind turbine facility to shut down at night to protect the local population from sleep disturbance.</strong></td>
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<td><strong>Clinicians and other researchers have documented victim symptoms and sleep disturbance which tends to be reported as the number one health complaint.</strong></td>
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<td></td>
<td><strong>The A/CanWEA Panel Review ignores the literature on the effects of annoyance, stress and sleep disturbance and the associated symptoms.</strong></td>
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<tr>
<td>4-8 4-11</td>
<td><strong>4.3 Wind Turbine Syndrome</strong></td>
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<tr>
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<td><strong>The A/CanWEA Panel Review does not deny there are victims experiencing symptoms from exposure to industrial wind turbines.</strong></td>
</tr>
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<td>“The symptoms are common in cases of extreme and persistent annoyance, leading to stress responses in the affected individual and may also result from severe tinnitus, when there is no external sound.”</td>
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<tr>
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<td><strong>The A/CanWEA Panel Review concludes</strong></td>
</tr>
<tr>
<td></td>
<td>“The symptoms are exhibited by a small proportion of sensitive...”</td>
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A/CanWEA Panel Review does not provide a credible reference for this statement.

4.6 Standards for Siting Wind Turbines

4.6.1 Introduction

“Opponents of wind energy development argue that the height and setback regulations established in some jurisdictions are too lenient and that the noise limits which are applied to other sources of noise (either industrial or transportation) are not sufficient for wind turbines for a variety of reasons.”

The A/CanWEA Panel Review uses biased pre-emptive stereotyping by labelling individuals or groups who have legitimate concerns about the adverse effects from exposure to industrial wind turbines as “opponents”. These pre-emptive stereotyping attempts to invalidate legitimate concerns at the onset.

This pre-emptive stereotyping extends to concerned medical professionals such as members of the Maine Medical Association who have passed a resolution calling for independent research and the development of authoritative wind turbine guidelines designed to protect human health.

This pre-emptive stereotyping dismisses the claim that the panel is independent and unbiased.

Preliminary findings of a controlled study (Mars Hill, Maine) being conducted by Dr. Michael Nissenbaum to investigate potential negative health effects concludes that adults living within 1100 meters of industrial wind turbines suffer high incidences of chronic sleep disturbances and headaches, among other somatic complaints, and high incidences of dysphoric psychiatric symptomatology, compared to a control group living 5000-6000 meters away.

Significantly, they require increased prescription medications to deal with these symptoms compared to the control group. Most symptomatology appears attributable to the quality and persistence of the noise generated by the turbine installations. Additional investigation of the children living in close proximity to industrial wind turbines is urgently needed. Improvements in pre-
construction sound modeling and siting ordinances are required to prevent the negative health effects observed in our study population. This is a work in progress.

http://windvigilance.com/mars_hill.aspx

The A/CanWEA Panel Review displays selective bias by failing to acknowledge that wind turbine noise is unique in character.

Alberts, D. 2006. Primer for Addressing Wind Turbine Noise states:

"Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise."

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Soysai, H., and O. Soysai. Wind farm noise and regulations in the eastern United States. 2007 states

"Sound generated by wind turbines has particular characteristics and it creates a different type of nuisance compared to usual urban, industrial, or commercial noise. The interaction of the blades with air turbulences around the towers creates low frequency and infrasound components, which modulate the broadband noise and create fluctuations of sound level. The lower frequency fluctuation of the noise is described as ‘swishing’ or ‘whooshing’ sound, creating an additional disturbance due to the periodic and rhythmic characteristic."

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Aero acoustics of large wind Turbines Harvey Hubbard Lockheed Engineering and Sciences Company, Kevin P Shepherd NASA

“There is a concern for the possible adverse environmental impact of noise from large horizontal axis wind turbines operated for electric power generation. Widespread deployment of such machines is anticipated in wind power
stations, some of which may be located in proximity to residential areas. Routine operations of such wind power stations may result in some unique community noise exposure situations.”

“Opponents of wind energy development argue that the height and setback regulations established in some jurisdictions are too lenient and that the noise limits which are applied to other sources of noise (either industrial or transportation) are not sufficient for wind turbines for a variety of reasons.”

The A/CanWEA Panel Review displays selective bias with this statement.

A European study concludes:

“Perhaps the main finding is that wind turbine sound is relatively annoying, more so than equally loud sound from aircraft or road traffic. A swishing character is perceived by most respondents, indicating that this is an important characteristic of wind turbine sound. Sound should therefore receive more attention in the planning of wind farms, and (more) sound mitigation measures must be considered.”

Project WINDFARMperception Visual and acoustic impact of wind turbine farms on residents Pedersen et al., 2008

“Consequently, there are those who advocate for a revision of the existing regulations for noise and setback pertaining to the siting of wind installations (Kamperman and James, 2009). Some have indicated their belief that setbacks of more than 1 mile may be necessary. While the primary purpose of this study was to evaluate the potential for adverse health effects rather than develop public policy, the panel does not find that setbacks of 1 mile are warranted.”

Note: the reference cited by the A/CanWEA Panel Review (Kamperman and James, 2009) should be dated (Kamperman and James, 2008).

This A/CanWEA Panel Review statement is ambiguous. The impression is the A/CanWEA Panel Review favours set backs based on public policy over those designed to protect humans from adverse health effects.
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<td>4-13 to 4-15</td>
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4.6.3 Wind Turbine Siting Guidelines

*The A/CanWEA Panel Review does not deny there are victims experiencing adverse health effects from industrial wind turbines.*

One of the authors of the A/CanWEA Panel Review W. David Colby, M.D. reinforced this position regarding wind turbines by stating

> “We’re not denying that there are people annoyed and that maybe some of them are getting stressed out enough about being annoyed that they’re getting sick.”

*Sounding Board, 97.9 FM The Beach December 17, 2009*

*The A/CanWEA Panel Review acknowledges that wind turbine noise can cause annoyance, stress and sleep disturbance.*

*The A/CanWEA Panel Review acknowledges that these effects “may lead to other consequences”.*

*The A/CanWEA Panel Review acknowledges wind turbine low frequency noise can cause annoyance.*

Geoff Leventhall, one of the authors of the A/CanWEA Panel Review acknowledges the serious nature of low frequency noise induced annoyance by asserting:

> “The claim that their "lives have been ruined" by the noise is not an exaggeration…”

*Leventhall HG. Low frequency noise and annoyance. Noise Health 2004*

A European study concludes:

> “Perhaps the main finding is that wind turbine sound is relatively annoying, more so than equally loud sound from aircraft or road traffic. A swishing character is perceived by most respondents, indicating that this is an important characteristic of wind turbine sound. Sound should therefore receive more attention in the planning of wind farms, and (more) sound mitigation measures must be considered.”
Despite these acknowledgments, the A/CanWEA Panel Review neglects to advocate for authoritative regulations to mitigate the risk of adverse health effects.

The A/CanWEA Panel Review discusses random noise limits based on policy, not health protection.

The A/CanWEA Panel Review uses a draft report titled “Environmental Noise and Health in the UK.” to support that World Health Organization noise guidelines do not need to be followed:

“Surveys have shown that about half of the UK population lives in areas where daytime sound levels exceed those recommended in the WHO Community Noise Guidelines. About two-thirds of the population live in areas where the night-time guidelines recommended by WHO are exceeded.”

This statement does not stand up to scrutiny under a preventative health care model.

The A/CanWEA Panel Review ignores the serious nature of noise induced annoyance, stress and sleep disruption.

The inclusion of this section displays selective bias: it favours noise intensive industries such as industrial wind energy. The A/CanWEA Panel Review does not state reasons for including this section. It is an attempt to encourage authorities to circumvent the World Health Organizations noise guidelines which are designed to protect human health.

World Health Organization states

“Just like air pollution and toxic chemicals, noise is an environmental hazard to health. While almost everyone is exposed to too much noise, it has traditionally been dismissed as an inevitable fact of urban life and has not been targeted and controlled as much as other risks,” concludes Dr Rokho Kim of the WHO Regional Office for Europe, who managed the project to draw up the guidelines.

“We hope that the new guidelines will create a culture of noise awareness, and prompt governments and local
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<td>authorities to invest effort and money in protecting health from this growing hazard, particularly in cities.”</td>
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<tr>
<td>“…one in five Europeans is regularly exposed to sound levels at night that could significantly damage their health.”</td>
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<tr>
<td><a href="http://www.euro.who.int/Noise/activities/20040721_1">http://www.euro.who.int/Noise/activities/20040721_1</a></td>
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<tr>
<td>SECTION 5 Conclusions</td>
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<tr>
<td>“There is nothing unique about the sounds and vibrations emitted by wind turbines.”</td>
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<tr>
<td>This conclusion contradicts the content of the A/CanWEA Panel Review which acknowledges that wind turbine noise is complex due to infrasound, low frequency noise, broadband noise, and amplitude modulation.</td>
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<tr>
<td>The US Department of Energy states:</td>
<td></td>
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<tr>
<td>“Types of Wind Turbine Sound Wind turbines make different types of sound, including broadband, infrasonic, impulsive, and tonal sound.”</td>
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<td>The HCN (2004) states:</td>
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<td>“The Committee has identified a number of forms of noise that may have a particularly pronounced effect on people exposed to them:</td>
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<td>• Noise characterised by low-pitch components (buzzing)</td>
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<td>• Noise consisting entirely of one or more low buzzing sounds (low-frequency noise)</td>
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<tr>
<td>• Tonal noise</td>
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<tr>
<td>• Noise events characterised by a rapid increase in intensity at the beginning (impulse noise)</td>
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<tr>
<td>• Industrial noise</td>
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• Noise characterised by sporadic high LAmax or SEL values.”

Wind turbine noise is known to contain most if not all of these forms of noise.

Alberts, D. 2006. Primer for Addressing Wind Turbine Noise states:

“Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise.”

(Note this reference is listed in the Additional References but this citation was neglected in the main body of the A/CanWEA Panel Review)

Soysai, H., and O. Soysai. Wind farm noise and regulations in the eastern United States. 2007 states:

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“There is a concern for the possible adverse environmental impact of noise from large horizontal axis wind turbines operated for electric power generation. Widespread deployment of such machines is anticipated in wind power stations, some of which may be located in proximity to residential areas. Routine operations of such wind power stations may result in some unique community noise
“In conclusion:

1. Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effect in humans.

   **Conclusion 1 contradicts the A/CanWEA Panel Review which acknowledges that wind turbine noise may cause annoyance, stress and sleep disturbance and that as a result people may experience adverse physiological and psychological symptoms.**

2. Subaudible, low frequency sound and infrasound from wind turbines do not present a risk to human health.

   **Conclusion 2 contradicts the NASA Technical paper “Wind Turbine Acoustics” which states:**

   “People who are exposed to wind turbine noise inside buildings experience a much different acoustic environment than do those outside....They may actually be more disturbed by the noise inside their homes than the would be outside.”

   **The NASA Technical paper also states:**

   “One of the common ways that a person might sense the noise-induced excitation of a house is though structural vibrations. This mode of observation is particularly significant at low frequencies, below the threshold of normal hearing.”

   **Conclusion 2 contradicts the A/CanWEA Panel Review statement from page 4-1 which states:**

   “The low frequency sound emitted by spinning wind turbines could possibly be annoying to some...”

   **The World Health Organization acknowledges annoyance as an adverse health effect.**

   *World Health Organization Guidelines For Community Noise 1999*
Conclusion 2 contradicts the A/CanWEA Panel Review statement from page 4-10 which states that physiological and psychological symptoms caused by annoyance include:

“…distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, nose bleeds, palpitations, pressure in the ears or head, skin burns, stress, and tension…”

There is no medical doubt that audible noise such as emitted by modern upwind industrial wind turbines sited close to human residences causes significant adverse health effects. These effects are mediated through sleep disturbance, physiological stress and psychological distress. This is settled medical science.

Sound energy in the infra and low frequency range may also be a factor for other adverse health effects. Although these sounds may be sub-audible to all but the most sensitive people, others may perceive it as internal body sensations. This is compounded indoors, because the sound pressure levels inside homes may be augmented by building resonance and harmonics. This can result in a larger percentage of the general population that may perceive the sound or vibration in their body or home, and stronger effects on those who responded without such augmentation. It can also result in perceptible audible noise to people who may not have perceived the sounds outdoors or in another building with different resonance characteristics.

The extent to which infra and low frequency noise from wind turbines inside or outside homes causes direct adverse effects upon the human body remains an open question - there is no settled medical science on this issue as yet.

3. Some people may be annoyed at the presence of sound from wind turbines. Annoyance is not a pathological entity.

Conclusion 3 contradicts World Health Organization which acknowledges annoyance is an adverse health effect.

World Health Organization Guidelines For Community Noise 1999

Conclusion 3 contradicts the A/CanWEA Panel Review
Table 1
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statement from page 4-10 which states that physiological and psychological symptoms caused by annoyance include:

“…distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, nose bleeds, palpitations, pressure in the ears or head, skin burns, stress, and tension…”

4. A major cause of concern about wind turbine sound is its fluctuating nature. Some may find this sound annoying, a reaction that depends primarily on personal characteristics as opposed to the intensity of the sound level."

Conclusion 4 contradicts World Health Organization which acknowledges annoyance is an adverse health effect and states:

“The annoyance response to noise is affected by several factors, including the equivalent sound pressure level and the highest sound pressure level of the noise, the number of such events, and the time of day.”

World Health Organization Guidelines For Community Noise 1999

Conclusion 4 contradicts The A/CanWEA Panel Review statement from page 3-13 which states that noise levels directly impact annoyance

“Noise from airports, road traffic, and other sources (including wind turbines) may annoy some people, and, as described in Section 4.1, the louder the noise, the more people may become annoyed.”

Throughout the A/CanWEA Panel Review it is acknowledged that the wind turbine noise may cause annoyance, stress and sleep disturbance.

The A/CanWEA Panel Review does not deny there are victims experiencing adverse health effects from exposure to industrial wind turbines.

One of the authors of the report W. David Colby, M.D. has stated:
“We’re not denying that there are people annoyed and that maybe some of them are getting stressed out enough about being annoyed that they’re getting sick.”

Sounding Board, 97.9 FM The Beach December 17, 2009

World Health Organization states:

“Sleep disturbance and annoyance are the first effects of night noise and can lead to mental disorders. The effects of noise can even trigger premature illness and death.”

http://www.euro.who.int/mediacentre/PR/2009/20091008_1

The Society for Wind Vigilance Conclusion:

It is apparent from this analysis that the A/CanWEA Panel Review is neither authoritative nor convincing. The work is characterized by commission of unsupportable statements and the confirmation bias in the use of references. Many important references have been omitted and not considered in the discussion. Furthermore the authors have taken the position that the World Health Organization standards regarding community noise are irrelevant to their deliberation - a remarkable presumption.

There is no medical doubt that audible noise such as emitted by modern upwind industrial wind turbines sited close to human residences causes significant adverse health effects. These effects are mediated through sleep disturbance, physiological stress and psychological distress. This is settled medical science.

There are many peer-reviewed studies showing that infra and low frequency sound can cause adverse health effects, especially when dynamically modulated. Modern upwind industrial scale turbines of the types now being located in rural areas of North America require study. The extent to which infra and low frequency noise from wind turbines inside or outside homes causes direct adverse effects...
| A/CanWEA Panel Review Page Reference | Table 1 Analysis |
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| upon the human body remains an open question - there is no settled medical science on this issue as of yet. | |
| Perhaps the most egregious conclusion is that no more research is required. That statement implies that the science is settled which quite simply is false. It also demonstrates a disdain for the scientific method itself. | |
| There is but one conclusion: independent third party studies must be undertaken to establish the incidence and prevalence of adverse health effects relating to wind turbines. Beyond that a deeper understanding of the potential mechanisms for the impacts must be elucidated in order to define the mechanisms by which the sleep disturbance, stress and psychological distress occur. | |
| In contrast to the statement of the A/CanWEA Panel Review, our view is that a great deal of research is required for the protection of people’s health. | |
| The A/CanWEA Panel Review displays selective bias favouring the positions of CanWEA and AWEA by omitting relevant references. | |
| Examples of obvious omissions of the A/CanWEA Panel Review include the research conducted by Dr Amanda Harry (UK) or Dr Michael A. Nissenbaum (USA). Both are available on the web. | |
| The A/CanWEA Panel Review ignores that members of the Maine Medical Association passed a Resolution RE: Wind Energy and Public Health*: | |
| “work with health organizations and regulatory agencies to provide scientific information of known medical consequences of wind development in order to help safeguard human health and the environment; and to ‘work with other stakeholders to encourage performance of studies on health effects of wind turbine generation by independent qualified researchers at qualified research institutions’,” | |
| and to | |</p>
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“ensure that physicians and patients alike are informed of evidence-based research results.”

Preliminary findings of a controlled study (Mars Hill, Maine) being conducted by Dr. Michael Nissenbaum to investigate potential negative health effects concludes that adults living within 1100 meters of industrial wind turbines suffer high incidences of chronic sleep disturbances and headaches, among other somatic complaints, and high incidences of dysphoric psychiatric symptomatology, compared to a control group living 5000-6000 meters away.

Significantly, they require increased prescription medications to deal with these symptoms compared to the control group. Most symptomatology appears attributable to the quality and persistence of the noise generated by the turbine installations. Additional investigation of the children living in close proximity to industrial wind turbines is urgently needed. Improvements in pre-construction sound modeling and siting ordinances are required to prevent the negative health effects observed in our study population. This is a work in progress.

http://windvigilance.com/mars_hill.aspx

Other important references ignored by the A/CanWEA Panel Review include but are not limited to:

- “Minnesota Department of Health (MDH) 2009 Public Health Impacts of Wind Turbines”


- Noise Radiation From Wind Turbines Installed Near Homes: Effects On Health With an annotated review of the research and related issues by Barbara J Frey, BA, MA and Peter J Hadden, BSc, FRICS

- “Sleep Disturbance And Wind Turbine Noise” Dr Christopher Hanning BSc, MB, BS, MRCS, LRCP, FRCA, MD dated June 2009.
### Table 1
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<td>Alberts, D. 2006. Primer for Addressing Wind Turbine Noise.</td>
<td>6-8</td>
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The A/CanWEA Panel Review displays selective bias by neglecting to include this reference in the body of the report.

Relevant citations not cited in the A/CanWEA Panel Review include:

- The acknowledgment of the risk of sleep disturbance being a health risk.

> “a Dutch study that showed noise from a 30 MW wind farm becomes more noticeable and annoying to nearby residents at night. This study noted that although the noise is always present, certain aspects of turbine noise, such as thumping and swishing, were not noticeable during the day, but became very noticeable at night. Residents as far as 1900 meters from the wind farm complained about the night time noise.”

> “For broadband noise, such as wind turbines produce, the low frequency components may travel further than the higher frequency components. Since low-frequency noise is particularly annoying to most people, it is important to specify limits for low frequency noise.”

> “Wind direction also has an influence on sound propagation. Within 900 ft of a sound source, the wind direction does not seem to influence the sound. After about 900 ft., the wind direction becomes a major factor in sound propagation. Downwind (meaning the wind is moving from the noise source towards the receiver) of the source, sound volume will increase for a time before decreasing.”

> “Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise. Light weight building home structures will not attenuate these frequencies components as well as higher frequency components.”

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<td>Chatham-Kent Public Health Unit. 2008. The Health Impact of Wind Turbines: a Review of the Current White, Grey and Published Literature 2008.</td>
<td>6-8</td>
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Regarding this reference Dr Colby stated:
**Table 1**

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“The research and writing was done by April Rietdyk but I endorse and take full responsibility for the content.”

An October 2009 letter from The College of Physicians and Surgeons of Ontario, Inquiries, Complaints and Reports Committees Decisions and Reasons states that:

“...the Committee observes, Dr. Colby’s expertise is in medical microbiology and infectious diseases, an area quite distinct from audiology or other fields to the physical impact of wind turbines on human health. Thus the committee wishes to remind Dr. Colby, going forward, of the importance of fully disclosing the extent of his qualifications in a field that he has been retained as an “expert” and also to ensure he fully disclose to the public the organization or corporation by whom he has been retained by an expert.”

In addition:

SkyPower, a wind energy developer advertised Dr Colby as one of their “representatives”. Dr Colby has stated that he received an honorarium for this service.

This document is an inadequate public health document. This statement is based on the following:

The report displays selective bias favouring the wind energy industry in the presentation of the material referenced.

- Heavy reliance on references from the wind energy industry (CanWEA, AWEA, BWEA, Danish Wind Energy Association)
- Heavy reliance on references from listed members of CanWEA (Howe Gastmeier Chapnik Limited. Mississauga HGC Engineering)
- The report displays selective bias favouring the wind energy industry by the omission of relevant references.
- As a result of the above deficiencies the report provides incomplete risk assessments related to health including the failure to adequately consider the health impacts of annoyance, stress or sleep disturbance. (based on a key word searches of “annoyance”, “stress” and “sleep disturbance”)
- The report uses pre-emptive stereotyping of individuals who
**Table 1 Analysis**

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<tr>
<td>6-8</td>
<td>The power point slides contain few references and much of the material is similar to that used by the wind energy industry.</td>
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<tr>
<td>6-8</td>
<td>The conclusion of the power point presentation is inconsistent as it states:</td>
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<tr>
<td></td>
<td>“No evidence of noise-induced health effects at levels emitted by wind turbines”</td>
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<tr>
<td></td>
<td>Then paradoxically concludes:</td>
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<tr>
<td></td>
<td>“Stress and sleep disturbance possible”</td>
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<td></td>
<td>“Sound, flicker, aesthetics may affect annoyance + stress”</td>
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<tr>
<td></td>
<td>“Health concerns are valid and must be addressed.”</td>
</tr>
<tr>
<td></td>
<td>“Any effects on health more likely related to annoyance/sleep disturbance than to direct effect of SPLs at residence.”</td>
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<tr>
<td>6-8</td>
<td>Draft New Zealand standard for wind turbine sound.</td>
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<td></td>
<td>The A/CanWEA Panel Review displays selective bias by neglecting to include this reference in the body of the report.</td>
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<tr>
<td></td>
<td>Relevant citations not cited in the A/CanWEA Panel Review include:</td>
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<tr>
<td></td>
<td>“Limits for wind farm noise are required to provide protection against sleep disturbance and maintain reasonable residential amenity.”</td>
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<td></td>
<td>“In certain situations (see 5.3), consideration of a noise limit more stringent than 40 dB may be appropriate to further protect amenity for particular noise sensitive locations.”</td>
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<td>As a result the draft standard recommends a secondary noise limit for quiet areas</td>
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<td></td>
<td>“Where a secondary noise limit is applicable, wind farm sound levels (LA90(10 min)) should not exceed the background sound level by more than 5 dB, or a level of 35 dB LA90(10 min), whichever is the greater.”</td>
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<td><em>The New Zealand draft standard recommends improvement to sound modelling including testing being conducted at various temperature and atmospheric conditions.</em></td>
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<td><em>The A/CanWEA Panel Review displays selective bias by including the Maine Osteopathic Association Resolution but neglecting to include the Maine Medical Association Resolution: Wind Energy and Public Health.</em></td>
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<tr>
<td></td>
<td><em>This article acknowledges both annoyance and sleep disturbance may occur from wind turbines noise even at levels of 40dBA or 45dBA.</em></td>
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<td></td>
<td><em>In an email exchange Dr Ramani Ramakrishnan, the author of this reference states</em></td>
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<td></td>
<td>“I am not a medical doctor or a psychoacoustician or a physiological acoustician. I am an acoustician from the engineering science perspective. So, to comment on health issues is outside my area of expertise.”</td>
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<td>“…additional concerns still need to be addressed in the next round of revisions to their assessment process. These revisions may need to be addressed after the results from future research provide scientifically consistent data for effects such as meteorology, human response and turbine noise source character.”</td>
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<td>It concludes:</td>
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<td>“…noise is a primary siting constraint.”</td>
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<td>“Community noise standards are important to ensure liveable communities. Wind turbines must be held to comply with these regulations.”</td>
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<td><em>The A/CanWEA Panel Review displays selective bias by neglecting to include this reference in the body of the report.</em></td>
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<td>Relevant citations not cited in the A/CanWEA Panel Review include:</td>
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|     | “Sound generated by wind turbines has particular characteristics and it creates a different type of nuisance compared to usual urban, industrial, or commercial noise. The interaction of the blades with air turbulences around the towers creates low frequency and infrasound components, which modulate the broadband noise and create fluctuations of sound level. The lower frequency fluctuation of the noise
Table 1

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<th>A/CanWEA Panel Review Page Reference</th>
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<td><strong>Table 1</strong> A/CanWEA Panel Review contents in non bold quotations**</td>
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<td><strong>The Society for Wind Vigilance analysis in bold italicized</strong></td>
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<td>Note any errors or omissions are unintentional.</td>
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<td><strong>is described as ‘swishing’ or ‘whooshing’ sound, creating an additional disturbance due to the periodic and rhythmic characteristic.”</strong></td>
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<td>“Specific noise limits need to be developed by considering the characteristics of wind turbine noise. Especially the low frequency sound components and the modulation of the background noise resulting must be considered to represent the activity interference of the wind turbine sound. Adequate criteria to assess the wind turbine sound will greatly help the development the wind industry by reducing the community reaction based on subjective opinions.”</td>
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<td><strong>The A/CanWEA Panel Review displays selective bias by neglecting to include this reference in the body of the report.</strong></td>
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<td><strong>The A/CanWEA Panel Review acknowledges that wind turbines may cause sleep disturbance.</strong></td>
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<td><strong>In 2009 World Health Organization released Night Noise Guidelines for Europe which is a 184 page peer reviewed summary of the risks to human health that may result from noise induced sleep disturbance. Some of the adverse health documented include poor performance at work, fatigue, memory difficulties, concentration problems, motor vehicle accidents, mood disorders (depression, anxiety), alcohol and other substance abuse, cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders, obesity, impaired immune system function and a reported increased risk of mortality.</strong></td>
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<tr>
<td><strong>The A/CanWEA Panel Review’s failure to include an analysis of this document in the context of wind turbine noise induced sleep disturbance is a conspicuous omission.</strong></td>
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END OF ANALYSIS
Testimony of Rick James, INCE

Exhibit RJ-05
The study analyzed data from 48 small and large wind turbines. The results show that large wind turbines (2.3 to 3.6 MW) emit relatively more low frequency noise [1] than small turbines (up to 2 MW). The farther away from the windmill the greater is the low frequency content due to a relatively larger atmospheric absorption of high frequencies. Considering the A-weighted sound level outdoors in relevant distances to neighbors, the lower frequencies constitute a substantial part of the noise. There is no doubt that the lower frequency part of the noise spectrum is of importance to the neighbors' perception of noise from large wind turbines.

The low frequency noise can also be annoying indoors, although it of course depends on sound insulation. If the outdoor sound pressure of total noise is close to the maximum allowable in Denmark [2] there is a risk that a considerable proportion of the neighbors will be bothered by low-frequency noise, even indoors.

The difference in low frequency noise from small and large turbines can be expressed as a shift downward in frequency of the relative frequency range by about 1/3 of an octave. A further shift of similar size can be expected from wind turbines of the 10 MW size with corresponding increase in annoyance from low-frequency noise.

Wind turbines also emit infrasound [3], but taking into account Human sensitivity to these frequencies, the levels are very low. Even close to the turbines the sound pressure is far below the normal threshold of hearing. Infrasound is therefore not considered to be a problem for turbines of the design and size included in the investigation.

The emitted A-weighted sound effect increases proportionally with the electrical power of the turbines or probably even more. Because of this large wind turbines pollute the same or an even larger area with noise, compared to that of small turbines with the same total electrical power.

The noise from various turbines of the same size varies several decibels even for turbines of the same make and model. During the planning phase it is necessary to incorporate a safety margin to ensure that the finished turbines comply with the noise limits. International technical specifications are available, but frequently they are not used. Noise from wind turbines is under certain atmospheric conditions more annoying and -
especially the low frequency part - spread much farther than generally accepted. There is
a need for increased knowledge of these phenomena and their occurrence.
The report can be obtained from Section of Acoustics on telephone 9940 8710 or by e-
mail: acoustics (at) es.aau.dk

[1] Noise in the frequency range 20-200 Hz  [2] An A-weighted sound pressure level of
44 dB  [3] Sound with frequencies below 20 Hz
Henrik Møller og Christian Sejer Pedersen

Lavfrekvent støj fra store vindmøller
Lavfrekvent støj fra store vindmøller

Af Henrik Møller og Christian Sejer Pedersen

Sektion for Akustik
Aalborg Universitet 2010
INDHOLD

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FORORD

Vindmøller bliver større og større, og der er opstået frygt for, at støjen fra møllerne derfor flytter sig nedad i frekvens, og at indholdet af lavfrekvent støj og infralyd vil stige og nå et niveau, hvor det kan genere naboerne. Dagspressen fortæller jævnligt om rumlende og generende støj fra store vindmøller, og det hævdes ofte, at støjen udbredes sig ret langt. Den videnskabelige litteratur om infralyd og lavfrekvent støj fra store vindmøller er derimod mere begrænset.


Der er modtaget økonomisk støtte fra Energiforskningsprogrammet under Energistyrelsen og fra Aalborg Universitet.

Aalborg, 11. juni 2010

Henrik Møller og Christian Sejer Pedersen
RESUMÉ

I undersøgelsen analyseres data fra 48 små og store vindmøller. Resultaterne viser, at store vindmøller (2,3-3,6 MW) udsender relativt mere lavfrekvent støj1 end små vindmøller (op til 2 MW). Efterhånden som støjen bevæger sig væk fra møllen, bliver det lavfrekvente indhold endnu mere udtalt, fordi luftens absorption reducerer de høje frekvenser mere end de lave.

Ser man på det A-vægtede lydtryk udendørs i relevante naboafstande, udgør de lave frekvenser en væsentlig del af støjen. Der er derfor ingen tvivl om, at den lavfrekvente del af støjspektret har betydning for naboernes oplevelse af støjgener fra store vindmøller.

Den lavfrekvente støj kan også genere indendørs, naturligvis afhængigt af lydisolationen. Hvis det udendørs lydtryk for den totale støj ligger i nærheden af det maksimalt tilladelige i Danmark², er der risiko for, at en betragtelig del af naboerne vil være generede af lavfrekvent støj, selv indendørs.

Forskellen i lavfrekvent støj fra små til store møller kan udtrykkes som en forskyldning nedad i frekvens af det relative frekvensspektrum på omkring 1/3 oktav. Et yderligere skift af lignende størrelse må forventes for vindmøller i 10 MW størrelsen med dertil svarende forøgede gener fra lavfrekvent støj.

Vindmøllerne udsender også infralyd³, men når man tager menneskets følsomhed overfor disse frekvenser i betragtning, er der tale om meget lave niveauer. Selv tæt på møllerne er lydtrykket langt under de normale høretærskel. Infralyd betragtes derfor ikke som et problem for møller af konstruktion og størrelse som de undersøgte møller.


Der er forskelle på flere decibel på støjen fra forskellige møller af samme størrelse, selv for møller af samme fabrikat og model. I planlægningsfasen må man derfor indregne en sikkerhedsmargin for at sikre, at de rejsede vindmøller vil overholde støjgrænserne. Der findes en international teknisk specifikation for dette, men den anvendes ofte ikke.


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1 Støj i frekvensområdet 20-200 Hz
2 Et A-vægtet lydtrykniveau på 44 dB
3 Lyd med frekvenser under 20 Hz
1 INTRODUKTION

1.1 Lavfrekvent lyd og infralyd

Det vil være hensigtsmæssigt med et par indledende bemærkninger om lavfrekvent lyd og infralyd. For en mere omfattende gennemgang af den menneskelige hørelse ved lave frekvenser og infralyd, se f.eks. Møller og Pedersen [3].

Det er normalt underforstået, at den nedre grænse for den menneskelige hørelse er omkring 20 hertz (forkortet Hz, lig svingninger per sekund), og for frekvenser herunder benyttes udtrykkene infralyd og infrasonisk. Frekvensområdet 20-200 Hz betegnes som det lavfrekvente område (undertiden med en lidt anden øvre grænse).

Men som en overraskelse for mange mennesker, stopper hørelsen ikke ved 20 Hz. Hvis lydtrykket er tilstrækkelig højt, kan mennesker høre infralyd i det mindste ned til én eller to hertz. Lyden opfattes gennem ørerne, men den subjektive kvalitet er anderledes end for lyd med højere frekvenser. Under 20 Hz forsvinder den tonale opfattelse, lyden får en diskontinuert karakter, og der opstår en trykksende fornemmelse ved trommehinderne. Ved nogle få hertz ændrer opfattelsen sig til diskontinuerede separate trykstød, og det er muligt at følge og tælle de enkelte svingninger af en tone.

Ved lave frekvenser og især infralyd, stiger hørestyrken (den subjektive lydstyrke) stelere over høretærsklen end ved højere frekvenser (Whittle et al. [4], Møller og Andresen [5], Bellmann et al. [6], ISO 226 [7]), og en lyd, som kun er moderat over tærsklen, kan opfattes ikke bare som kraftig, men også generende (Andresen og Møller [8], Møller [9], Inukai et al. [10], Subedi et al. [11]). Da der er en naturlig spredning i høretærskler, kan en lyd, der er uhørlig eller svag for nogle mennesker, være kraftig og generende for andre. Lavfrekvent støj over høretærsklen kan også påvirke arbejdservnen (Waye et al. [12]) og give sovnforstyrrelser (Waye et al. [13]). Der er ingen troværdig dokumentation for fysiologiske eller psykologiske virkninger af infralyd eller lavfrekvent støj under høretærsklen (se f.eks. Berglund og Lindvall [14]).

Infralyd måles med G-vægtningskurven [15], som dækker frekvensområdet 1-20 Hz. Ved den normale høretærskel for rene toner (Whittle et al. [4], Yeowart og Evans [16], Yamada et al. [17], Landström et al. [18], Watanabe og Møller [19] og Inukai et al. [10]), er det G-vægteede lydtrykniveau i størrelsesordenen 95-100 dB. Man regner normalt ikke med, at mennesker kan opfatte G-vægteede lydtrykniveauer under 90 dB [15] eller 85 dB [20].

1.2 Tidligere undersøgelser

Der findes mange undersøgelser, som beskæftiger sig teoretisk med de mekanismer, der skaber lavfrekvent støj og infralyd fra vindmøller, mens det er langt mere begrænset, hvad der findes af originale studier vedrørende støjen fra komplette vindmøller. I det følgende betragtes kun vindmøller med vandret akse.
Hubbard og Shepherd [21] og Shepherd og Hubbard [22] gennemgik litteraturen om vindmøllestøj især med fokus på undersøgelser udført ved NASA i mere end to årtier og omfattende vindmøller på op til 4,2 MW. Det blev konstateret og forklaret ved numeriske modeller, at harmoniske af vingepassage-frekvensen skyldes forskelle i vindhastighed henover rotorarealet og, for vindmøller med rotoren på læsiden af mølletårnet (’bagløbere’), impulser skabt ved vingens passage gennem tårnets slipstrøm. Især den sidste mekanisme er ansvarlig for et højt niveau af diskrete frekvenser i infralyd- og lavfrekvensområdet for vindmøller med rotoren i læ. Der skabes også ’bredbånds’- (stokastisk, kontinuert-spectrum) støj ved lave og infrasoniske frekvenser på grund af turbulens i den tilstrømmende luft. Turbulens i tilstrømnningen er hovedårsagen til bredbåndsstøj under nogle hundrede hertz. Udbredelsen af lyd fra vindmøller blev også undersøgt, og det blev observeret og forklaret med atmosfærisk refraktion, at udbredelsen i læretningen af lave frekvenser (vist som eksempel ved 8-16 Hz) var cylindrisk fra en vis afstand og ikke sferisk, som normalt antaget ved beregninger af støj. Det betyder, at niveauet falder med 3 dB per fordobling af afstanden og ikke 6 dB. At møllestøj nogle gange opfattes lettere indendørs end udendørs, blev forklaret med rumresonancer og lav lydisolation ved lave frekvenser. Infralyddelen af spektret lå under den normale høretærskel i alle de undersøgte tilfælde af klager, men det blev hævdet, at infralyden var årsag til mærkbare vibrationer og klirren af vinduer og vægmonterede genstande, hvilket bidrog til negative reaktioner over vindmøllestøj. Med nogle af de samme møller som eksempler, viste Guidati et al. [23], at interaktionen mellem vinger og tårn skaber impulsiv infrasonisk og lavfrequens støj også ved møller med rotoren i vindretningen (’frontløbere’), dog væsentligt mindre end for møller med rotoren i læretningen.

Legerton et al. [24] målte støj fra to 450 kW vindmøller i en afstand af 100 m. De rapporterede niveauer for 1/3-oktavbåndene op til 20 Hz er langt under den normale høretærskel for rene toner, mens niveauerne i 31,5 Hz båndet er lige under tærsklen.


Jakobsen [27] gennemgik data fra de undersøgelser, der er nævnt i de tre foregående paragraffer og sogte yderligere oplysninger i de originale målerapporter og ved kontakt til forfatterne. Han estimerede G-vægtede niveauer for 10 vindmøller på 50 kW til 4,2 MW og fandt, at niveauet fra vindmøllerne med rotoren i vindretningen er omkring 70 dB eller lavere i en afstand af 100 m, mens niveauet fra vindmøllerne med rotoren i læ er 10-30 dB højere. Det blev konkluderet, at selv tæt på møller med rotoren i vindretningen vil det G-vægtede niveau såvel udendørs som indendørs være under grænse på 85 dB i de danske retningslinjer for lavfrequens støj og infralyd [20]. For vindmøller med rotoren i læ af tårnet kan denne grænse
overskrider på afstande op til flere hundrede meter. Selv for møller med rotoren i læ
var niveauet af infralyd dog for lavt til at kunne forklare klager rapporteret i de
oprindelige undersøgelser på afstande op til 2 km. I et forsøg på at finde en
alternativ forklaring estimerede Jakobsen det indendørs A-vægtede niveau for
10-160 Hz frekvensområdet, et mål der anvendes af de danske retningslinjer for lave
frekvenser. Den anbefalede aften/natgrænse på 20 dB for boliger var overskredet i
teilfælde på nær ét. På den anden side var de normale udendørs A-vægtede
niveauer i disse tilfælde også høje nok til at forklare klagerne (47-61 dB), så det er
ikke muligt sige, om klagerne skyldtes den normale eller den lavfrekvente støj.
(Jakobsen henviste fejlagtigt til den danske aften/natgrænse som 25 dB).

Van den Berg [28] gjorde opmærksom på, at vingernes passage foran mølletårnet
giver anledning til støj i infralydområdet, men endnu vigtigere til modulation af
støjene ved højere frekvenser, så der opstår en 'swish-swish’ lyd. I en stabil
atmosfære, som ofte findes om natten, er forskellen i vindhastighed mellem top og
bund af rotoren meget højere end på andre tidspunkter, og dette øger modulationen
og ændrer swish-lyden til en ”klapren, banken eller dunken”. For en vindmøllepark
med 17 vindmøller på hver 2 MW, kunne dette høres tydeligt mindst én kilometer
væk. Der blev lavet målinger om natten, 100 m fra hver af to af mølnerne samt
750 m fra den nærmeste række af 10 møller. Selv for de nærmeste målinger var
niveauerne langt under den normale høretærskel for 1/3-oktavbåndene op til 20 Hz.
Pedersen og Møller [30] analyserede indendørs lavfrekvent støj og infralyd fra fire
huse i nærheden af en eller flere vindmøller (0,6-2,75 MW) med en afstand til
nærmeste mølle på 90-525 m. Der var ingen hörbare harmoniske af vinge-passage-
frekvensen, men der var hörbare komponenter i lavfrekvensområdet, i flere tilfælde
med en tonal karakter. G-vægtede niveauer var 65 dB eller lavere, hvilket vil sige
langt under den normale horetæskel, og det blev konkluderet, at infralyden ikke vil
give anledning til gener. A-vægtede niveauer for 10-160 Hz frekvensområdet var
omkring eller under den danske aften/natgrænse for boliger på 20 dB [20]. De
højeste niveauer var målt ved en lav vindhastighed (6,6 m/s), men tættere på en
vindmølle end folk normalt vil bo (90 m), eller længere væk (325 m) i den eneste
måling, som blev lavet ved en højere vindhastighed (9,4 m/s). Målingerne blev lavet
efter målemetoden i de danske retningslinjer, dog uden at der var en klager til at
udpege målepositioner, hvor støjen var højest, hvilket er vigtigt i metoden [20].
Målingerne blev ikke generelt korrigeret for baggrundsstøj, men der blev gjort en
betydelig indsats for kun at analyseres perioder uden forstyrrelser. Ekstra målinger i
to af husene tyder på, at folk kan blive udsat for højere niveauer andre steder i
rummet, end der blev målt med den officielle metode. Resultaterne var ikke entydige
vedrørende den lavfrekvente støj, og undersøgelsen var en del af motiveringen for
det aktuelle projekt.

Konsulentfirmaet Hayes Mckenzie Partnership Ltd. [31] målte infralyd i en afstand
af 360 m i læretningen af en vindmøllepark med tolv 1,65 MW møller. Ved
vindhastigheder på op til 20 m/s, var de G-vægtede niveauer op til 80 dB. I en
anden del af undersøgelsen blev der målt lavfrekvent støj i tre huse, hvor beboerne
havde klaget over lavfrekvent støj fra vindmølleparker med 3-16 møller. Møllestørrelse og afstand til mølleparken blev kun angivet for et af tilfældene (tre 1,3 MW møller, afstand 1030 m). Det blev konkluderet, at for 10-160 Hz området var niveauerne lavere end grænser foreslået af Moorhouse et al. [32, 33] for det britiske ministerium for miljø, fødevarer og landdistriktsopgørsområd (DEFRA), og den danske 20 dB grænse [20]. Ikke desto mindre viser data, at begge grænser faktisk blev overskredet i to af de tre huse. I det ene hus skete det jævnligt, indtil mikrofonen blev flyttet til en anden placering i rummet. Det blev fremført, at mikrofonen i den første position optog lyd fra et nærliggende vandløb snarere end fra vindmøllerne. Forfatterne af denne rapport er skeptiske over for idéen om, at flytning af mikrofonen inden for det samme rum skulle reducere lavfrekvent lyd og infralyd fra vandløbet, men ikke fra vindmøllerne. Både de britiske og de danske retningslinjer specificerer, at støjen skal måles, hvor lyden er kraftigst, og det er ikke muligt at se af data, om lyden i det første målepunkt (eller begge) var domineret af lyd fra vandløbet. I det andet hus blev der kun rapporteret gener to gange i måleperioden, og både de britiske og de danske grænser var overskredet den ene gang. Et vindue stod åbent begge gange, og det hævdedes, at både de britiske og de danske retningslinjer kræver, at vinduerne er lukket under målingerne. Dette er dog ikke korrekt. De britiske dokumenter har ikke instruktioner om vinduesindstillinger under målingerne, men kræver en omfattende udspørgsel af den generede person om forholdene under generne, og det er logisk at antage, at målingerne skal foretages under samme betingelser. De danske retningslinjer angiver specifikt, at det er korrekt. De britiske dokumenter har ikke instruktioner om vinduesindstillinger under målingerne, men kræver en omfattende udspørgsel af den generede person om forholdene under generne, og det er logisk at antage, at målingerne skal foretages under samme betingelser. De danske retningslinjer angiver specifikt, at der skal foretages målinger med åbne vinduer, hvis klageren finder, at støjen er kraftigere i denne tilstand.


Lee et al. [37] og Jung et al. [38] målte støj fra to vindmøller med rotor i vindretningen på henholdsvis 660 kW og 1,5 MW nominel elektrisk effekt. Den A-vægtede støj steg med vindhastigheden for 1,5 MW møllen, mens den var nogenlunde konstant over det meste af driftsområdet for 660 kW møllen. De to møller var henholdsvis stall- og pitch-regulerede, og den manglende stigning i den A-vægtede støj ved højere vindhastigheder hævdedes at være typisk for pitch-regulerede møller og til at være en af årsagerne til, at denne form for regulering foretrækkes for store vindmøller. Infralydområdet var domineret af vingepassagesfrekvensen og dens harmoniske, og niveauet steg med stigende vindhastighed for
begge møller. Der blev udtrykt bekymring for, at infralyd og lavfrekvent støj vil blive et problem med moderne vindmøller, hvor pitch-reguleringen begrænser den A-vægtede støj, men ikke den lavfrekvente støj og infralyd. Det blev konkluderet, at den lavfrekvente del af støjen fra begge vindmøller er hørbar for en gennemsnitlig person og sandsynligvis vil føre til klager, og at infralyddelen kan medføre klager på grund af klirren, f. eks. fra vinduerne. Afstanden til møllerne for denne konklusion blev ikke rapporteret, men det kan udledes af andre data i artiklen, at det må have været ganske tæt på, i størrelsesordenen 70-100 m.


Ramakrishnan [40] målte støj tæt på en enkelt 660 kW mølle og tæt på en enkelt mølle i en vindmøllepark med mere end 50 møller på hver 1,5 MW. G-vægtede niveauer var omkring 70 dB i begge tilfælde.

Harrison [41] gjorde opmærksom på, at da turbulens i den tilstrømmende luft er afgørende for udsendelse af lavfrekvent støj, bør der være mere fokus på kontrol af turbulens under målinger og ved støjberegninger. Et særligt problem er, at turbulenzen øges i slipstrømmen fra vindmøller, og det tages ikke i betragtning under målinger af lydudsendelsen, som laves med enkelstående vindmøller. Barthelmie et al. [42] viste, at turbulenzen er markant forøget ved afstande op til mindst fire gange rotordiameteren. Slipstromsturbulen kan således være vigtig for udsendelse af lavfrekvent støj fra vindmølleparkere.

1.2.1 Opsummering af resultater fra tidligere undersøgelser

Ovenstående undersøgelser har anvendt en række forskellige metoder, og de fleste data kan ikke sammenlignes direkte. Ingen af undersøgelserne har systematisk undersøgt udviklingen af lavfrekvent støj og infralyd med møllestørrelse. Nogle af undersøgelserne mangler grundlæggende oplysninger, såsom information om mølle(r), måleafstand, -retning og -højde, vindhastighed, analysebåndbredde, baggrundsstøj, lydisonlation ved indendørs målinger, osv. osv. Ikke desto mindre synes det at være muligt at drage nogle konklusioner.


For vindmøller med rotoren i vindretningen i forhold til tårnet (‘forløbere’) er niveauet for infralyd langt under den normale horetærskel, selv tæt på møllen. På møller med rotoren i læ af tårnet (‘bagløbere’) skaber vingernes passage gennem
slipstrømmen fra tårnet infralyd, som kan overskrive den normale høretærskel tæt på vindmøllen og muligvis forårsage klirren af f.eks. vinduer selv i relevante naboadfstande. De fleste moderne vindmøller, men ikke alle, har rotoren i vindretningen.

For lavfrekvensområdet er resultaterne mindre sikre. Indikationerne afviger mellem undersøgelserne, og det er ikke muligt fra ovenstående at konkludere, i hvilket omfang lavfrekvent støj fra vindmøller er skyld i eventuelle gener. Svaret vil formentlig afhænge af mølle, afstand, atmosfæriske forhold, om man er indendørs eller udendørs osv.


1.3 Oversigt over undersøgelsen

2 METODER

2.1 Vindmøller
Der indgik i alt 48 vindmøller i projektet. Fire prototype-møller med nominel elektrisk effekt på over 2 MW blev målt af Delta som en del af projektet (Mølle 1-4), mens data for syv andre møller over 2 MW blev hentet fra målinger foretaget af Delta uden for projektet (Mølle 5-11) [43, 44]. Data for 37 vindmøller med en nominel effekt på eller under 2 MW blev hentet fra tidligere målinger foretaget af Delta [45]. Blandt de små møller optræder nogle få fysiske møller mere end én gang, og de repræsenterer således møllen målt ved forskellige lejligheder. Alle møller var tre-bladede med rotoren placeret på vindsiden af tårnet (‘forløbere’).

2.2 Udsendt lydeffekt

Det apparente lydeffektniveau blev bestemt for 1/3-oktavbånd og som et samlet A-vægtet niveau, $L_{WA}$. Desuden blev et særligt lavfrekvensmål, $L_{WALF}$, det apparente A-vægtede lydeffektniveau for 1/3-oktavbåndene 10-160 Hz beregnet. Det A-vægtede lydtrykniveau for dette frekvensområde, $L_{PALF}$, benyttes af de danske retningslinjer for lavfrekvent støj [20].

Ordet apparent er meget lidt mundet og sjældent brugt på dansk, men der findes desværre ikke et andet dækkende udtryk til brug for en oversættelse af det engelske ’apparent sound power level’. Det eneste lydeffektniveau i denne rapport, som ikke er apparent lydeffektniveau, optræder i det følgende afsnit 2.3, og ordet apparent udelades derfor i den efterfølgende del af rapporten, inklusive resultatafsnit og diskussioner.

Data blev fremskaffet for alle møller i læretningen, benævnt referenceretningen, ved en vindhastighed på 8 m/s (10 m over jorden). Denne vindhastighed bruges ofte ved støjregulering, og de fleste analyser i denne rapport er lavet for denne hastighed. Møllerne 1-4 blev også målt ved forskellige andre vindhastigheder. For vurdering af indholdet af rene toner blev tonal hørbarhed (tonal audibility), $\Delta L_{\alpha}$, bestemt for Mølle 1-4, og for at give et indblik i en mulig retningsafhængighed af lydudsendelsen, blev Mølle 1-3 også målt ved ±60° til siderne i forhold til referenceretningen samt i vindretningen, stadig på jorden. Alle møller blev målt i det frekvensområde, standarden kræver, 50 Hz til 10 kHz, og de fleste møller blev målt ned til 31,5 eller 25 Hz. Mølle 1-4 blev målt ned til 4 Hz.
2.3 Udendørs lydtrykniveau ved naboer

Fritfelt-lydtrykniveau, $L_p$, hos naboer i læretningen blev beregnet efter metoden i ISO 9613-2 [48], bortset fra at der blev anvendt 1/3-oktavbånd i stedet for oktavbånd.

Retningen til naboer er mere vandret end den retning, hvor det apparente lydeffektniveau blev målt, men i mangel af mere præcise data, blev lydeffektniveaet plus retningsfaktoren, $L_{WA} + D_C$, erstattet af det apparente lydeffektniveau, $L_{WA}$, for referenceretningen. Dæmpningen som følge af atmosfærisk absorption, $A_{atm}$, blev beregnet ved hjælp af data fra ISO 9613-1 [49] for 10° C og en relativ luftfugtighed på 80 %. ‘Dæmpningen’ på grund af jordens indvirkning, $L_{gr}$, blev sat til -1,5 dB, hvilket betyder, at der lægges 1,5 dB til den direkte lyd fra møllen. De to resterende led i ISO 9613-2 (dæmpninger på grund af en eventuel barriere $A_{bar}$ og diverse $A_{misc}$) blev sat til nul.

Hvis den skrå afstand fra rotorcenter til observationspunktet betegnes $d$, og dæmpningskonstanten er $\alpha$, bliver

$$L_p = L_{WA} - 20 \, \text{dB} \cdot \log_{10} \left( \frac{d}{1 \, \text{m}} \right) - 11 \, \text{dB} - \alpha \cdot d + 1.5 \, \text{dB} \quad (1)$$

Denne beregning svarer til den, der anvendes i den danske regulering af støj fra vindmøller [50].

2.4 Lydisolation

For at gøre det muligt at beregne den lavfrekvente støj indendørs, blev lydisolationen ved lave frekvenser målt for ti rum, to rum i hvert af fem normale beboelseshuse [46].


Ved lave frekvenser kan indendørsniveaet variere meget inden for det samme rum, og det er en generel opfattelse, at til vurdering af støjpåvirkning bør det målte niveau afspejle områder med højt niveau frem for gennemsnittet for rummet (se f. eks. Jakobsen [52], Simmons [53] og Pedersen et al. [54]). For at opfylde dette, blev som indendørs lydtrykniveau benyttet energimiddelverdien af målinger lavet i fire vilkårlige tredimensionelle hjørner, dvs. hvor gulvet eller loftet møder to vægge. Hjørner tæt på mulige koncentrerede transmissionsveje (eksempelvis ventilationskanaler, vinduer eller døre) blev dog undgået, og de valgte hjørner repræsenterede tilsammen alle overflader. Pedersen et al. [54] har vist, at denne metode giver et godt estimat på det
niveau, som er overskredet i 10 % af rummet, dvs. tæt på maksimum for rummet, men uden at give niveauer, der kun eksisterer i en meget lille del af rummet.

At 3D-hjørnemetoden er velegnet til at estimere det maksimale niveau, som folk normalt vil blive udsat for i et rum, bekræftes af data fra Brunskog og Jacobsen [55], som simulerede 100 forskellige frekvens/rum-kombinationer, hver med to forskellige efterklangstider. De fandt, at 3-D-hjørne metoden rammer ret centralt et mål defineret som det maksimale niveau i rummet, eksklusive positioner tættere på væggene end 1 m (gennemsnitlig fejl under 1 dB, standardafvigelse af fejlen 3-4 dB afhængig af efterklangstid).

*Lydisolationen* blev målt for 1/3-oktavbåndene i frekvensområdet 8-200 Hz, og den blev beregnet som forskellen mellem udendørs fritfelt-lydtrykniveau og indendørs lydtrykniveau.

Der blev lavet ekstra indendørsmålinger i et forsøg på at benytte en målemetode givet i de danske retningslinjer for lavfrequent støj [20]. Metoden kræver to målinger i områder af rummet, hvor personer vil blive udsat for lyd under normal brug af rummet (med visse geometriske begrensninger), og én måling i nærheden af et hjørne af rummet (0,5-1,0 m fra vægge, 1,0-1,5 m over gulvet). Målinger blev lavet i positioner, som stemmer overens hermed. Imidlertid er metoden beregnet til brug i tilfælde af støjklager, og det er meningen, at der ikke må blive positioner tættere end 1 m fra væggene (gennemsnitlig fejl under 1 dB, standardafvigelse af fejlen 3-4 dB). Selvom de geometriske betingelser i målemetoden var opfyldt, var målingerne således ikke i overensstemmelse med metoden, og resultatene er ikke rapporteret. Det må konkluderes, at metoden er uegnet til måling af lydisolation, medmindre proceduren tilføjes en form for søgning efter maksimalniveauer.

### 2.5 Indendørs lydtrykniveau ved naboer

Indendørs lydtrykniveauer blev fundet ved at trække lydisolationen fra det udendørs fritfelt-lydtrykniveau, begge givet i 1/3-oktavbånd.

### 2.6 Statistiske metoder

Forskelle er testet med Student’s t-tests, og den højeste p-værdi, der regnes som signifikant og rapporteres, er 0,05. I to-sample tests, er der ikke forudsat samme varians for de to samples, og der anvendes derfor Welch’s tilpasning af t-testen og Welch-Satterthwaite frihedsgrader (degrees of freedom, d.f.). Ensidede tests anvendes, når hypotesen omfatter en bestemt retning af den mulige forskel, mens tosidede tests bruges de øvrige steder. Eksempelvis indebærer hypotesen om, at frekvensspektret bevæger sig nedad i frekvens for øget møllestørrelse, at de relative niveauer for store møller vil være højere ved lave frekvenser og lavere ved høje frekvenser. Der anvendes derfor ensidede tests ved lave og høje frekvenser, mens der anvendes tosidede tests i det mellemliggende frekvensområde, valgt som 315-1600 Hz.
3 RESULTATER OG DISKUSSIONER

Tre vindmøller, en på 1650 kW og to på 2,3 MW, blev føjet til materialet på et sent tidspunkt, og der er ikke data for 1/3-øktavbånd tilgængelige for disse, så kun resultater for $L_{WA}$ og $L_{WALF}$ rapporteres. Der var uheldigvis benyttet 20 Hz højpasfiltre under nogle af målingerne (retninger reference, venstre og højre for Mølle 1, referenceretning for Mølle 3), så inden databehandlingen blev virkningen af disse filtre kompenserer ved at trække filterkarakteristikken fra de målte niveauer i det berørte frekvensområde. Højfrekvent elektrisk støj fra frekvensomformeren påvirkede nogle af målinger ved frekvenser over 5 kHz, og data for Møllerne 1-4 er således ikke rapporteret ved disse frekvenser. Der er enkelte uoverensstemmelser mellem de data, som Delta har angivet i de forskellige rapporter, tabeller og figurer. Resultaterne i denne rapport er baseret på de mindst behandlede data, hvilket med få undtagelser vil sige de absolutte lydeffektniveauer i 1/3-øktavbånd.

3.1 Udsendt lydeffekt

3.1.1 $L_{WA}$ og $L_{WALF}$

Figur 1 viser $L_{WA}$ og $L_{WALF}$ for alle møllerne som funktion af møllestørrelse. Den vandrette akse er logaritmisk for at passe til den lodrette decibel-akse, som i sig selv er logaritmisk. Simple potessammenhænge mellem udsendt akustisk effekt og nominel elektrisk effekt vil således svare til rette linjer, og regressionslinjer er inkluderet i figuren.

Det ses – ikke overraskende – at både $L_{WA}$ og $L_{WALF}$ stiger med stigende møllestørrelse. Det bemærkes også, at $L_{WALF}$ stiger kraftigere end $L_{WA}$, hvilket betyder, at den relative andel af lavfrekvent støj stiger med stigende møllestørrelse. Forskellen på regressionslinjernes hældning for alle data (tynde linjer) er statistisk

Figur 1. Lydeffektniveauer ($L_{WA}$ and $L_{WALF}$) som funktion af møllestørrelse for 48 møller. Referenceretning, vindhastighed 8 m/s. Regressionslinjer: Alle møller medregnet (tynde linjer), fire møller under 450 kW ikke medregnet (tykke linjer). Sorte symboler gælder Mølle 1-4.
signifikant \(t=3,94; \text{d.f.}=90,0; \text{ensidet } p<0,001\). Da det kan hævdes, at de fire mindste møller måske ikke er repræsentative for moderne vindmøller, er der også beregnet regressionslinjer uden disse møller (tykke linjer). Hældningerne er lidt højere end med alle møller inkluderet, og forskellen er mindre, men stadig statistisk signifikant \(t=1,82; \text{d.f.}=79,8; \text{ensidet } p=0,036\).

Den relative andel af lavfrekvent støj kan udtrykkes som \(L_{WALF} - L_{WA}\), og en lineær regression af denne størrelse har en signifikant positiv hældning med alle møller inkluderet \(t=5,42; \text{d.f.}=46; \text{ensidet } p<0,001\), såvel som med de fire mindste møller fjernet \(t=2,54; \text{d.f.}=42; \text{ensidet } p=0,007\).

Det ses også af Figur 1, at der er nogen variation mellem møller af samme størrelse. Som nævnt i afsnit 2.1 kan møller af samme størrelse være af samme eller forskellige modeller eller, for nogle få møller under 2 MW, den samme fysiske mølle målt ved flere lejligheder.

### 3.1.2 Lydeffektniveau i 1/3-oktavbånd

Lydeffektniveauer i 1/3-oktavbånd er vist i Figur 2.

![Figur 2. A-vægtede lydeffektniveauer i 1/3-oktavbånd. 45 møller med nominel elektrisk effekt mellem 75 kW og 3,6 MW.](image-url)

Ved de frekvenser, hvor der er data for alle møller, varierer niveauet mellem møllerne med 20 dB eller mere. Dette er forventeligt, da møllerne omfatter et stort område af nominel elektrisk effekt. For tydeligere at vise mulige spektrale forskelle mellem møllerne er niveauerne i 1/3-oktavbånd normeret til den enkelte mølles samlede A-vægtede lydeffektniveau $L_{WA}$. Resultatet er vist i Figur 3.

**Figur 3.** Normerede A-vægtede lydeffektniveauer i 1/3-oktavbånd. 45 møller med nominel elektrisk effekt mellem 75 kW og 3,6 MW. (Normeret svarer til, at $L_{WA}$ for den individuelle mølle er trukket fra alle niveauerne i 1/3-oktavbånd).

En eventuel forskel i spektret mellem små og store møller er undersøgt ved at opdele møllerne i to grupper: Møller op til og med 2 MW, og møller over 2 MW. Figur 4 viser middelværdi og standardafvigelse af middelværdi (standard error of mean, s.e.m.) for hver af de to grupper.
Figur 4. Normerede A-vægtede lydeffektniveauer i 1/3-oktavbånd. Middelværdier for to grupper af møller: ≤ 2 MW og > 2 MW. Lodrette streger angiver ±1 standard error of mean (s.e.m.).

Spektret ligger tydeligt lavere i frekvens for de store møller end for de mindre møller. Forskellen i niveau er signifikant for alle 1/3-oktavbånd i frekvensområdet 63-250 Hz og ved 4 kHz (t=[3,49; 4,52; 2,81; 3,27; 3,49; 2,63; 2,52; -2,10], d.f.=[14,3; 23,1; 17,0; 13,5; 13,6; 23,8; 22,6; 12,5], ensidet p=[0,002; <0,001; 0,006; 0,003; 0,002; 0,007; 0,010; 0,028]). (Hvis de fire mindste møller ikke medregnes, er forskellen signifikant ved de samme frekvenser plus 5 kHz (t=[2,94; 4,09; 2,22; 2,76; 2,97; 1,93; 1,83; -2,07; -1,93], d.f.=[11,7; 18,0; 14,5; 11,1; 11,6; 18,7; 20,1; 12,9; 11,7], ensidet p=[0,006; <0,001; 0,022; 0,009; 0,006; 0,035; 0,041; 0,030; 0,039]).

De signifikante forskelle mellem små og store møller er moderate, 1,5-3,2 dB, men som nævnt i introduktionen (afsnit 1.1), kan selv små forskelle påvirke menneskers opfattelse af lyd ved lave frekvenser. Hertil kommer, at hvis lave frekvenser er afgørende for kravene til afstand til naboer, kan små forskelle have stor indflydelse på den nødvendige afstand.

Figur 5 viser middelværdien af de små møller op til og med 2 MW og de enkelte møller på over 2 MW.
Figur 5. Normerede A-vægtede lydeffektniveauer i 1/3-oktavbånd. Middelværdi af 36 møller ≤ 2 MW (tyk sort linje) og 9 individuelle møller > 2 MW.

De store møller ligger over middelværdien af de små møller i næsten hvert eneste 1/3-oktavbånd under 315 Hz. Nogle af møllerne har en top i et eller flere 1/3-oktavbånd, hvilket kan skyldes tonale komponenter. Toner kan stamme fra møllens mekaniske dele, f.eks. gearkassen eller hjælpeudstyr såsom generatorens kølesystem (se f.eks. Wagner et al. [56]).

Ved høje frekvenser forstyrres billedet af et atypisk mønster over 2 kHz for Mølle 6. Der er ikke andre data fra denne mølle, for eksempel for en anden vindhastighed eller en anden retning, som kan bruges til at kontrollere, om dette virkelig er støj fra møllen og ikke elektrisk støj som ved nogle af de andre møller (se indledende bemærkninger til Afsnit 3). Hvis Mølle 6 udelades ved disse frekvenser, ligger de store møller på eller under middelværdien af de små møller i næsten hvert 1/3-oktavbånd over 2 kHz. Forskellen mellem middelværdien af de to grupper er i dette tilfælde signifikant for alle 1/3-oktavbåndene i frekvensområdet 2,5-10 kHz ($t=[-1,83; -2,49; -3,47; -3,18; -2,42; -2,76; -2,64]$, d.f.=$[15,2; 15,6; 14,5; 14,8; 4,1; 4,6; 6,3]$, ensidet p=$[0,044; 0,012; 0,002; 0,003; 0,036; 0,022; 0,018]$).

3.1.3 Toneindhold
Toneanalyserne viser, at tonerne generelt varierer i niveau og frekvens med vindhastigheden. Figur 6 viser tonal hørbarhed for de mest fremtrædende toner for Mølle 1-4.
Figur 6. Tonal hørbarhed, $\Delta L_{ta}$, som funktion af vindhastighed for Mølle 1-4, referenceretning. Farvekode for møller som i Figur 5.

Værdierne er under 3-4 dB med undtagelse af Mølle 3 ved høje vindhastigheder. For Mølle 1 og 3 gælder værdierne en tone, som varierer med vindhastigheden, en tone, som varierer med vindhastigheden i området 110-145 Hz, omtrent samme frekvensområde for begge møller. For Mølle 2 gælder værdierne en tone med næsten konstant frekvens omkring 40 Hz. Mølle 4 har flere toner ved højere frekvenser, og forskellige frekvenser i området 800-1400 Hz dominerer på skift afhængigt af vindhastigheden. Der kan identificeres toppe i de tilsvarende 1/3-oktavbånd i Figur 5 for de to møller med tonalitet over 0 dB ved 8 m/s (Mølle 2, 40 Hz; Mølle 3, 160 Hz).

ISO 1996-2 [57] specificerer et tonetillæg, som skal benyttet, når den tonale hørbarhed overstiger 4 dB. Nationale grænser for tonetillæg kan variere, f.eks. kræver de danske regler, at den tonale hørbarhed overstiger 6,5 dB, før der gives tillæg [58].

Kun én af møllerne overstiger 4 dB grænsen og kun ved høje vindhastigheder, hvor der ofte ikke findes regler for vindmøllestøj. Det er ganske overraskende, at selv ikke den tydeligste tone i spektrene for 1/3-oktavbånd, 40 Hz tonen for Mølle 2, giver et tonetillæg. Det er sandsynligvis et resultat af, at de kritiske bånd, som benyttes ved tonevurderingen, er meget brede ved lave frekvenser. Det er uden for rammerne af denne rapport at vurdere, om tonerne vil blive opfattet som tydeligt tonale, på trods af det manglende tonetillæg.

### 3.1.4 Direktivitet

Figur 7 viser direktiviteten for de tre møller, den er målt for.
Figur 7. Direktivitet for Mølle 1-3. Vindhastighed 8 m/s undtagen for Mølle 2, frontretning, som blev målt ved 10 m/s (og sammenlignet med referenceretningen ved 10 m/s). På grund af elektrisk støj i målingen mangler data for Mølle 2, frontretningen ved 5 kHz. Farvekode for møller som i Figur 5.

Data varierer noget mellem møllerne, og det er svært at finde et generelt mønster. Der ses både højere og lavere niveauer i andre retninger end referenceretningen. Ved de laveste frekvenser ville man forvente en lav direktivitet, men dette ses ikke. En målt retningsvirkning kan afspejle en sand retningsvirkning, men hvis den vigtigste støjikilde er til den ene side i rotorplanet, f.eks. på en nedadgående vinge som vist af Oerlemans og Schepers [59] og Oerlemans et al. [60], er målingerne i denne side tættere på kilden, hvilket kan give en falsk indikation af en retningsvirkning.


Retningen fra mollen til naboer er typisk mere vandret end retningen til målepositionerne. Især hvis der udsendes lyd ved synkron vibrationer i vinger og/eller tårn, er det sandsynligt, at udstrålingen vil være kraftigere vinkelret på
rotorplanet og/eller tårnet, dvs. tæt på det vandrette plan. Der er brug for mere viden om dette.

### 3.1.5 Betydning af vindhastigheden

Figur 8 viser $L_{WA}$ som funktion af vindhastigheden for de fire møller, der er data for.

![Figur 8. A-vægtet lydeffektniveau, $L_{WA}$, som funktion af vindhastigheden for Mølle 1-4. Farvekode for møller som i Figur 5.](image)

Støjen stiger med vindhastigheden, men kurven flader dog ud over 7-8 m/s. De fire møller er alle pitch-regulerede, og udfladningen stemmer overens med observationerne fra f.eks. Lee et al. [37] og Jung et al. [38] vedrørende pitch-regulerede møller.

### 3.2 Udendørs lydtrykniveau ved naboer

For hver af de store møller er beregnet den afstand, hvor det A-vægtede lydtrykniveau er faldet til 35 dB. Pedersen og Waye [61] har vist, at andelen af stærkt generede personer når op over 5% omkring ved dette lydtrykniveau, og andelen af generede når over 10% (Pedersen et al. [62]). Pedersen og Nielsen [63] har anbefalet en minimumsaftstand fra vindmøller til naboer, så møllestøjen er under 33-38 dB. En grænse på 35 dB bruges ved vindmøller, f.eks. i Sverige for stille områder [64]. Det er også den grænse, der gælder i Danmark i områder med åben og lav boligbebyggelse (nat) og i rekreative områder (aften, nat og weekend) for støj fra virksomheder [65] (men ikke for vindmøllestøj [50]). 35 dB synes derfor at være en ganske fornuftig grænse for vindmøllestøj.

Tabel 1 viser afstanden til de enkelte møller samt forskellige nøgletal ved 35 dB grænsen.
Tabell 1. Nøgletal ved den afstand fra en enkelt mølle, hvor det totale A-vægtede lydtrykniveau er 35 dB. Afstanden er anført som skrå afstand til rotorcentrum, hvilket for de aktuelle møllehøjder er tæt på den vandrette afstand.

Den mindste afstand, hvor en 35 dB grænse er overholdt, varierer betydeligt mellem de store møller, selvom møllerne er forholdsvis ens i størrelse (2,3-3,6 MW). Afstanden varierer fra lidt over 600 m til mere end 1200 m.

Spektrene for 1/3-oktavbånd ved disse afstande er vist i Figur 9.

På disse afstande, begynder luftens absorption at få betydning. Den påvirker især de høje frekvenser, og resultatet er, at flytningen af spektret i retning mod lavere frekvenser bliver mere udtalt end for lydeffektniveauet (sammenlign med Figur 5).

Det er vigtigt at bemærke, at for flere af møllerne findes det højeste niveau for 1/3-oktavbånd ved 250 Hz eller lavere, selv når der ses på de A-vægtede niveauer (Figur 9). Det er således hævet over enhver tvivl, at den lavfrekvente del af spektret spiller en vigtig rolle for støj på naaboerne, og at lavfrekvent lyd skal tages alvorligt i vurderingen af støj fra store vindmøller.
I mange tilfælde tillades højere udendørs A-vægtede niveauer end 35 dB. Som et eksempel tillader de danske regler 44 dB for huse uden for boligområder eller rekreative områder [50]. Af visuelle hensyn tillader de danske regler ikke boliger tættere på møller end fire gange den samlede møllehøjde, og på denne afstand er lydtrykniveauet ofte under 44 dB, hvis der er tale om en enkelt mølle. Der kan dog sagtens forekomme niveauer på 44 dB længere væk end fire gange møllehøjden, når der er flere møller sammen i vindmølleparker. Tabel 2 viser afstanden til små vindmølleparker, hvor det A-vægtede lydtrykniveau er 44 dB, såvel som forskellige nøgletal for denne afstand.

<table>
<thead>
<tr>
<th>Mølle</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>Middel små</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afstand [m]</td>
<td>530</td>
<td>546</td>
<td>831</td>
<td>759</td>
<td>585</td>
<td>679</td>
<td>631</td>
<td>1241</td>
<td>1142</td>
<td>393</td>
</tr>
<tr>
<td>L_{PA} [dB]</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
<td>44,0</td>
</tr>
<tr>
<td>L_{PA,lf} [dB]</td>
<td>37,9</td>
<td>35,9</td>
<td>38,1</td>
<td>36,8</td>
<td>37,2</td>
<td>38,3</td>
<td>38,0</td>
<td>36,3</td>
<td>36,3</td>
<td>33,9</td>
</tr>
<tr>
<td>L_{PA,lf}-L_{PA} [dB]</td>
<td>-6,1</td>
<td>-8,1</td>
<td>-5,9</td>
<td>-7,2</td>
<td>-6,8</td>
<td>-5,7</td>
<td>-6,0</td>
<td>-7,7</td>
<td>-7,7</td>
<td>-10,1</td>
</tr>
<tr>
<td>L_{LG} [dB]</td>
<td>68,4</td>
<td>63,9</td>
<td>64,6</td>
<td>67,4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tabel 2. Nøgletal ved den afstand, hvor det totale A-vægtede lydtrykniveau er 44 dB. Mølleparker med to rækker på hver 6 identiske møller, 300 m afstand mellem møller i begge retninger (200 m for små møller). Observationspunkt centreret ud for den lange side. Afstand angivet som skrå afstand til nærmeste mølle.

### 3.3 Lydisolation

Under målingerne var der alvorlige problemer med baggrundsstøj ved de tre laveste frekvenser. 18 målinger med et signal/støj-forhold på under 1,3 dB blev kasseret. Syv rum/frekvens-kombinationer måtte derfor beregnes ud fra målinger i kun to eller tre 3D-hjørner. To rum/frekvens-kombinationer, hvor der kun var målinger fra et enkelt 3D-hjørne blev ikke beregnet. Figur 10 viser lydisolationen for de ti rum.

![Figur 10. Lydisolation målt for 10 rum.](image-url)

Vær opmærksom på, at for hvert 1/3-oktavbånd refererer det indendørs niveau til det maksimale niveau, som man normalt vil blive udsat for i rummet (afsnit 2.4). Isolationstallene er derfor, især for den øverste del af frekvensområdet, lavere end traditionelle isolationstal beregnet til tekniske formål, hvor man typisk anvender det gennemsnitlige niveau i rummet.

### 3.3.1 Mangler ved lydisolationsmålemetoden

En mangel ved den anvendte metode er, at eksponeringen er fokuseret på facaden af huset. I en situation, hvor huset udsættes for støj fra vindmøller, bliver hele huset inklusive tag, og ved lave frekvenser også bagsiden af huset, udsat for næsten den samme lyd. I målesituationen var der mindre lyd på disse flader på grund af højttalerens retningsvirkning, højere afstand til højttaleren, skyggevirkning osv.

Et yderligere problem er, at det udendørs fritfelt-lydtrykniveau beregnes ved blot at trække 6 dB fra det målte niveau på facaden. Dette forudsætter, at facaden er stor nok til at være totalt reflektørerende overfor alle frekvenser, en antagelse, som næppe holder ved de laveste frekvenser. En bedre løsning kunne have været at måle fritfelt-lydtrykniveauet fra højttaleren på et sted uden reflektørerende flader (bortset fra jorden), og bruge denne værdi i beregningen.

Problemerne med baggrundsstøj kunne formodentlig have været løst ved hjælp af moderne teknik, der udnymmer sammenhængen mellem de udendørs og indendørs signaler, f.eks. maximum-length-sequence (MLS) teknik. Alternativt kunne det have været muligt at hæve signalniveauet ved at måle ét 1/3-oktavbånd ad gangen, fremfor hele frekvensområdet samtidigt.

### 3.4 Indendørs lydtrykniveau ved naboer

Figur 11 viser indendørs lydtrykniveauer for 1/3-oktavbånd for alle 81 kombinationer af 9 møller og 9 rum i afstanden med et samlet A-vægtet udendørs lydtrykniveau på 35 dB. Vær opmærksom på, at de indendørs niveauer estimerer det maksimale niveau, som man normalt vil blive udsat for i rummet og ikke det gennemsnitlige niveau i rummet (se afsnit 2.4).

Der ses store forskelle mellem mølle/rum kombinationerne. Det meste af variationen skyldes forskelle i rummenes lydisolation, undtagen ved 63 og 80 Hz, hvor både rum og mølle bidrager nogenlunde lige meget til variationen. Værdier ved 40 Hz i den øvre ende af intervallet skyldes det høje lydeffektniveau for en enkelt mølle, mens høje værdier ved 200 Hz skyldes lav lydisolation af et enkelt rum.

Det ses af den indsatte høretærskel (stiplet linje), at den lavfrekvente lyd kan høres i mange mølle/rum-kombinationer, især ved de højeste af de lave frekvenser. Lyden vil ikke være ret kraftig, men som nævnt i indledningen, kan lavfrekvent lyd være generende, selvom den ikke er ret langt over høretærsklen (afsnit 1.1), og nogle personer kan være generet af lydene i Figur 11.

Figur 12 viser indendørsniveauer for situationen fra Tabel 2, hvor det udendørs A-vægtede lydtrykniveau fra en mølepark er 44 dB.

Her vil der være hørbar lyd nogle steder i alle rum og for alle møller. I mere end halvdelen af tilfældene (48 ud af 81), overskrides den normale høretærskel med mere end 15 dB i et eller flere 1/3-oktavbånd, og der er risiko for, at en betydelig del af beboerne vil være generet af lyden.

Med henblik på at undgå søvnforstyrrelser anbefaler WHO for kontinuert støj en indendørs grænse på 30 dB for det A-vægtede lydtrykniveau [66], men bemærker også, at hvis støjen indeholder en stor andel af lavfrekvent støj, ”anbefales en endnu lavere grænse, fordi .... lavfrekvent støj kan forstyrre hvile og søvn selv ved lave lydtryk”. Hvor meget lavere er ikke angivet, men medmindre niveauet over 200 Hz er usædvanlig lavt, vil det samlede A-vægtede lydtrykniveau tydeligvis overstige f.eks. 25 dB i mange af tilfældene i Figur 12.

3.4.1 Den danske indendørsgrænse

Den danske indendørs aften/nat grænse for \( L_{T,ALF} \) i boliger på 20 dB [20] gælder ikke for målinger i enkelte positioner, men for niveauet målt med den metode, som er nævnt i afsnit 2.4. Metoden benytter energimiddelværdien af målinger i tre positioner. Én position i nærheden af et hjørne af rummet og to positioner, hvor klageren opfatter støjen som værende kraftigst. Antages det, at klageren udpeger
sådanne positioner korrekt, vil resultatet af hele metoden – energimiddelværdien med en hjørnemåling – stadig være et niveau tæt på det maksimale.

Det er ikke muligt umiddelbart at finde den maksimale værdi af $L_{\text{pALF}}$ blot ved at lægge niveauerne for 1/3-oktavbånd sammen fra Figur 11 eller Figur 12, da de forskellige 1/3-oktavbånd kan have deres maksimum i forskellige områder af rummet. Men 40 af de 81 mølle/rum kombinationer i Figur 12 overstiger et A-vægtet niveau på 20 dB for mindst ét 1/3-oktavbånd i 10-160 Hz området, og det er rimeligt at regne med, at det samlede lydtrykniveau for dette frekvensområde, $L_{\text{pALF}}$, vil overstige 20 dB for endnu flere mølle/rum kombinationer.

4 GENERELLE DISKUSIONER

4.1 Støj som funktion af møllestørrelse

Datamaterialet give et nyttigt overblik over, hvilken lydeffekt der udsendes fra vindmøller af forskellig størrelse, og med forsigtighed kan resultaterne benyttes til at anslå lydeffektniveauet for fremtidens større møller. Figur 13 gentager data for $L_{WA}$ fra Figur 1, nu med en ekstrapolering mod højere nominel elektrisk effekt samt data for den indsatte regressionslinie.

Regressionsslinjen i Figur 13 svarer til følgende sammenhæng mellem lydeffekten $P_A$ og den nominelle elektriske effekt, $P_E$:

$$P_A = konstant_1 \cdot \left( \frac{P_E}{1 \text{ MW}} \right)^{hældning}$$

$$10 \text{ dB}$$

(2)

hvor $hældning$ er hældningen af regressionslinjen, og $konstant_1$ kan beregnes fra det sidste led i ligningen for regressionslinjen. Da hældningen er 11,0 dB, er eksponenten 1,10, hvilket betyder, at lydeffekten stiger mere end proportionalt med den nominelle elektriske effekt. I den udstrækning, møllerne følger udviklingen fra regressionslinjen, udsender en vindmølle af dobbelt størrelse altså mere end den dobbelte lydeffekt.

Arealet $A$ af en cirkel, inden for hvilken en given støjgrænse er overskredet, er særlig Interessant. Radius af cirklen kan findes ved at løse ligning (1) med hensyn til $d$, og hvis den atmosfæriske absorption, som hovedsageligt har betydning ved høje
frekvenser og på lang afstand, udelades, finder man, at arealet er proportionalt med lydeffekten. Efter indsættelse af ligning (2) følger, at

\[ A = \text{konstant}_2 \cdot P_A = \text{konstant}_2 \cdot \text{konstant}_1 \cdot \left( \frac{P_E}{1 \text{ MW}} \right)^{\text{hældning}} \]

hvor \( \text{konstant}_2 \) afhænger af støjgrænsen.

Med regressionslinjens hældning stiger det støjramte areal altså mere end proportionalt med den nominelle elektriske effekt. Dette er et bemærkelsesværdigt resultat, når man tænker på den aktuelle udvikling med konstant stigende møllestørrelser og endda, i hvert fald i Danmark, strategien med at erstatte mange små møller med få større. Fra et støjforurenings-synspunkt forekommer dette som et skridt tilbage. Hvis den installerede nominelle elektrisk effekt er den samme, vil store vindmøller ramme et større areal med støj, end små møller vil.

Det skal tilføjes, at hældningen af regressionslinjen ikke er signifikant højere end 10 dB (90 % konfidensinterval [9,53 dB; 12,40 dB], \( p(\text{hældning} \leq 0 \text{ dB})=0,133 \)). Med en hældning på 10 dB er det støjbelastede areal det samme for store og små møller for den samme installerede nominelle elektriske effekt.

### 4.2 Variation mellem møller

Hvert datapunkt i Figur 13 er baseret på målinger på en enkelt mølle. For at tage højde for variationer mellem forskellige eksemplarer af samme møllemodel, bør der anvendes et højere lydeffektniveau ved projekplanlægning. Ifølge IEC TS 61400-14 [68], skal fabrikanterne specificere værdier, som er 1,645 gange standardafvigelsen mellem møller højere end middelværdien af møller af den givne model. Denne værdi svarer til den øvre grænse på et 90 % konfidensinterval, hvilket betyder, at sandsynligheden er 5 %, for at en tilfældig mølle af den aktuelle model udsender mere støj end den specifikerede værdi.

Størrelsen af denne sikkerhedsmargin afhænger således af variationen mellem møller af den aktuelle model. I Figur 13 er standardafvigelsenerne for møller af samme størrelse og fabrikat i området 1,6-3,5 dB, når der ses bort møllestørrelser, der omfatter gentagne målinger på en eller flere fysiske vindmøller. Da standardafvigelsen skal ganges med 1,645, bliver det typisk til en margin på adskillige decibel.

Broneske [69] påpegede, at mølleproducenterne ofte specificerer værdier, som ikke har den sikkerhedsmargin, der er angivet i IEC TS 61400-14. Forfatterne af denne rapport har også det indtryk, at minimumsaftande til boliger ofte beregnes ud fra støjdata, der mangler en passende sikkerhedsmargin. Brug af data uden sikkerhedsmargin som for eksempel middelværdier for en given møllemodel, målinger fra en enkelt mølle, eller ’bedste gæt’ for fremtidens vindmøller giver i princippet en sandsynlighed på 50 %, for at den/de faktisk opførte vindmølle(r) vil udsende mere støj end antaget, og at støjgrænsene vil blive overskredet, hvis projektet er planlagt lige til grænsen.
Det skal bemærkes, at selv små ændringer i lydeffektniveau kan resultere i betydelige ændringer i afstandskravene. Som et eksempel vil 3 dB højere lydeffektniveau resultere i et 41 % højere afstandskrav, når der er tale om en enkelt mølle.

4.3 Data fra projekt WINDFARMperception
Van den Berg er al. [70] har gennemført en undersøgelse af visuelle og akustiske effekter af vindmøller for naboerne. Som en del af undersøgelsen (kendt som projekt WINDFARMperception) blev indsamlet målte spektrer af støj fra vindmøller. Lydeffektniveauer målt ved 8 m/s for 28 møller på 80 kW til 3 MW og givet i oktavbånd blev udvalgt til beregning af lydtrykniveauer hos naboer. Kun fire møller er over 2 MW, men hvis tre 2 MW møller regnes med i gruppen af store møller, er det muligt at foretage en relevant sammenligning af store og små møller.

Figur 14 viser middelværdierne for møller < 2 MW og ≥ 2 MW.

Også med disse data ligger den lavfrekvente del klart højere for store møller end for små. Niveauforskellen ved 63 og 125 Hz er statistisk signifikante (t=[2,70; 2,39], d.f.=[12,8; 16,9], ensidet p=[0,009; 0,015]).

Forskellene (3,6 og 2,2 dB) er i samme størrelsesorden som forskellene i denne undersøgelse (sammenlign med Figur 4).

En sammenligning med data fra denne undersøgelse regnet om til oktavbånd viser desuden næsten ens værdier i de to undersøgelser, se Figur 15. Data fra de to
undersøgelser for den samme møllegruppe er ikke signifikant forskellige ved nogen frekvens. (Der er ingen overlap i de originale data).

**Figur 15.** Normeret A-vægtet lydeffektniveau i oktavbånd, middelværdi af to grupper af møller: < 2 MW og ≥ 2 MW og fra to undersøgelser: van den Berg et al. [70, Appendix D] og denne undersøgelse.

### 4.4 Tonekomponenter

Søndergaard og Madsen [71] konkluderer 1) at "frekvensspektrene af den aerodynamiske støj fra vindmøllestationerne afviger for de store vindmøller ikke væsentligt fra frekvensspektrene for de mindre vindmøller. Det betyder, at den lavfrekvente aerodynamiske støj ikke er mere fremtrædende for store møller end for mindre møller", 2) at en konstaterer "tværs af bogseringsfrekvenser under 200 Hz", og 3) at dette "er ikke usædvanligt for prototyper, og almindeligvis er de færdigudviklede vindmøller forbedret med hensyn til støjemission og specielt med hensyn til hørbare toner i støjen".

tydelige toppe i 1/3-oktavbånd (Figur 5), og at deres støjudsendelse ($L_{WA}$ og $L_{WALF}$) ikke er lavere end for Mølle 1-4, måske tværtimod (Figur 1).

Med hensyn til reduktion af tonestøj, refererer Søndergaard og Madsen flere gange til tonetillægget som et middel til at sikre, at tonerne faktisk bliver reduceret, inden møllerne kommer på markedet, og de bruger udtryk som ”den nødvendige reduktion af tonerne” [71] og ”...reduced to a level where there is no penalty, according to the Danish rules...” [44, 71] (”...reduceret til et niveau, hvor der ikke er noget tillegg efter de danske regler... ”, forfatternes oversættelse). Søndergaard og Madsen har åbenbart set bort fra det faktum, at resultaterne af deres toneanalyser ikke udløser tonetillæg til nogen af møllerne (afsnit 3.1.3).

Et nærmere kig på data viser, at selvom nogle af toppene i 1/3-oktavbånd ved lave frekvenser er meget tydelige, er toppene ikke generelt ansvarlige for forskellen mellem små og store møller. Figur 16 viser en tænkt situation, hvor alle toppe under 200 Hz er fjernet fra de store møller ved at erstatte niveauet ved toppene med niveauer fremkommet ved lineær interpolation mellem niveauerne i de to tilstødende 1/3-oktavbånd. 1-3 toppe er fjernet for de enkelte møller, bortset fra Mølle 4, som ikke har toppe i dette frekvensområde. Det er kun fjernelsen af 40 Hz-toppen for Mølle 2, der påvirker middelværdien for de store møller med mere end 1,0 dB.

*Figur 16. Normerede A-vægtede lydeffektniveauer givet i 1/3-oktavbånd. Middelværdi af 36 møller $\leq$ 2 MW (tyk sort linje) og individuelle møller $> 2$ MW. Toppe i 1/3-oktavbånd under 200 Hz fjernet fra de store møller ved at erstatte niveauet ved toppen med niveauer opnået ved lineær interpolation mellem niveauerne for de to omkringliggende 1/3-oktavbånd. Farvekode for møller som i Figur 5.*
Generelt ligger de store møller stadig over middelværdien af de små møller i lavfrekvensområdet. Forskellen mellem middelværdien af de store (> 2 MW) og små møller (≤ 2 MW) er fortsat signifikant i de samme 1/3-oktavbånd, som den var med toppene (63-160 Hz (uændret over 160 Hz): $t=[3,03; 3,59; 2,81; 2,83; 3,18]$, d.f.$=[22,4; 23,6; 17,0; 19,2; 18,9]$, ensidet $p=[0,003; <0,001; 0,006; 0,005; 0,003]$).

Den påfaldende lighed med spektrene fra van den Berg et al. [71] (Figur 15) støtter, at spektrene for de store møller fra det foreliggende projekt er representativt for møller i denne størrelse.

4.5 Jordrefleksion

I beregningerne af lydtrykniveau ved naboerne, tages der hensyn til jordrefleksionen ved at lægge 1,5 dB til den direkte lyd. Som nævnt i afsnit 2.3, benyttes værdien 1,5 dB i de danske regler for vindmøller [50]. De svenske retningslinjer siger, at der skal lægges 3 dB til den direkte lyd (for afstand op til 1000 m) [72], en værdi, som også følger af ISO 9613-2 [48] for det lavest angivne oktavbånd, 63 Hz, uafhængigt af jordoverfladen. Under målerne af lydeffektniveau fra møllerne [47] antager det, at jordens refleksion tilføjer så meget som 6 dB til den direkte lyd. Der anvendes ganske vist en reflekterende plade under mikrofonen, men pladen har kun ringe effekt ved lave frekvenser, hvor den antagne 6 dB refleksion hovedsageligt skyldes selve jordfladen.

En mulig destruktiv interferens mellem den direkte lyd og jordrefleksionen, hvis modtageren er hævet over jorden, vil have ringe virkning ved lave frekvenser. Ved eksempelvis en kildehøjde på 75 m, en vandret afstand på 800 m og en modtagerhøjde på 1,5 m vil forsinkelsen mellem direkte lyd og jordrefleksionen kun være 0,8 ms, hvilket svarer til et første dyk i lydtransmissionen ved 625 Hz (retilinet lydudbredelse).

På denne baggrund er det rimeligt at formode, at et tillæg på 1,5 dB for jordrefleksionen er for lavt ved lave frekvenser, og at højere værdier op til et teoretisk maksimum på 6 dB vil være mere passende. Således vil den procedure, der er anvendt til at beregne det udendørs lydtrykniveau ved naboerne, sandsynligvis undervurderen den lavfrekvente lyd.

4.6 Vinduer

Målerne af lydisolation blev lavet med lukkede vinduer. Men i store dele af verden, foretrækker mange mennesker at sove med vinduerne i det mindste lidt åbne, og WHO anbefaler, at stoigrenserne skal muliggøre dette [66, 73]. I Danmark laves indendørs målinger af lavfrekvent støj som regel med lukkede vinduer, men hvis klageren mener, at stoen er kraftigere med åbne vinduer, skal der også laves målinger for denne situation [20]. Det havde derfor været relevant også at have målt lydisolationen med lidt åbne vinduer og vurderet de deraf følgende indendørs lydtrykniveauer.
4.7 Estimerede lydeffekter for endnu større møller

I afsnit 3.1.2 sås den spektrale forskel mellem små og store møller i form af forskelle i de normerede lydeffektniveauer for bestemte 1/3-oktavbånd. Som en alternativ måde at betragte dette på viser Figur 17 normerede spektrer for store og små møller, men med data for de små møller flyttet en 1/3 oktav nedad i frekvens.

![Figur 17. Normerede A-vægtede lydeffektniveauer for 1/3-oktavbånd. Middelværdier for to grupper af møller; ≤ 2 MW og > 2 MW, gruppen af små møller forskudt 1/3 oktav nedad i frekvens. (Mølle 6 ikke medregnet over 2 kHz, se Afsnit 3.1.2).](image)

De to kurver ligger meget tæt på hinanden i det meste af frekvensområdet, hvilket betyder, at spektret har fastholdt sin form, men er forskudt cirka 1/3 oktav nedad i frekvens fra små til store møller (sammenlign med Figur 4). Forskelle ved de laveste frekvenser kan være reelle eller være resultatet af måleusikkerhed ved disse frekvenser på grund af baggrundsstøj, et spørgsmål der ikke er gjort fuldstændigt rede for i datamaterialet.

For den læser der måtte mene, at en forskydning på en enkelt 1/3 oktav er beskeden, er det værd at bemærke, at det svarer til det musikalske interval en stor ters, næsten forskellen mellem to strenge ved siden af hinanden på en guitar.

De logaritmiske middelværdier af de nominelle elektriske effekter for små og store møller er omkring henholdsvis 650 kW og 2,6 MW, og det spektrale skift nedad på cirka 1/3 oktav svarer derfor til et skift opad i den nominelle elektriske effekt med en faktor i størrelsesordenen 4. Det vil derfor være relevant at foreslå, at støjspektret forskyder sig yderligere cirka 1/3 oktav nedad for fremtidige vindmøller i 10 MW klassen.
Som et supplement til den lineære regression og ekstrapolation for $L_{WA}$ i Figur 13, er konstrueret et bud på typiske spektre for vindmøller omkring 2,5, 5 og 10 MW til mulig (forsigtig) brug i fremtidige projekter. Figur 18 viser en sjette-ordens-polynomie regression af middelværdien af det relative spektrum for møllerne over 2 MW.

![Diagram](image.png)

**Figur 18.** Sjette-ordens-polynomie regression (blå linje) af middelværdi af normerede A-vægtede lydeffektniveauer (rød linje med runde markeringer) for møller med nominel elektrisk effekt > 2 MW. (Mølle 6 ikke medregnet over 2 kHz, se Afsnit 3.1.2).

Tabel 3 giver relative lydeffektniveauer i 1/3- og 1/1-oktavbånd for 2.5 MW møller fra regressionen i Figur 18 og, for 5 og 10 MW møller, data forskudt henholdsvis 1/6 og 1/3 oktav nedad i frekvens. Desuden giver tabellen absolutte niveauer baseret på den lineære regression af $L_{WA}$ i Figur 13. Bemærk, at estimaterne er baseret på middelværdier af møller, og at de ikke indeholder en sikkerhedsmargin som nævnt i afsnit 4.2.

Tabellens værdier for det absolutte niveau i 1/3-oktaver er desuden vist i Figur 19.
<table>
<thead>
<tr>
<th>Frek. [Hz]</th>
<th>Relativt niveau i forhold til LWA</th>
<th>Absolut niveau</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2.5MW 5 MW 10 MW 2.5MW 5 MW 10 MW</td>
<td>2.5MW 5 MW 10 MW 2.5MW 5 MW 10 MW</td>
</tr>
<tr>
<td>31.5</td>
<td>-37.4 -35.3 -33.2</td>
<td>68.1 73.5 78.9</td>
</tr>
<tr>
<td>40</td>
<td>-29.0 -27.0 -25.3</td>
<td>76.5 81.8 86.8</td>
</tr>
<tr>
<td>50</td>
<td>-25.3 -23.6 -22.0</td>
<td>80.2 85.2 90.1</td>
</tr>
<tr>
<td>63</td>
<td>-22.0 -20.5 -19.1 -16.7 -15.3 -14.0</td>
<td>83.5 88.3 93.0 88.8 93.5 98.1</td>
</tr>
<tr>
<td>80</td>
<td>-19.1 -17.8 -16.8</td>
<td>86.4 91.0 95.3</td>
</tr>
<tr>
<td>100</td>
<td>-16.8 -15.8 -15.0</td>
<td>88.7 93.0 97.1</td>
</tr>
<tr>
<td>125</td>
<td>-15.0 -14.2 -13.4 -10.0 -9.3 -8.6</td>
<td>90.5 94.6 98.7 95.5 99.5 103.5</td>
</tr>
<tr>
<td>160</td>
<td>-13.4 -12.8 -12.3</td>
<td>92.1 96.0 99.8</td>
</tr>
<tr>
<td>200</td>
<td>-12.3 -11.9 -11.5</td>
<td>93.2 96.9 100.6</td>
</tr>
<tr>
<td>250</td>
<td>-11.5 -11.2 -11.0 -6.8 -6.5 -6.3</td>
<td>94.0 97.6 101.1 98.7 102.3 105.8</td>
</tr>
<tr>
<td>315</td>
<td>-11.0 -10.8 -10.6</td>
<td>94.5 98.0 101.5</td>
</tr>
<tr>
<td>400</td>
<td>-10.6 -10.6 -10.5</td>
<td>94.9 98.2 101.6</td>
</tr>
<tr>
<td>500</td>
<td>-10.5 -10.5 -10.5 -5.8 -5.8 -5.8</td>
<td>95.0 98.3 101.6 99.7 103.0 106.3</td>
</tr>
<tr>
<td>630</td>
<td>-10.5 -10.6 -10.7</td>
<td>95.0 98.2 101.4</td>
</tr>
<tr>
<td>800</td>
<td>-10.7 -10.8 -11.0</td>
<td>94.8 98.0 101.1</td>
</tr>
<tr>
<td>1000</td>
<td>-11.0 -11.3 -11.5 -6.3 -6.5 -6.8</td>
<td>94.5 97.5 100.6 99.2 102.3 105.3</td>
</tr>
<tr>
<td>1250</td>
<td>-11.5 -11.9 -12.4</td>
<td>94.0 96.9 99.7</td>
</tr>
<tr>
<td>1600</td>
<td>-12.4 -12.9 -13.5</td>
<td>93.1 95.9 98.6</td>
</tr>
<tr>
<td>2000</td>
<td>-13.5 -14.3 -15.1 -8.8 -9.5 -10.2</td>
<td>92.0 94.5 97.0 96.7 99.3 101.9</td>
</tr>
<tr>
<td>2500</td>
<td>-15.1 -16.0 -17.2</td>
<td>90.4 92.8 94.9</td>
</tr>
<tr>
<td>3150</td>
<td>-17.2 -18.4 -20.0</td>
<td>88.3 90.4 92.1</td>
</tr>
<tr>
<td>4000</td>
<td>-20.0 -21.6 -23.3 -14.7 -16.1 -17.8</td>
<td>85.5 87.2 88.8 90.8 92.7 94.3</td>
</tr>
<tr>
<td>5000</td>
<td>-23.3 -25.3 -27.5</td>
<td>82.2 83.5 84.6</td>
</tr>
<tr>
<td>6300</td>
<td>-27.5 -29.9 -32.8</td>
<td>78.0 78.9 79.3</td>
</tr>
<tr>
<td>8000</td>
<td>-32.8 -35.6 -38.5 -26.1 -28.7 -31.5</td>
<td>72.7 73.2 73.6 79.4 80.1 80.6</td>
</tr>
<tr>
<td>10000</td>
<td>-38.5 -41.9 -45.2</td>
<td>67.0 66.9 66.9</td>
</tr>
<tr>
<td>$L_{WA}$</td>
<td></td>
<td>105.5 108.8 112.1 105.5 108.8 112.1</td>
</tr>
</tbody>
</table>

**Tabel 3.** Estimerede relative og absolutte A-vægtede lydeffektniveauer for møller omkring 2,5, 5 og 10 MW baseret på sjette-ordens-polynomie approksimationen af middel relativt niveau for møller > 2 MW fra Figur 18 og $L_{WA}$ fra den lineære regression i Figur 13. Relative niveauer forskudt 1/6 og 1/3 oktav kedad i frekvens for henholdsvis 5 og 10 MW. Approksimationen justeret med +0,38 dB for at opnå et totalt relativt niveau på 0 dB, hvilket middelværdien af relative data (og dens approksimation) ikke nødvendigvis har. Bemærk, at estimaterne er baseret på middelværdier af møller, og at de ikke indeholder en sikkerhedsmargin som nævnt i afsnit 4.2.
4.8 Atmosfæriske forhold


Med cylindrisk udbredelse fra 200 m gælder følgende ligning (for afstande over 200 m):

\[ L_p = L_{WA} - 20 \text{ dB} \cdot \log_{10} \left( \frac{200 \text{ m}}{1 \text{ m}} \right) - 10 \text{ dB} \cdot \log_{10} \left( \frac{d}{200 \text{ m}} \right) - 11 \text{ dB} \cdot x \cdot d + 1,5 \text{ dB} \]  

\[(4)\]

Tabel 4 og Figur 20 viser henholdsvis nøgletal og lydtrykniveauer i 1/3-oktavbånd i den afstand, hvor det A-vægtede lydtrykniveau er faldet til 35 dB under forudsætning af cylindrisk udbredelse fra 200 m.

<table>
<thead>
<tr>
<th>Afstand [m]</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>Middel</th>
<th>små</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_{pA} [dB]</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
</tr>
<tr>
<td>L_{pAFL} [dB]</td>
<td>29.7</td>
<td>28.2</td>
<td>30.3</td>
<td>29.2</td>
<td>29.4</td>
<td>29.7</td>
<td>30.7</td>
<td>30.0</td>
<td>29.7</td>
<td>29.6</td>
<td>25.6</td>
</tr>
<tr>
<td>L_{pAFL-L_{pA}} [dB]</td>
<td>-5.3</td>
<td>-6.8</td>
<td>-4.7</td>
<td>-5.8</td>
<td>-5.6</td>
<td>-4.3</td>
<td>-5.0</td>
<td>-5.3</td>
<td>-5.4</td>
<td>-9.4</td>
<td></td>
</tr>
<tr>
<td>L_{pG} [dB]</td>
<td>60.4</td>
<td>56.2</td>
<td>57.1</td>
<td>60.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Det er nødvendigt med meget større afstande (1414-3482 m) for at nå ned på 35 dB end med ren sfærisk udbredelse, og den lavfrekvente karakter af spektret er blevet endnu mere udtalt (sammenlign med Tabel 1 og Figur 9). Cylindrisk udbredelse kan forklare tilfælde, hvor rumlen af vindmøller hævdes at være hørbar kilometre væk. Et worst-case scenario, der kombinerer temperaturinversion med en vindmøllepark, der opfører sig som en linjekilde i et vist afstandsområde, kan teoretisk set reducere den geometriske dæmpning i dette område til nul. Det er imidlertid nødvendigt med mere viden om de atmosfæriske forhold og forekomsten af forskellige fænomener.

Der er også andre fænomener med relation til de atmosfæriske forhold, som fortjener en vis opmærksomhed. Det antages normalt, at vindhastigheden stiger logaritmisk med stigende højde over jorden, startende med en hastighed på nul i en højde svarende til den såkaldte ruhedslængde af jordoverfladen. Når man kender ruhedslængden, kan vindhastigheden i alle højder således bestemmes ud fra målinger i en enkelt højde. Vindhastigheden i en højde af 10 m anvendes som reference for målinger af vindmøllestøj [47].

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En anden konsekvens af stor variation af vindhastigheden med højden er, at møllen kan udsende støj, som svarer til en høj vindhastighed – og langt højere end antaget ud fra vindhastigheden målt i 10 meters højde – mens det er helt stille ved jorden. Der er således mere møllestøj end forventet, men mindre vind, og møllestojen vil derfor ikke være maskeret med naturlig vindskabt lyd, sådan som den måske ville have været med den logaritmiske vindprofil.

Flere forfattere har fremført, at den logaritmiske vindhastighedsprofil og en referencehøjde på 10 m ikke er hensigtsmæssige for moderne, høje vindmøller (f.eks. van den Berg [81], Botha [78], Palmer [79], Almgren et al. [84]), og en revideret IEC 61400-11 vil benytte den reelle vindhastighed i navhøjde som reference [85]. Vindprofiler og -statistik for det faktiske opstillingsområde kan derefter anvendes i støjberegning og regulering.
5 KONKLUSIONER

Resultaterne bekræfter den hypotese, at spektret af vindmøllestøj flytter sig nedad i frekvens med stigende møllestørrelse. Den lavfrekvente relative andel af den udsendte støj er højere for store vindmøller (2,3-3,6 MW) end for små vindmøller (≤2 MW). Forskellen er statistisk signifikant for 1/3-oktavbåndene i frekvensområdet 63-250 Hz. Forskellen kan også udtrykkes som en forskydning af spektrum på omkring 1/3 oktav. Et yderligere skift af lignende størrelse må forventes for vindmøller i 10 MW størrelsen.

Når man ser på lydtrykniveauet udendørs i relevante naboafstande, bliver det lavfrekvente indhold endnu mere udtalt. Det skyldes, at luftens absorption reducerer de høje frekvenser meget mere end de lave. Selv når der ses på A-vægtede niveauer, udgør lave frekvenser en væsentlig del af stojen, og for mange af de undersøgte store vindmøller ligger det 1/3-oktavbånd, som har det højeste lydtrykniveau, på eller under 250 Hz. Det er således hævet over enhver tvivl, at den lavfrekvente del af spektrum spiller en vigtig rolle i støjen ved naboerne.

Den indendørs lavfrekvente støj i naboafstand varierer med vindmølle, lydisolation af rummet og position i rummet. Hvis stojen fra de undersøgte store vindmøller har et udendørs A-vægtet lydtrykniveau på 44 dB, det maksimale i den danske regulering af støj fra vindmøller, er der risiko for, at en betragtelig del af beboerne vil være generet af lavfrekvent støj, selv indendørs. Den danske aften/nat-grænse på 20 dB for A-vægtet støj i frekvensområdet 10-160 Hz, som gælder for støj fra virksomheder (men ikke for vindmøllestøj), vil blive overskredet i opholdsrummene hos mange af de naboer, der ligger tæt ved grænsen på de 44 dB. Problemerne reduceres betydeligt med en udendørs grænse på 35 dB.

Vindmøllerne udsender ganske vist infralyd (lyd under 20 Hz), men niveauerne er lave, når man tager menneskets følsomhed overfor disse frekvenser i betragtning. Selv tæt på møllerne er lydtrykniveauet langt under den normale høretærskel, og infralyd betragtes således ikke som et problem for møller af samme konstruktion og størrelse som de undersøgte møller.

Den lavfrekvente støj fra flere af de undersøgte store møller indeholder toner, formodentlig fra gearkassen, som resulterer i toppe i de tilsvarende 1/3-oktavbånd. Tonetillægg hjælper ikke til at sikre, at tonerne bliver fjernet eller reduceret, da tonerne ikke er tilstrækkeligt udtalte, til at de overhovedet udloser et tonetillæg. Den spektrale forskel mellem store og små vindmøller er i øvrigt fortsat statistisk signifikant, selvom toppene i 1/3-oktavbåndene fjernes.

Ovenstående konklusioner er baseret på data for møller i området 2,3-3,6 MW nominel elektrisk effekt. Problemerne med lavfrekvent støj må forventes at blive større med endnu større møller.

Den udsendte A-vægtede lydeffekt stiger proporcionalt med den nominelle elektriske effekt eller sandsynligvis endnu mere. Derfor forurener store vindmøller

Der er forskelle på flere decibel mellem støjen fra forskellige møller af samme størrelse, selv for møller af samme fabrikat og model. Det er derfor ikke relevant at foretage beregninger ned til brøkdele af en decibel og træ på, at dette holder for de aktuelle møller, som bliver stillet op. Der må indregnes en vis sikkerhedsmargin i planlægningsfasen for at sikre, at de faktisk rejste vindmøller vil overholde støjgrænserne. Der findes en international teknisk specifikation til dette, men den anvendes ofte ikke.

Referencer


[31] "The measurement of low frequency noise at three UK wind farms", Hayes McKenzie Partnership Ltd. for Department of Trade and Industry (DTI), Contract No. W/45/00656/00/00, URN No. 06/1412, UK, 2006.


