Wind Turbines and Health:

A Modified Scoping Review

April 2011

KFL&A PublicHealth

An accredited local public health agency affiliated with Queen's University

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This report has been prepared for Kingston, Frontenac, Lennox & Addington (KFL&A) Public Health. The opinions expressed herein are the opinions of the authors and do not necessarily represent those of KFL&A Public Health.

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Table of Contents

MAIN MESSAGES

Overview - The increased use of wind turbines has created a situation where there have been strong negative reactions from community-based organizations (CBOs) with acceptance issues and conclusions that wind turbines cause ill health. However, government and Public Health support the assertion that there is no evidence of adverse health effects. CBO conclusions typically are based upon individual claims and several case studies reported on the internet; whereas, Public Health generally relies on the limited wind turbine research and expert opinion. To address the different conclusions and to better understand the situation, we conducted a modified scoping review of the literature from multiple sources: wind turbine and health, noise and health, government and industry, and advocacy groups and news media.

1) **A review of the literature in the five categories does not provide evidence of and does not suggest the likelihood of a causal relationship between ill health and wind turbine noise emissions that meet Canadian and international guidelines.**
    - Two large sample European studies (N = 754 & 725) using masked surveys found no association between self-reported health outcomes and sound exposure levels.
    - Evidence from the noise and health evidence base supports the lack of health effect findings from the large sample studies and the conclusions that wind turbine noise exposure levels are below levels known to cause ill health.

2) The case series and other studies that are highly reported on the internet in CBO websites had significant methods problems such as: a) self-selection of subjects who had previously concluded the wind turbines were causing ill health and who also knew the purpose of the survey, b) use of a symptoms check list and proxy respondents, and c) use of terms such as 'affected' or 'victims' in the recruitment process. These issues serve to significantly decrease confidence in results and conclusions from those studies. In addition, case studies can never be used to make conclusions of causal relationships.

3) Debate exists about whether annoyance is a feeling or state or a negative health outcome. Wind turbine research indicates a dose-response between noise and annoyance exists. The research indicates that a small percentage of people are very annoyed by wind turbine noise and that only a small percentage of annoyance is explained by the noise itself and that other factors exert a considerable influence (e.g., attitudes, can see the source, culture, ability to control the noise, mental health, financial benefits and perceived importance). There exists an intermediate pathway that includes knowing of the existence of the wind turbines and seeing and/or hearing them which then goes through the individual characteristics before the response is annoyance. Thus, we cannot attribute the annoyance (and effects of chronic annoyance) to the wind turbine noise alone.

4) Addressing local acceptance will require better approaches to the public consultation process including community equity issues. Public Health and government need to develop a better response such as: a) improved knowledge broker activities that include public education; b) developing a more comprehensive web presence which implements strategies to ensure credible websites and documents appear among the first results of internet searches; and c) providing the public with access to the tools to assess the validity of the health related information they find.

5) Research - Although our main finding is that wind turbine and the noise and health evidence do not support conclusions that wind turbines cause ill-health, there is a need to conduct further rigorous research in multiple settings that do not rely on self-reported health outcomes and where noise exposure is measured (not modeled) both outside and inside residences.

6) There is need of a formal complaint resolution mechanism that can provide effective remedies for residences with complaints. This mechanism should involve sound pressure level measurements at the residences (inside and outside) under different wind conditions and a pre-determined resolution/adjudication process.

EXECUTIVE SUMMARY

INTRODUCTION

Medical Officers of Health at local Public Health Agencies are frequently approached by individuals and community-based organizations (CBOs) with strongly expressed concerns about health impact of wind turbines. Consequently, local Public Health agencies have identified wind turbines as a priority issue that warrants attention. The rapid increase in current and planned use of wind turbines as a source of renewable energy has created a situation where there are often strong negative reactions from community groups and an inadequate response from Public Health and provincial government. The result is two groups with opposing conclusions. Provincial governments and Public Health generally support for the assertion that there is no credible evidence that exposure to wind turbine noise or other emissions causes ill health; whereas, some community groups support the belief that living near wind turbines causes serious health problems.

Two main factors appear to be driving this rift. One is that the internet is often the first or only source of information for many. A second factor is the lack of empirical peer-reviewed evidence from large sample studies that evaluated the health impact of wind turbines. For example, a review of statements and documents available in the websites of CBOs indicates that they are: a) less willing to accept statements from Public Health, provincial governments, or industry experts; and b) more willing to accept, and believe as proof of causality, individual claims or anecdotal evidence from several case studies frequently reported on the internet.

Given the above, there was a need to provide information that better inform those with concerns and which would increase the ability of Public Health to provide a more informed response to health concerns about exposure to wind turbines. Thus, to address this gap, we conducted a *modified scoping review* of the literature: to synthesize the current information by documenting and evaluating what is known; to assess the evidence typically used by groups with opposing conclusions; to identify where gaps exist; and to borrow from other relevant research. The focus of our review was on noise emissions.

Research Question

1) What information is reported in peer reviewed and grey/self published literature about the health impact of wind turbines?
2) Are there differences in the quality of the information and the conclusions reached in the peer reviewed versus the grey/self-published literature?
3) What information is reported in the peer reviewed noise and health literature that is relevant and can be applied to concerns about noise exposure from wind turbines?

Methods

We used a modified version of the five stage methodological framework for conducting scoping studies developed by Arksey and O'Malley (2005). The five stages used in this study are:

1) Identifying the research question
2) Identifying relevant studies (& other documents)
3) Study (& other document) selection
4) Charting the data
5) Collating, summarizing and reporting the results

The literature search included the following electronic databases: Medline, CINAHL, Embase, Cochrane Library, PsychInfo, and Global Health. The initial search covered literature from 1985 to the 2009. [Note: as time passed we also included documents (indexed and grey literature) published in 2010.] Identified papers were then grouped according to thematic categories: 1) Wind Turbines and Health - Peer Reviewed Research; 2) Wind Turbines and Health - Self-Published/Grey Literature Research;3) Government and Industry – Technical Information, Guidelines and Standards; 4) Community Based Organizations, Advocacy Groups and News Media; 5) Noise and Health in Other Settings - Peer Reviewed Research.

Results

Internationally, the proliferation of wind energy capacity has generated local resistance and concerns about possible adverse health consequences associated with wind turbine noise emissions. The peer reviewed wind turbine and health evidence base is limited and has mostly focused on the relationships between wind turbine noise emissions, perceptions and attitudes, and annoyance. This gap in the evidence has resulted in a situation where those with concerns were not satisfied with the available research or the responses from government and Public Health and where they have increasingly looked to the internet to provide this information.

In the following section we will first summarize information from the Community Based Organizations, Advocacy Groups and News Media category to contextualize the issue relating to public concern and what is frequently available on the Internet. Second, we will summarize the results from Categories 2 and 3 (Wind Turbines and Health - Peer Reviewed Research and Wind Turbines and Health - Self-Published/Grey Literature Research) which will include an analysis of what we know and need to know. Third, we will summarize the results from Category 3 (Government and Industry – Technical Information, Guidelines and Standards) which will provide information on known wind turbine sound emissions and government guidelines. Fourth, we will summarize the results from Category 5 (Noise and Health in Other Settings - Peer Reviewed Research) in order to contextualize what is known about wind turbine emissions based upon the noise and health evidence and to better understand and the strengths and weaknesses of the opposing conclusions reached about the potential health impact of exposure to wind turbine noise emissions.

1. Community-based Organizations, Advocacy Groups and News Media

This category was created to group together documents from entities writing about wind turbines that were commenting on or retransmitting information from other sources. This includes community and advocacy groups, frequently found on the Internet, as well as all forms of news media. Our intention was not to be exhaustive in identification of these documents which number in the hundreds of thousands but to give a representative sample of what someone searching the internet would come across. Thus preference was given to those articles or organizations appearing high on Google searches, as well as to those news articles and other sources relied upon by community-based groups. Results in the full report are reported in two categories: 1) articles, opinion pieces, advertising or other commentary by community or advocacy groups, and 2) news media.

Results

The total number of documents that could have been reviewed for this category is vast. However, repetition (saturation) occurs very quickly upon a review of the available document. We selected 18 documents for analysis and to be included in the full report. Below is a list of symptoms reported by news sources, CBOs and advocacy groups as being attributed to wind turbine exposure. Some or all of these symptoms are reported in the large number of websites and documents available on the internet and in many news articles. Some of these symptoms are include in the broad descriptions of wind turbine syndrome and/or vibroacoustic disease, and may have been reported that way.

Symptoms reported by news sources, CBOs and advocacy groups

Anxiety	Stress	Irritation	Panic episodes
Dizziness	Vertigo	Nausea	Hearing problems
Tinnitus/Ringing in ears	Earaches	Headaches	Acute hypertension
Increased blood pressure	Sleep disturbances	Insomnia	Tiredness
Work disturbances	Loss of motivation	Body vibrations	Chest flutters
Heart beat irregularities	Heart palpitations	Loss of feeling in body parts	
Weight changes	Depression	Cognitive Impairment	

Conclusions

a) **Understanding fear/concern -** For many people the internet is often the first and frequently the main source of health information. Given this and based upon list of health issues an internet searcher would come across, one can clearly understand why the average person consulting the Internet or reading the newspaper could become very worried.

b) Notable features of the non-news documents from this category are the extreme skepticism towards the government (and industry) and the belief that only medical doctors or other health professionals are qualified to do research or comment on the known or potential health impact of wind turbines. A notable feature of the news media documents was the pursuit of a 'balanced' approach (both critics and proponents being interviewed). This allowed for the introduction of inflammatory statements (e.g., industrial plague) and claims/conclusions in the absence of a critical review of the evidence.

c) **Problems with the Internet -** The internet has been described as "information without knowledge" and the amount of information is vast. For example, simple internet search using the terms wind turbines and health will return close to 2 million results and a search using the term 'wind turbine syndrome' will provide close to 60,000 results. Internet searchers will frequently come across documents that claim research by experts has proven a causal relationship. The problem with the web documents is their extensive use of the results and conclusions from the few but widely reported case and community-survey studies in the absence of any critical appraisal of the methods used and the validity of conclusions reached based upon the methods.

2. Wind Turbines and Health - Peer Reviewed Research and Self-Published/Grey Literature

At the beginning of this project we decided to create two separate categories (e.g., 1) peer reviewed, and 2) grey/self-published literature) for documents based upon whether or not the papers were published in peer reviewed scientific journals or if they were self-published or grey literature. This decision was a result of initial literature searches suggesting that scientific rigor and frequently reported results and conclusions differed depending upon the category. Further literature searches demonstrated that this was not the situation. To address this finding in the full report we separated Category 2 documents (Wind Turbines and Health – Grey/Self Published Research) into two sub-categories based upon the conclusions or suggestions that wind turbine noise emissions were associated with adverse health consequences. Thus, in the full report we present the results and conclusions separately for documents in the two main wind turbine and health categories (Peer Reviewed and Grey/Self-Published Research) with the Grey/Self-Published section separated by two sub-categories: i) Case studies and other papers that support the conclusion of negative health effects; and ii) Other papers that do not support or suggest adverse health effects. However, in this summary we will combine the results.

Overview
We evaluated 52 papers that we found eligible for Categories 1 and 2. Study designs included: a) cross sectional studies with sample sizes ranging from 115 -1,822; b) a single experiment; c) case study; d) key informants; e) grounded theory; and f) Other (e.g., literature review, descriptive, mixed methods, synthesis)
We recognize that there are some documents that we missed particularly in the grey/self-published category and additional ones published after 2009. However, it was not our intent and time and human resources did not permit an exhaustive review of all available literature. Our main objective was to achieve a good understanding of what is known or not known and also to identify common policy suggestions and gaps or research needs.

Two themes clearly emerged when reviewing the documents. The first was that there were two distinct groups with opposing conclusions. One group concluded that exposure to wind turbines causes serious health problems; whereas, the second group supported the assertion that there is no evidence that exposure directly causes ill health. The group that reached the conclusion that wind turbines do not directly cause ill health acknowledges that a small percentage are annoyed by wind turbines; whereas, those in the ill-health group have concluded that the list of illnesses and symptoms (below) can or will result from exposure to wind turbines.

anxiety	stress	irritation/annoyance	panic episodes
dizziness	hearing problems	vertigo	tinnitus
ear aches	acute hypertension	cognitive impairment	work disturbances
loss of motivation	chest flutters	body vibrations	palpitations -
sleep disturbances	insomnia	tiredness	heart beat irregularities
headaches	migraines	nausea	loss of feeling in body parts
weight changes	depression	Wind Turbine Syndrome	Vibroacoustic Disease

The second theme that emerged was that it was not in the separation between peer reviewed and the non-peer reviewed (grey and self-published) literature where the different conclusions were generally found. It was based upon the methods used. For example the documents that reported the case studies (Pierpont, Harry, Nissenbaum, Alves-Pereira & Castelo Branco) or the invited community survey (Krogh et al.) concluded or supported the claims of ill health as opposed to the two masked cross sectional studies and synthesis papers that did not.
A very clear example of the differences can be illustrated by a comparison between an Ontario study reported by Krogh et al., (2010) and the Dutch study reported by Frits van den Berg et al., (2008). In short, Krogh et al., reported that 80.3% of their sample (N = 132) suffered from adverse health effects. Whereas, van den Berg et al., found no statistically significant association between wind turbine exposure and health outcomes (N = 725).

Krogh et al. (2010)
The Ontario study is titled: "A self-reporting survey: adverse health effects with industrial wind turbines and the need for vigilance". The report includes the following from the abstract:

> *"Victims report disturbed living conditions and loss of quality of life and enjoyment of their homes and property, and financial loss due to the negative impact to the health of their families….. Comments from the victims are included in this report. They are both revealing and disturbing. No authority or compassionate member of our society can ignore the moving descriptions of the victims' experiences."*

Methods for this study included distributing "Health Survey Contact Flyers" to people who lived near wind farms where the fliers included statements such as: "victims suffering from adverse health effects from wind turbine complexes are hesitant to report due to the manner in which their reports have been discounted". People who responded to the fliers were then provided access to the survey instrument which included a symptoms check list (borrowed from the Harry study). The design allowed initial self-selection and multiple respondents per residence if additional adults were 'affected'. Sound pressure levels (exposure) were not measured or modeled but distances from residence to the wind turbines were provided.

Results **- The authors found that 106/132 (80.3%) of respondents reported adverse health effects.**
[Note – In our secondary analysis of the data on the distances from residences to the wind turbines we found that the average distances to the wind turbines for the two groups were: a) 816.1 metres for the ill-health group (n = 106); and b) 820.6 metres for the no health effects group (n=26). The total group average was 643 metres with a range of 300 – 5,000m.]

Van den Berg et al., (2008).
The report is a detailed statistical analysis about various factors and how they relate to wind turbine annoyance and health outcomes. The study looked at how people perceived the wind farm in their living environment (e.g., sight and sound). It consisted of a postal survey (n = 725, 37% response rate) of Dutch residents.

The sample came from 50,375 addresses that were identified and subdivided into the three environment types (quiet countryside, countryside with main road, build-up area). Based upon modeling, the residences were placed in four exposure groups: 1) 25-30 dBA, 2) 30-35 dBA, 3) 35-40 dBA, and 4) 40-45 dB(A) with an equal number of individuals in each exposure group and at least 50 respondents each.

The purpose of the study was masked to the respondents so they did not know about the focus on wind turbines. The researchers also conducted a survey in a random sample of 200 non-respondents and reported no statistically significant differences in annoyance between the responders [n=725] and the sample of non-responders.

Results - **The authors reported that chronic disease, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease and migraine were *not* associated with sound levels or annoyance.** The authors also found that those who received financial benefits from the wind turbines, and who were in the highest exposure category, (e.g., ≥45 dBA) were less annoyed than those in the lower exposure categories who did not receive financial benefits.

Summary

What do we know from the peer reviewed and grey/self-published literature?

- **Evidence Base - There is a small evidence base of the relationship between exposure to wind turbine noise emissions and possible adverse health effects.** The strongest evidence is focused on the relationships between wind turbine noise and the pathway through individual characteristics (e.g., perception and attitudes) to annoyance.

- **Adverse Health Impact - No evidence was found that demonstrated a dose-response causal relationship between noise emitted from wind turbines and adverse health effects.** This conclusion is best supported by evidence from two large sample European studies conducted by Van den Berg (2008) and Pedersen & Waye (2007) and by the conclusions and recommendations in the reports by the Chief Medical Officer of Health of Ontario (2010) and Colby et al., (2009).

- A French study (French Agency for Environmental and Occupational Health Safety) was conducted in response to the recommendation from the French Academy of Medicine that until a study was completed that a 1,500 set-back distance be used. **The conclusion of the subsequent French Study was that the precautionary distance of 1,500 metres was not warranted.** (See Dixaut G et al., (2008).

- **Annoyance/Dose-Response**
  a) A dose-response relationship between noise and annoyance exists with more people being annoyed when exposed to higher noise levels. Results also suggest that people become annoyed by wind turbine noise at lower levels than for other outdoor transportation related noises such as aircraft, road traffic and railways.
  b) The total percentage of those exposed who are highly or fairly annoyed is low. Pederson & Waye, (2008, 2007) reported that 7.7% (84/1095) were fairly to highly annoyed and for those exposed to <37.5 dBA it was less than 5%. In those exposed to 40 dBA Pederson & Waye found 15% reported being fairly to highly annoyed ranging from %15. [*Note - in the 2007 study only 2% of the respondents (20/754) were exposed to SPLs above 40 dBA.*]
  c) Annoyance and sleep disturbances were associated with a dose-response with increases observed at higher SPLs and those who are more annoyed are more likely to report higher stress levels.
  d) Multiple studies found that individual characteristics (e.g., negative attitudes of wind turbines or of their impact on the visual landscape) were also correlated with annoyance with the effect being as strong as noise levels. Other examples include decreased annoyance among those receiving financial benefits and increased annoyance/acceptance among those who perceived the decision-making process to be inequitable or the wind farm as existing outside of their perceptions of the purpose of the land.
  e) Self-reported stress is more strongly associated with annoyance than noise levels.

- **<u>Studies which conclude or support adverse health effects</u>**
  a) The evidence in support of a relationship between noise emitted from wind turbines and adverse health effects mostly comes from several case series or the community survey study. These types of studies are only appropriate for generating hypotheses and can never be used to make assertions about a causal relationship between exposure and illness.
  b) We know that some of these studies had very significant methodological problems that make the results and conclusions difficult if not impossible to accept. Examples include: self-selection and sample bias, use of symptoms check lists and proxy respondents, exposure not modeled or measured, no comparison between exposed and non-exposed, and information that suggests a clear lack of objectivity in the primary investigators.
  c) We also know that neither wind turbine syndrome nor vibroacoustic disease are well accepted as pathological entities by the international medical and research communities. Both are based upon exposure to low frequency noise and strong arguments exist to dispute the hypotheses and wind turbine associated conclusions (see Colby et al., 2009 and Appendix 3).

<u>What do we need to know?</u>

- **The available research evidence and conclusions from Public Health does not support the conclusions that exposure to wind turbines causes ill health. However, the evidence base is: small, self-reported, based on modeled not measured A-weighted exposure levels, and did not measure or estimate unweighted low frequency noise SPLs.** Given this, research should be conducted at multiple wind farms with different geographic, population, and wind farm characteristics. Unweighted sound exposure levels should be measured (not modeled) at all residences before and after the wind farms are operational. SPLs should be measured at multiple times under different conditions. Individual characteristics and attitudes should be documented. In addition, data should also include self reported health outcomes and quality of life indicators, biomarkers, administrative utilization data and other objectively measurable health outcomes.

This data should be collected in randomized samples of exposed and non-exposed residents. A primary aim of the studies would be to evaluate whether any observed dose-response relationships exist between noise exposures and both measured and self-reported health outcomes. Until this research is conducted it is very likely that the increasing vocal opposition groups will continue to reject the assertions from industry, government and Public Health. .

- We need to know more about the relationship between individual and community characteristics and the likelihood of becoming highly annoyed by visual and noise exposures to wind turbines under different conditions. This includes a better understanding of how to improve the local political decision-making process and perceptions of community-wide equity.

- We need to know more about how to decrease 'Amplitude Modulation' considered to be the main source of noise annoyance associated with wind turbines. It is the 'swish swish' sound that is heard and is reported to be more pronounced at night and under colder conditions.

3. Government and Industry – Wind Turbines, Technical and Standards Information

This category was created to group together technical information about wind turbines. **16** documents were selected for review and analysis for this category. There are three distinct sources reported in this category: government documents and commissioned reports, industry documents and commissioned reports, and information from relevant peer-reviewed journals. For the peer-reviewed sub-category, journals articles identified in literature review that did not relate to health were reviewed. Google searches were also conducted to identify additional key reports. Our intention was not to be exhaustive, because the technical nature of the information was beyond the scope of this study, but to provide an adequate amount of information of what is known about wind turbine sound emissions and international guidelines. In the full report, results are presented by each of the three categories; whereas, in this summary they are presented together.

Summary

International Trends

The World Wind Energy Association reported global capacity (2010) to be 196,630 MW or roughly the consumption of Great Britain. Canada is the 9th ranked country in installed capacity at 4,008 MW, including the local Wolfe Island wind farm, the second largest in Canada.

Sound modeling

Sound modeling is used to predict wind turbine emissions based upon the following factors: sound pressure level generated at the hum, directivity, steradian factor, distance, atmospheric absorption, ground and meteorological absoption, vegetation absorption, buildings, and influence of the wind.

Concerns have been raised about the validity of sound models used by industry in proposals. For example, Tickell (2006) found that at 1,000m different model results varied by 9dB and suggested there must be internationally-conducted model validation in order to narrow the credibility gap between developers/regulators and communities.

International Noise Guidelines

A review indicated that international maximum noise guidelines for wind turbines at the receptor sites (e.g., residences) range from 35 dBA to 65 dBA depending upon settings and wind speeds. For most residential (and rural) settings the limits were 35-45 dBA with frequent allowable increases with increased wind speed. Denmark has set 85 dBG as the recommended indoor limit for infrasound (<20 Hz).

Ontario Guidelines
Wind turbine sound guidelines are based on wind speeds and urban versus rural categories. Maximum sound levels range between 41 dBA to 51 dBA depending upon the wind speed and category.
Setback guidelines are based upon the number of wind turbines within a 3 km radius from the centre of the noise receptor (residence). The minimum setback is 555m for 1-5 turbines producing 102 dBA and increases incrementally to 1,500m with more powerful wind turbines or larger wind farms.

Wind Turbine Noise Emissions
At the hub, modern wind turbines emit between 102 and 107 dBA. The noticeable 'whooshing' sound comes from the blades is in the 1,000 Hz range and is not low frequency noise.

Hau (2006) reported that: i) background noise generated by wind (blowing around trees, grass and buildings) increases by about 2.5 dBA per 1 m/s increase in wind speed whereas noise emission from wind turbines increase by 1 dBA per 1 m/s wind increase; and ii) if the background noise level exceeds the calculated wind turbine noise level by 6dBA, the WT noise will no longer contribute to any perceptible increase.

Infrasound/Low Frequency Sound – Infrasound (<20 Hz) and Low Frequency Noise (< 250 Hz)
These naturally exist and increase with increasing wind speed. Wind turbines also emit infrasound and low frequency sounds; however, measuring infrasound emissions presents problems because the background wind always contains infrasound.

G-weighted measurements from one study conducted at a wind farm near the Atlantic Ocean reported sound levels (5-35 Hz) between 74 – 81 dBG (measured at 60 – 700 m) and concluded the contributions from the waves and the wind turbines could not be differentiated.

In an Alberta study of a 60 turbine wind farm, Hepburn (2006) found that under different wind speeds, wind turbines can add to or take away low frequency nosise/infrasound. For example, under high wind conditions the levels were 91 dBG at 50 metres but the normal (ambient) conditions with the wind turbines turned off were 83 dBA under the same wind speed. This study also found under different conditions wind turbines can add or take away low frequency noise/infrasound.

- The Hepburn results indicated that the wind turbines added about 24 decibels (unweighted) of infrasound under low wind conditions and about 9.5 decibels under medium wind conditions. However, the wind turbines decrease infrasound by about 7 decibels under high wind conditions.

- **Infrasound -** Under all wind speed conditions infrasound ranged from **55-75 dBL** (at 50 M) with the Wind Turbine **ON** and ***37 – 82 dBL*** with the Wind Turbines ***OFF***.

- **Low frequency noise** (25-200 Hz)- Under all wind speed conditions low frequency noise ranged from **31-67 dBL** (at 50 M) with the Wind Turbine **ON** and 28 ***– 75 dBL*** with the Wind Turbines **OFF**.

- The main conclusions from these studies is that under medium and high wind conditions, infrasound and low frequency noises are naturally present and that the wind turbines contribute little and sometimes nothing to ambient levels.

4) Noise and Health in Other Settings, Published Peer Reviewed Research

Overview

Our purpose in adding this section was to provide information from peer reviewed noise and health research that will help contextualize the issues and themes that emerged in our reviews of different wind turbine documents. For example, one of the main tenets of causality described by Hill (1965) is the 'Biological Gradient' or the 'Dose-Response' which in this case would argue that, if noise causes ill health, one would expect that more noise (i.e., duration and power) would result in more illness. In addition, we also thought it would help to contextualize the wind turbine concerns by comparing international wind farm exposure guidelines to the evidence in other non-wind farm settings.

Health Canada considers noise annoyance to be an adverse health outcome and indicates that noise starts to make people highly annoyed when the sound level outside the home is around 55 dBA (compared to highway noise 80 – 90 dBA). However, debate exists regarding whether noise annoyance is or is not an adverse health effect that can always be attributed to the source or whether it is a subjective response to unwanted stimuli. Adding to the debate is that dictionaries describe annoyance as a state of mind or a mood and that the evidence indicates that only a small percent of a noise annoyance response can be directly attributed to the actual noise itself.

The research also clearly indicates that many other individual factors contribute such as: attitudes about the source, culture, fear, perceived preventability, value placed on the source, psychological sensitivity to unwanted sounds and other environmental stimuli, economic benefits tied to the source, perceptions of inequity and mental health. This creates a situation where one could reasonably conclude that a state of chronic annoyance is an adverse health outcome but also where one cannot conclude that most significant or main cause of the annoyance is the wind turbine sound emissions. [*Consider the example of constant background Rap music versus Country music versus Classical music. Medicine and a sleep aid for some but poison for others.*]

Those who have concluded that wind turbines cause ill health typically argue one or both of the following: a) exposure to the noise emitted directly causes adverse health effects (e.g., symptoms, illness or disease); and b) noise from the wind turbines causes annoyance which then causes sleep problems and stress and then leads to adverse health effects.

What do we know from the peer-reviewed noise and health literature?

Health Effects

Narrative reviews of the literature and the WHO document indicate that noise affects health. Passchier-Vermeer W & Passchier W. (2000) found sufficient evidence that the following health effects occur at the corresponding levels:

hearing impairment	70-85 dBA	hypertension	70-85 dBA
ischemic heart disease	70 dB A	performance	70 dBA
annoyance	55 dBA	changes in sleep pattern	<60 dBA
awakening	55 dBA.	mood next day	<60dBA
subjective sleep quality	40 dBA	heart rate	40 dBA
sleep stages	35 dBA		

These results are also supported by the additional evidence indicating that: a) exposure to high levels of noise (65-85 dBA or more) is associated with health effects such as: hearing impairment, hypertension, ischemic heart disease, cardiovascular risk, and balance (at higher levels 95 – 130 dB); and b) exposure to lower levels are known to affect changes in sleep patterns (<60 dBA), awakening (55 dBA), subjective sleep quality (40dBA), heart rate (40 dBA), mood next day (<60 dBA), annoyance (55 dBA outdoors), continuous sleep (30 dBA), and stress hormones - adrenaline & cortisol (>57 dBA).

- **Infrasound -** There is no reliable evidence that infrasound (< 20 Hz) below the hearing threshold (> 84 – 105 dB) causes adverse physiological or psychological effects.

- Sound with low frequency components are more likely to result in complaints and annoyance at lower sound levels (SPLs) compared to sounds with fewer low frequency characteristics.

Noise Annoyance

- Data indicate that daytime sound pressure levels of less than 50 dB LAeq cause little or no serious annoyance in the community. Given this, the WHO recommends that the continuous (average) sound pressure levels outdoors should not exceed 50 dB LAeq during the daytime.

- Annoyance is a very individual response that is affected by: cultural factors, activity at the time, attitude and value attached to the noise source, noise sensitivity, controllability of the stressor, and other individual differences. It appears to first start with knowing about and/or hearing the sound and then which goes through an intermediate pathway (affected by perceptions, attitudes, culture, and physiological and psychological characteristics) before resulting in an annoyance response. [*Note – we provide the example of constant but different back ground music (rap versus country versus classical) where the response can range from pleaseant/sleep aid for some to intolerable/painful for others.*]

- Sound can be detected through skeletal bones, the ear, harmonics, tactile senses, or resonance in body organs.

Sleep Disturbance

- Recommended guideline values for bedrooms inside are 30 dB LAeq for steady-state continuous noise and 45 dB LAmax. At night time <u>outside</u> noise levels should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open.

- Individual differences are very pronounced and measureable effects start at about 30 dBLAeq. 10-20 % of sleep disturbance is due to other reasons than noise. Sensitive groups include: elderly persons, shift workers, persons who are especially vulnerable due to physical or mental disorders, and other individuals who have sleeping difficulties.

- Primary and secondary sleep disturbance effects include: a) difficulty to fall asleep, b) alterations of sleep pattern or depth, c) awakening, d) increased blood pressure, e) increased heart rate, f) increased finger pulse amplitude, g) vasoconstriction, h) change in respiration and cardiac arrhythmia, i) body movements, j) reduced perceived sleep quality, k) increased fatigue, l) decreased mood or wellbeing, and m) decreased performance.

Assessing Noise and Health

An assessment of the causal relationship between noise exposure and nonspecific health effects presents difficulties. For example, it is difficult to exercise control over all relevant risk factors in epidemiological studies such as: social class, personal habits, and personality characteristics are difficult to define. In addition, cross sectional studies can't be used to conclude causality because they do not provide information on temporal relationships between exposure and onset of disease.

There is evidence to suggest that assessing the relationship between noise and health can be problematic particularly when using self-reported health outcomes. For example, Berglund and Lindvall provided the following examples from the literature:

a) Self-reported differences in subjective health complaints between noise exposed and nonexposed groups were dependent upon subjects' perceived control over noise, and were independent of sound pressure level.
b) Individual responses to noise may be more highly correlated with symptoms of ill health than with the noise itself.
c) Noise is not believed to be a direct cause of mental illness but might accelerate and intensify the development of latent mental disorders and/or that noise sensitivity may be an indicator of subclinical psychological morbidity.
d) Noise sensitivity may be a self-perceived indicator of vulnerability to stressors in general and may also be indirectly measuring a subclinical level of psychological morbidity.

With Respect to Wind Turbines

International and Canadian noise guidelines for emissions from wind farms generally set the allowable limit to be between 40 and 54 dBA for exposure at the receptor with allowances allowed for increasing wind speeds (because the ambient levels would exceed the guidelines). Studies measuring wind turbine infrasound and low frequency noise emissions indicate that levels for infrasound (<20 Hz) fall below the threshold indicated by the WHO known to cause adverse physiological or psychological effects.

MAIN CONCLUSIONS

Health Impact - A review of the available wind turbine and health literature does not provide evidence of a direct causal relationship between wind turbine noise emissions and ill health and does not suggest the likelihood of a causal relationship between ill health and wind turbine noise emissions that meet Ontario noise guidelines.

This conclusion is based upon the following:

- Two large sample European studies (N = 754 – 725 subjects) found no association between self-reported health outcomes and sound levels. Van den Berg also reported no association between self-reported health and annoyance. These studies used a masked survey design where the randomly selected respondents did not know the purpose of the study.

- Ontario wind turbine guidelines specify a maximum sound pressure level of 40 – 51 dBA at residences depending upon residential category and wind speeds.

- Evidence from the peer reviewed noise and health literature base supports the lack of health effect findings from the two European studies. Internationally, countries have set allowable limits for wind turbine noise exposure outside residences to be within a range of about 35-54 dBA depending upon different conditions. If these limits are met, noise exposure from wind turbines (includes infrasound and low frequency noise) falls well below levels known to have adverse health effects.

Annoyance - Annoyance is both defined in dictionaries as a feeling or state and by others as a negative health outcome. The research indicates a relationship between chronic stress and future morbidity and people who are annoyed also report higher stress levels. However, attributing wind turbine annoyance to the actual wind turbine noise and also to future negative health outcomes is a complex issue.

The large sample studies found that only a small percentage (E.g., 4.1 % - 7.7%) of total residents living close to industrial wind farms report being annoyed by wind turbine noise. The noise and health evidence indicates that only a small percentage of annoyance can be attributed to the noise source itself and that other factors exert a considerable influence (e.g., attitudes, can see the source, culture, ability to control the noise, mental health, financial benefits, and perceived importance of the source). Supporting this is the results from the van den Berg et al., (2008) study of 725 randomly selected subjects who did not know the purpose of the surveys. Van den Berg, found that those in the highest noise exposure category (> 45 dBA) which meant they were receiving financial benefits from the turbines were less annoyed than respondents in lower SPL categories. In addition, research has found that those who report being highly annoyed also score higher on self-reported sensitivity test which indicates increased sensitivity to noise, odour, air pollution, and litter. Given this complex situation, we cannot attribute the annoyance (and future effects of annoyance) to the wind turbine noise alone.

IMPLICATIONS

Our findings are the result of a review of the international body of English language literature that included peer reviewed indexed research, grey/self-published literature and community-based organization and news media documents. The main implications of our findings are:

- There is a need for multiple well-designed epidemiological studies. The studies should not rely on self-reported health outcomes, should include some pre-post studies, and should include noise exposure measurements (not models) at receptor sites (in and outdoors) and at control locations with similar ambient wind conditions.

- We need to know more about the relationship between individual and community characteristics and the likelihood of becoming highly annoyed by visual and noise exposures to wind turbines under different conditions. This includes a better understanding of how to improve the local political decision-making process and perceptions of community-wide equity.

- To narrow credibility gaps between developers/regulators and communities, there would be a value in improving or standardizing sound propagation models where the data and results are available and presented in an interpretable format to communities.

- The evidence supports the conclusions of the French study (French Agency for Environmental and Occupational Health Safety) that was conducted following recommendations from the French Academy of Medicine that a precautionary 1,500 metre set-back distance be implemented until a study was completed. The conclusion of the subsequent French Study was that the precautionary distance of 1,500 metres (from the existing 650m) was not warranted. [Note - Set-back limits should be based upon current research and improved sound propagation models.]

- There is need of a formal complaint resolution mechanism that can provide real and effective remedies for residences with complaints. This mechanism should involve sound pressure level measurements at the residences (inside and outside) under different wind conditions. Reports should be made available to the complainants and the general public that compare the measured SPLs to noise guidelines limits. If the maximum and equivalent average noise levels exceed the guideline, a pre-determined resolution/adjudication process should be implemented. (E.g., shut-down during some conditions or compensation.)

- There is a need for a better response from Public Health. This should include increased collaboration, a better web presence to ensure credible sources appear more frequently during internet searches, and more careful messaging. Public Health should also provide information to improve public education about critically evaluating information sources, methods and conclusions.

MAIN CONTRIBUTIONS

The main contributions from this research derive from a modified scoping review of the international body of English language literature that included peer reviewed indexed research, grey/self-published literature and community-based organization and news media documents. Our objective was to to discover and synthesize knowledge and identify what is known and where primary research is needed. Contributions include:

- The development and analysis of five categories for evaluating what is known about potential health effects of noise emissions from wind turbines: 1) Wind Turbines and Health - Peer Reviewed Research; 2) Wind Turbines and Health - Self-Published/Grey Literature Research;3) Government and Industry – Technical Information, Guidelines and Standards; 4) Community Based Organizations, Advocacy Groups and News Media; 5) Noise and Health in Other Settings - Peer Reviewed Research.

- An evaluation of vibroacoustic disease (VAD) and the suggested link to low frequency noise emissions from wind turbines.

- A recognition that there is a need for an improved response from government and Public Health regarding: local equity and the public consultation process, public education, access to information on the internet, and health concerns

- Identification of an international body of indexed and unindexed literature relevant to wind turbine noise emissions and concerns about human health (1985-2009) and documentation of suggestions made by the international body of authors.

REPORT TO
KINGSTON, FRONTENAC AND LENNOX & ADDINGTON PUBLIC HEALTH

APRIL 2011

Wind Turbines and Health: A Modified Scoping Review of the Literature

INTRODUCTION

Medical Officers of Health at local Public Health Agencies (PHAs) are frequently approached by individuals and community-based organizations (CBOs) with strongly expressed concerns about health impact of wind turbines. Consequently, PHAs have identified wind turbines as a priority issue that warrants attention. The rapid increase in current and planned use of wind turbines as a source of renewable energy has created a situation where there are often strong negative reactions from community groups and an inadequate response from Public Health and provincial government. The result is two groups with opposing conclusions. Provincial governments and Local Public Health Agencies generally show support for the assertion that there is no credible evidence that exposure to wind turbine noise or other emissions causes ill health; whereas, some community groups support the belief that living near wind turbines causes serious health problems.

Two main factors appear to be driving this rift. One is that the internet is often the first or only source of information for many. A second factor is the lack of empirical peer-reviewed evidence from large sample studies that evaluated the health impact of wind turbines. For example, a review of statements and documents available in the websites of CBOs clearly indicates that they are: a) less willing to accept statements from Public Health, provincial governments, or industry experts such as the Canadian Wind Energy Association; and b) more willing to accept, and believe as proof of causality, individual claims or anecdotal evidence from several case studies frequently reported on the internet.

Given the above, there was a need to provide information that will increase the ability of Public Health to provide a more informed response to health concerns about exposure to wind turbines. At this time, it does not appear that large sample studies are near completion or currently being conducted to address this need which would add to the results currently available in the limited peer reviewed research. Thus, to address this gap, we conducted a **modified scoping review** to: synthesize the current information by documenting and evaluating what is known; to assess the evidence typically used by CBOs and Public Health; to identify where gaps exist; and to borrow from other relevant research.

PROJECT OVERVIEW

As part of our overall goal of obtaining a better understanding of the known and possible relationships between exposure to wind turbine noise and human health, our main objective was to conduct a modified Scoping Review of the literature to summarize and evaluate both what we can and cannot conclude from the available evidence about the impact of wind turbine noise emissions on human health. It was not our intention to prove that we accessed all possible sources of relevant indexed and non-indexed literature such as: published peer reviewed, self-published non-peer reviewed, grey and white. However, we wanted to access and evaluate enough relevant literature to help contextualize the issues and to better understand the claims and evidence used by groups with opposing conclusions about the health impact of wind turbines.

To achieve our main objective we set out to document and describe the literature and the sources and types of evidence typically used by different groups with opposing opinions. We recognized that the body of peer reviewed evidence on wind turbines and health is small and that most of the health concerns are related to noise emissions. Thus, to address the gaps in the wind turbine and health literature, relating to exposure to noise, we also accessed information from the noise and health literature.

BACKGROUND

Why is this issue important to Public Health and provincial government?

Three main factors make this issue important. First, there clearly is a high degree of public interest and concern regarding possible negative health consequences of living near wind turbines and Public Health Agencies are often the first entity approached. Second, public concern is being driven more by information on the internet than from scientific evidence or evidence-based opinions [Hodgettes et al., 2009]. And third, this issue will continue given government green energy policy to pursue increased use of wind farms.

a) Public Interest and Health Concerns – Public health officials are frequently approached about concerns relating to the health effects of wind turbines. A common response has been to indicate that there is 'no evidence that wind turbines cause harm' or pose a health risk [Colby et al., 2009; Chatham-Kent PHU, 2008]. However, Public Health generally acknowledges that this response is based upon expert opinion and narrative reviews of the published peer reviewed literature base, which is small and does not include a sufficient number of definitive case control or prospective cohort studies with the same results. The problem with the overall response is that community groups do not find it to be adequate and recognize that 'no evidence of harm' does not mean there is 'evidence of no harm'. Given this, it appears that many people have looked to the internet.

One imperfect but useful measure of the public's interest is the amount of activity on the internet. For example, a September 21, 2009 Google search using the terms 'wind turbines and health' generated 1,880,000 results and also illustrated a steady increase in activity between 1992 and 2008 (See Appendix 2, presentation, Slide 8). Searches on the same date produced 57,000 results for 'wind turbine syndrome' and 1,908 for 'vibroacoustic disease and wind turbines '[Hodgettes et al., 2009]. Both ***wind turbine syndrome*** and ***vibroacoustic disease*** are frequently reported on websites as being scientifically linked to wind turbines. A partial list of health symptoms reportedly associated with these 'conditions' includes the following: pericardial thickening, respiratory pathology, late onset epilepsy, cardiovascular diseases, respiratory pathology, sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration or memory, and panic episodes [Pierpont N, 2009; Harry A, 2007; Alves-Pereira M & Castelo Branco N, 2007; CBC, 2009; Pierpont N, 2006; Pierpont N, 2006; Nissenbaum M, 2009; Cockle R, 2006]. These health concerns and the belief of scientifically proved links are high among some community groups. For example, groups have used human rights terminology, referred to people living near wind turbines as 'victims', and called for the resignation of government officials (Coalition for the Protection of Amherst Island , 2009). This contrasts the peer reviewed literature that has not reported a direct link between wind turbines and ill health [Dixsaut G, 2008; Pedersen E & Way KP, 2007; Pedersen et al, 2008].

b) Quality and Source of Information - We also know that the internet may be the primary or first source of information for many people, as the majority of internet users (63.7% - 80%) report looking for health information online [Hess BW et al, 2005; Fox S & Fallows D, 2003]. However, while the internet provides a source for the quick access to much information, problems exist with the accuracy of the information and with people's willingness to believe what they read online to be true [Pandolfini et al, 2000; Impicciatore et al, 1997; Soot et al, 1999; Bremer J, 2005; Jemenez-Pernett J et al., 2010.]. When compared to scientific peer-reviewed journals, information available online is often different and targets different populations [Alejandro R & Jadad MD, 1998] and regulations or guidelines do not exist to help the information seeker make informed decisions about the quality of the information [Soot LC et al., 1999]. The result is that internet information seekers may see conclusions reached by seemingly credible experts or other researchers that cannot be supported by the methods used (e.g., such as claims of causality following a case study).

c) We can expect this issue to continue and to increase - Advances in Wind Turbine technology now make wind farms an economically viable source of renewable energy. Since they do not produce CO_2, NO_2 or SO_2, wind farms are also considered to be politically feasible and socially acceptable. This combination has led to rapid growth in world capacity [WWEA 2008; Hess BW, 2004; Kaygusuz K, 2004]. For example, in 2010, Canada ranked 9th worldwide in total capacity, with an annual growth rate of 21% [23 WWEA, 2011].
We can expect to see Canadian growth rates to increase given that federal and provincial 'green energy' policy clearly demonstrates Canadian intentions to significantly increase capacity in the near future [Industry Canada, 2009; Sustainable Development Technology Canada, 2009].

How will a 'modified' Scoping Review better inform and support Public Health's response?

Scoping review studies are designed to draw on the main findings of published research and other sources. They can be seen as a preliminary attempt to provide an overview of existing literature on a specific topic and to subsequently identify areas where more research might be required [Arksey H & O'Malley L, 2005; O'Malley L & Croucher K, 2005]. Scoping reviews are also appropriate to address broad research questions such as the following one used by Masotti et al., in a CIHR funded Scoping Review: "*What is known from the existing literature about the occurrence of adverse events experienced by patients in the delivery of homecare services?*"[Masotti et al, 2010]. The methodological framework for conducting scoping studies developed by Arksey and O'Malley consists of the following main stages: 1) identifying the research question; 2) identifying relevant studies; 3) study selection; 4) charting the data; 5) collating, summarizing and reporting the results [Arksey H & O'Malley L, 2005].

Given the above and the problem previously described, a single broad research question will not provide the information needed to better inform Public Health in order to provide a better response to public concerns about wind turbines. However, a modified scoping review that addresses the research questions indicated below will provide the needed information in five categories that will better enable Public Health to respond with information more acceptable those with concerns. First, it will provide a review of peer reviewed research. Second, it will provide a review of the grey and white (non-peer reviewed) wind turbine and health literature. Third, it will identify and evaluate what information is typically used to support the arguments of the two groups that have reached different conclusions about wind turbines and health. And fourth, based upon the results in the other categories, it will provide a review of the relevant noise and health literature that can be applied to concerns about wind turbines. (A review of the noise and health literature base will help contextualize issues such as: a) exposure to low frequency noise & infrasound and health symptoms, b) mental health conditions and reactions to noise exposure, and c) individual characteristics and reactions to noise, visual and other environmental stimuli.)

RESEARCH QUESTIONS

1) What information is reported in peer reviewed and grey/self-published literature about the health impact of wind turbines?

2) Are there differences in the quality of the information and the conclusions reached in the peer reviewed versus the grey/self-published literature?

3) What information is reported in the peer reviewed noise and health literature that is relevant and can be applied to concerns about noise exposure from wind turbines?

METHODS

We used a modified version of the five stage methodological framework for conducting scoping studies developed by Arksey and O'Malley [2005]. The five stages used in this study are illustrated below.

1) Identifying the research question

2) Identifying relevant studies (& other documents)

3) Study (& other document) selection

4) Charting the data

5) Collating, summarizing and reporting the results

Stage 1 – Identifying the Research Question

The impetus for this project came from discussions the Medical Officer of Health had with other provincial Public Health Agencies and Environmental Health Division staff at KFL&A Public Health. It reflects Public Health’s need to provide an informed response to current public concerns regarding Wind Turbines. As a result, we developed the research questions indicated above. Public health experiences, and the reactions from the public, indicated a need to do more than summarize the results from the peer reviewed wind turbine literature.

Stage 2 - Identifying Relevant Studies/Documents (wind turbines & health and noise & health)

The literature search included the following electronic databases: PubMed/Medline, CINAHL, EMBASE, Cochrane Library, PsychInfo, and Global Health. The initial search covered the indexed literature from 1985 to the 2009. Search strategies for each database were developed using natural language text words and controlled vocabulary terms specific to each database, e.g. MeSH, Emtree headings and CINAHL headings. Search terms included, but were not limited to, terms covering the concepts or themes related to the effects on human health caused by electric power generation from wind, i.e., Wind Turbines.

Additional literature was identified by reviewing reference lists in papers identified by the literature searches. World Wide Web searches using Google (advanced search mode) was also undertaken to: a) identify grey literature documents from major organizations involved in wind energy and its regulation; and b) grey literature/self published documents from Community-based Organizations that support the argument that living near wind turbines causes serious health problems.

[Author's note: work on this project was stopped pending the results of a proposal submitted to CIHR for funding to conduct a comprehensive Scoping Review. Unfortunately, our proposal was ranked 10th of 40 submitted proposals where the cut off line for funding was the 9th ranked proposal. During the hiatus period, sporadic work continued and additional documents published in 2010 (mostly grey literature documents) were also included.]

Documents and papers eligible for review included: research studies (e.g., observational, descriptive, retrospective/prospective cohort, case/case series & clinical trials), review articles, policy papers, legal briefs, and opinion and descriptive articles from industry or policy-makers and non-government community-based organizations. (We conducted a non-exhaustive review of web-based documents from CBO websites to illustrate frequent information, concerns and conclusions posted by the CBOs. We also conducted a non-exhaustive review of the noise and health literature with the objective of providing evidence to help contextualize issues that emerged from analysis of the documents identified for the peer-reviewed and grey literature wind turbines and health categories.)

The documents addressed at least one of the database appropriate search terms. Examples include: wind turbines (technical or other information); wind turbines and health outcomes (physical, mental, stress, annoyance and other); wind turbines and psychological, psychosomatic, mental & physical symptoms; wind turbine emissions (noise, electrical and other); noise and health; wind turbines and safety risk (mechanical/electrical failures or mishaps). Two reviewers applied the inclusion/exclusion criteria to all documents. If a document received a 'split decision', a third team member was brought in to adjudicate. Where there was a match for the main research questions, full copies of the articles were obtained and read. Articles that did not meet the inclusion criteria were excluded from Stage 3. All references were recorded in a database created using Reference Manager 11.

Stage 3 – Study/Document Selection for More Detailed Analysis

We knew that there was not a large body of peer reviewed evidence that addresses the impact of exposure to wind turbines on health. We also knew, from a preliminary investigation of Community-based Organization (CBO) websites, that claims that wind turbines cause ill health were widely reported. Thus we thought it would also help to expand our search to include other information to help better contextualize the issue. As a result we expanded our search and grouped the documents according to the following categories:

1) Wind Turbines and Health - Published Peer Reviewed Research

2) Wind Turbines and Health - Grey/Self Published Research

3) Government and Industry – Technical Information and Guidelines

4) Community Based Organizations, Advocacy Groups and Newspapers

5) Research – Noise and Health in Other Settings, Published Peer Reviewed

1) Wind Turbines and Health - Published Peer Reviewed Research

A preliminary pool of 93 documents was identified using the search strategies in the different databases. Titles and authors of the 93 papers identified were first reviewed and duplicates eliminated. The remaining papers (abstracts) were reviewed using the inclusion/exclusion criteria. This resulted in **17 papers** selected for full review in more detail. These were the papers that were **placed in category number 1: Indexed/Peer Reviewed Research – Wind Turbines and Health**.

2) Wind Turbines and Health - Grey/Self-Published Research

Our interest was in identifying research articles that were self-published or found in the grey literature. Our definition for Grey Literature was literature that was self-published or which were reports written for organizations or agencies where the literature did not go through a structured peer review process and which was not published in peer reviewed journals. Examples of Grey Literature typically would include: scientific and technical reports, government documents, theses, conference abstracts, and working papers from research groups or committees. However, with the increased use of the internet, the definition of Grey Literature has broadened somewhat. This is because it is now very easy for almost anyone to self-publish and make a document available on the internet which can then be posted in one or multiple websites. The main criteria for this category was that the paper had a research component that addressed the possible health impacts associated with wind turbines. As a result we also included literature frequently referred to as the 'white literature'. Most documents in this category were identified using Google or Google Scholar. After applying the eligibility criteria - Our search strategy resulted in

Stage 4 – Charting the Data

As previously indicated, identified papers were grouped according to the following thematic categories:

1) Wind Turbines and Health - Published Peer Reviewed Research
2) Wind Turbines and Health - Grey/Self Published Research
3) Government and Industry – Wind Turbines, Technical and Standards Information
4) Community Based Organizations, Advocacy Groups and Newspapers
5) Research – Noise and Health in Other Settings, Published Peer Reviewed

Papers in each of the five categories were then charted according to seven different data categories that included:

i) Type of Article (research, descriptive, policy, CBO)
ii) Background Information
iii) Technical Information
iv) Issues & Concerns (e.g., noise annoyance, health impact, other)
v) Results (Health Impact)
vi) Results (Non-health)
vii) Policy Implications/Suggestions and Conclusions
viii) Methods (Research Articles)

The document analysis form used is found in Appendix 1 (Document Analysis Template). Data were entered into each cell of the different data categories of the Document Analysis form for later use in Stage 5.

Stage 5 – Collating, Summarizing and Reporting the Results

When we started this project we set out to conduct a scoping review and not a systematic review of the literature for two main reasons. First we knew that there had not been much research that investigated the relationship between wind turbines and human health. Second, given the small evidence base, we did not think it was appropriate to develop and implement methods for formally evaluating and ranking the quality of research studies.

In our preliminary literature searches, several themes emerged which suggested the need to review the literature based upon whether the documents were published in peer reviewed journal or were considered grey or self-published literature. For example, we found that there clearly are two groups with opposing conclusions about wind turbines. One group has concluded there is sufficient evidence that wind turbines cause serious health problems; whereas, the other group argues that there is no evidence that wind turbines directly cause ill health. Further investigation also revealed that both of these groups typically relied on different sources of information with the first group (negative health effects) relying heavily on several case studies (grey/self-published) that are highly reported on the internet but which had significant methodological problems and consequently which would very likely never be published in peer reviewed journals. This contrasted the second group (no health effects) which depended more on the results of several peer reviewed European studies and additional reports from government and industry experts.

Given the above, we decided to separate identified documents into the two categories: 1) Research – Wind Turbines and Health, Published Peer Reviewed; and 2) Research – Wind Turbines and Health, Grey/Self Published) for analysis. However, this did not completely address the intended issue. For example some of the identified documents were white papers that later became peer reviewed publications and others were reports of research that likely could be published. Thus to address this situation, we divided the Category 2 papers (grey/self-published) into two subgroups: i) Cases studies and other papers that support or suggest adverse health effects; and ii) Other papers that do not support or suggest adverse health effects. The results for Category 1 (Peer Reviewed) and Category 2 (Grey/Self-Published) literature sources will be presented separately. Following the this section, we will provide our analysis and conclusions of what is known from these two sections.

RESULTS

1) Wind Turbines and Health - Published Peer Reviewed Research

A preliminary pool of 93 documents was identified using the search strategies in the different databases. Titles and authors of the 93 papers identified were first reviewed and duplicates eliminated. The remaining papers (abstracts) were reviewed using the inclusion/exclusion criteria. This resulted in 16 papers selected for full review in more detail. Table#1 below lists the publications by research category. **Results will be summarized by category.** Full references are found at the end of this section.

Table 1 – Peer Reviewed Research

Author/Year	Research Category
2008 Pedersen & Waye	Cross Sectional (N = 1,822)
2008 Pedersen & Larsman	Cross Sectional (N = 1,095)
2007 Pedersen & Waye	Cross Sectional (N =754)
2004 Pedersen & Waye.	Cross Sectional (N=351)
2004 Kaldellis et al.	Cross Sectional (N=417)
2005 Warren et al.	Cross Sectional (N=115 & 240)
2002 Waye & Ohrstrom	Experiment
2007 Gross	Case Study, Key Informants & Grounded Theory
2007 Pedersen, Hallberg & Waye.	Case Study, Key Informants & Grounded Theory
2007 Alves-Pereira & Branco	Case Study, Key Informants & Grounded Theory
2008 Dixaut et al.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2008 Harding, Harding & Wilkins.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2008 Keith, Michaud & Bly	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2006 Leventhall.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2006 Bastasch et al.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2006 Nash, Martin et al.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2003 Kaldellis et al.	Other (e.g., literature review, descriptive, mixed methods, synthesis)
2005 Devlin	Other (e.g., literature review, descriptive, mixed methods, synthesis)

Wind Turbines and Health, Published Peer Reviewed - Cross Sectional Studies

Five studies were identified that were a fit for this category. Sample sizes ranged from 351 to 1,822. Iit should be noted that some studies (Pedersen & Larsman, 2008) pooled the data from two previous studies.

Pedersen E, Waye KP. Wind Turbines - low level noise sources interfering with restoration?
Pedersen E, Larsman P. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines.
Pedersen E, Waye KP. Wind turbine noise, annoyance, and self-reported health and well-being in different living environments.
Pedersen E, Waye KP. Perception and annoyance due to wind turbine noise – a dose–response relationship.
Kaldellis J, Kavadias K. Evaluation of Greek Wind Parks Visual Impact. “The Public Attitude”.

Methods Overview

The **five studies in this category** invited adults living in residences close to wind farms to participate by completing surveys. (Note: Pedersen and Waye used those living in areas with sound levels [SPLs] >30 dB A-weighted). In the Pedersen studies, one adult ($\geq$ 18 years old) per residence was randomly selected to complete the questionnaires. Response rates ranged from 37% - 68%.

Studies evaluated: 1) variables associated with individual responses to wind turbines: noise levels (sound pressure levels), visual stimuli (e.g, can see wind turbine from residence), individual self-reported noise sensitivity, perception of visual impact, attitudes about wind turbines, residential history (lived in urban and/or rural environments); and 2) individual responses to wind turbines: noise annoyance, dose-response (annoyance and different sound levels), sleep interruption, self-reported stress, and self-reported health outcomes.

The focus of the above studies was on attitudes and noise annoyance. We also recognize that annoyance is an individual reaction to unwanted stimuli and that debate exists regarding whether or not it can be considered a direct health outcome from the unwanted stimuli or an indirect outcome that is more strongly influenced by individual characteristics than by the actual stimulus itself. Given this and the recognition that chronic stress is associated with morbidity, we decided to include the studies that did not specifically address some of the standard measurable health outcome indicators such as chronic disease/conditions, health services utilization, lost productivity and bio markers.

Noise Exposure Levels

In all of the Pedersen studies (2008 Pedersen & Larsman; 2008 Pedersen and Waye; 2007 Pedersen & Waye; 2004 Pedersen & Waye) the outdoor A-weighted sound pressure levels (SPLs) were calculated using the 'sound propagation model' that was adopted by the Swedish Environmental Protection Agency and were the sum of contributions from the wind power plants. Calculations were based upon wind conditions of 8 metres per second at 10m in height with wind direction towards the respondent's residence which was an approach in accordance with Swedish Environmental Protection guidelines. Residences in different geographic areas were included if noise prediction models placed their homes in areas expected to be over 30 decibels (dBA). Analysis was then stratified by predicted exposure level categories: 1) < 30dB, 2) 30.0–32.5 dB, 3) 32.5-35 dB, 4) 35-37.5 dB, 5) 37.5-40 dB, 6) >40 dB.

Since the focus of the Kaldellis paper was on visual impact, we did not find and didn't expect information on sound levels.

Measurements of Noise Annoyance, Attitudes and Self-reported Health

In the Pedersen studies, questionnaires were masked to give the impression of investigating general living conditions in the different locations. Questions in the different studies addressed combinations of the following areas:

- Subjective Response to wind turbine noise 5-point scale:
  1) do not notice, 2) notice but not annoyed, 3) slightly annoyed, 4) fairly annoyed, 5) very annoyed.
  The same scale was used to measure responses to different wind turbine sounds.

- Individual evaluation of wind turbines on landscape was measured on a 5-point scale:
  1 = very positive……. 5 = very negative

- Sensitivity to noise, odour, air pollution and litter was measured on a 4-point (verbal rating scale):
  1 = not at all sensitive…. 4 = very sensitive.

- A sub sample were surveyed to obtain perceptions of their living environment to find out about:
  perceptions of noise, restorative quality, expectations of the environment:
  1 = do not agree at all …. 5 = completely agree

- Individual Scores were calculated for: A) Sensitivity (to noise, odour, air pollution & littering), and B) Stress

- **Self-reported health indicators**: hearing impairment, diabetes, cardiovascular diseases, stress symptoms, sleep, tinnitus, and general well-being (headache, undue tiredness, pain, stiffness, feeling stressed).

Results

Health Impact - Cross Sectional Studies

Three of the Pedersen papers presented self-reported health results: Pedersen & Waye (2008); Pedersen & Waye (2007); and Pedersen and Waye (2004). Below is a summary of results presented.

Pederson & Waye. (2008) Wind Turbines - low level noise sources interfering with restoration?

- "**No differences as regards to self-reported hearing impairment, diabetes or cardiovascular diseases were found between respondents that were fairly or very annoyed versus other respondents**". However, respondents who were very annoyed by wind turbine noise were under more strain and reported stress symptoms; the mean stress scores were statistically significantly higher in this group than among the other respondents." (p 3-4) People who were more annoyed by wind turbine noise also had higher mean stress scores and self-reported stress symptoms.

Pedersen E & Waye KP. (2007) Wind turbine noise, annoyance, and self-reported health and well-being in different living environments.

Health factors and well being:

- **The authors reported that A-weighted (dB) noise (SPLs) were not correlated to any of the health factors or factors of well-being asked in the questionnaire.**

- The authors reported that sleep quality and negative emotions were associated with annoyance. For example, of the 31 respondents classified as annoyed, 36% reported sleep disturbance compared to 9% among the 733 not classified as noise annoyed. People who were annoyed were more likely to report being tired and tense in the morning.

Pedersen E& Waye KP. (2004) Perception and annoyance due to wind turbine noise – a dose–response relationship.

Sleep disturbance:

- 23% of respondents reported sleep disturbance caused by different noises: road traffic, rail traffic, neighbors, and wind turbines.

- None of the respondents in the lower wind turbine noise categories were disturbed in their sleep. However, **16% of the respondents exposed to >35 dB reported sleep disturbances caused by the wind turbines.** (90% of this group slept with their windows open.)

- The authors reported that **sleep disturbance appeared to be associated with a dose-response** with increased disturbances associated with higher sound levels (SPLs). The authors indicated the sample was too small for meaningful statistical analysis, "but that the probability of sleep disturbances due to wind turbine noise cannot be neglected at this stage".

<u>Noise Annoyance, Attitudes and Perception - Cross Sectional Studies</u>
The results from the three Pedersen & Waye studies (2008, 2007, 2004) and the Pedersen & Larsman study (2008) are summarized below**.**

<u>Pedersen & Waye (2008) Wind Turbines - low level noise sources interfering with restoration?</u>

- **Response to wind turbine noise was correlated with SPL** ($r = 0.401$, $p<0.001$) as SPL increased the proportions of respondents indicating they noticed the sound increased.

- Swishing, whistling, resounding and pulsating/throbbing sounds were the most highly correlated with annoyance.

- **Response to wind turbine noise was correlated to attitudes** towards wind turbines ($r = 0.23$, $p<0.001$) and attitude towards the impact of wind turbines on the landscape scenery ($r = 0.341$, $p <0.001$). Annoyance was associated with a negative attitude towards wind turbines (in general) and their visual impact. Of these two, a negative attitude towards visual impact of wind turbines was more strongly associated with annoyance.

- **In the multiple linear regression – the <u>Visual Impact</u> had the same effect (co-efficient range) as SPL (sound volume). A more negative attitude towards visual impact had the same effect on annoyance as did an increase in SPL.** Rs who were fairly or very annoyed by wind turbine noise could all see wind turbines from their dwelling.

- Response to wind turbine noise was <u>negatively correlated</u> with perceptions of recovery and gaining strength in the living. The Rs who were annoyed did not think the area was suitable for recovery/gaining strength ($r= 0.128$, $p<0.001$).

- **Only a small number (84 of the 1095) of respondents reported being fairly or very annoyed by the wind turbine noise.** This group reported they were more sensitive to noise. **They also scored higher on the sensitivity test ($t=3.38$; $df=1072$; $p<0.01$) – they were more sensitive to noise, odour, air pollution, and litter.** (No hearing differences between groups were reported.)

- Fairly or Very Annoyed (by wind turbine noise) were: a) more likely to live (have lived) in rural areas than in suburban areas compared to the non-annoyed (85% vs 28%, $p<0.001$); and b) more likely to live in an area considered to be quiet areas.

- All those considered fairly or **very annoyed could see the wind turbines** from their dwelling.

- The prevalence of noise annoyance was higher among people living in more rural settings.

<u>Pedersen & Larsman (2008) The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines</u>

- **Response to wind turbine noise was positively correlated with A-weighted SPL ($r = 0.37$; $n=1095$; $p<0.001$).**
- Noise levels affected noise annoyance with the effect being significantly higher for respondents who could see wind turbines from their residence.
- Response to wind turbine noise was correlated with attitudes about wind turbines in general and attitudes/perception of their visual impact on the landscape ($r = 0.63$; $p<0.001$).
- Response was not correlated with age or sex.
- Respondents who could see at least one wind turbine from their residence were exposed to higher noise levels and responded more negatively to the noise from the wind turbines.

<u>Pedersen & Waye (2007) Wind turbine noise, annoyance, and self-reported health and well-being in different living environments.</u>

- The odds of perceiving wind turbine noise increased with Sound Pressure Levels (SPL) [OR 1.3; 99% CI 1.25-1.4.]
- The Odds of being annoyed by wind turbine noise increased with increasing SPL [OR 1.1; 95%, CI 1.01-1.25]
- Perception and annoyance were associated with terrain and urbanization: a) rural areas increased the risk of being annoyed compared to urban; and b) complex ground (hilly or rocky) increased the risk.
- Annoyance was associated with both subjective and objective factors and wind turbine visibility.
- **The percent of Rs living in areas with SPLs $\leq$ 37.5 dB who reported being Annoyed was less than 5%** and slightly above 5% for those living with SPLs of 37.5-40.0.
- **2% of Rs [20/754] lived in areas with SPLs > 40.0 dB. Of these 20, about 15% reported being annoyed**.
- 39% of Rs noticed sound from wind turbines outside their dwellings (Note: Rs were not included if the SPLs were not expected to be at least 30 dB.)
- **At 37.5-40 dB(A), 71 % of Rs reported they could hear wind turbine noise. And at 40 dB or more 90% of 20 Rs reported hearing wind turbine noise.**
- **Total # annoyed = 31/754 (4.1%) Note: Average noise level across 7 locations was 33.4 dBA with an avereage distance of 780m.**
- **% annoyed: a) under 37.5 dBA ranged from 3-4%, b) 6% for 37.5-40 dBA, and c) 15% for over 40 dBA.**
- Living in a rural area, living in an area with a low subjectively rated background noise, being noise-sensitive, and having a negative attitude to wind turbines (in general) or to their visual impact on the landscape were factors positively associated with annoyance.

<u>Pedersen & Waye (2004)) Perception and annoyance due to wind turbine noise – a dose–response relationship.</u>

- Noise **annoyance was correlated with both sound levels (dBA) and the 3 subjective factors** with the strongest correlation between dBA and negative impact on landscape.

- Annoyance was associated with increased dBA but also that when adding the subjective factor

- "negative attitude to visual impact" the influence of noise exposure alone decreased but was still statistically significant (The new model that explained 46% of the variance in annoyance).

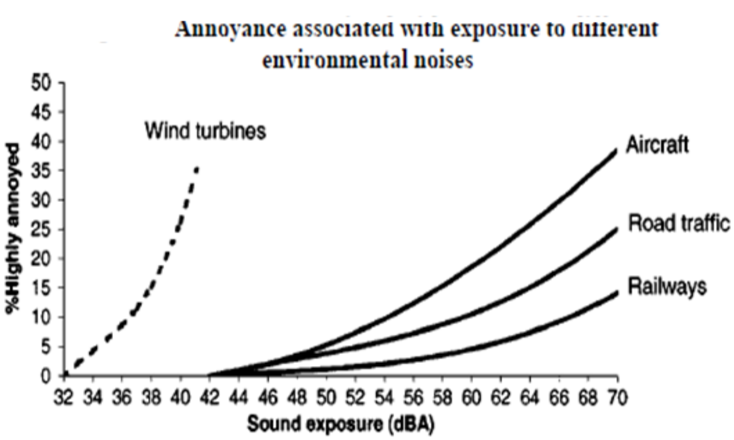
- The proportion of those who noticed noise increased sharply as SPL increased. (39% of Rs noticed WT noise at 30-32.5dB, 85% of Rs noticed noise at 35-37, and 96% noticed noise at >40dB)

- The proportion of Rs annoyed (outdoors) increased at sound categories exceeding 35.0 dBA. (At 37.5-40.0 dBA, 20% of Rs were annoyed. At >40 dBA, 36% of Rs were annoyed.)

- **Of those who noticed WT noise, 25% reported they were disturbed by it daily or most days.**

- 7% of Rs were also annoyed by WT noise while <u>indoors</u>

Below is copy of a figure used by Pedersen & Waye to illustrate a comparison between the dose-response relationships for transportation noises and wind turbine noises. The figure shows that people tend to be annoyed more easily by wind turbine noise at lower noise levels (dBA) compared to the different sources of transportation noises.



Kaldellis & Kavadias (2004) Evaluation of Greek Wind Parks Visual Impact. "The Public Attitude".

- Reaction to the sight of a wind farm is highly subjective.
- Visual impact was found to be one of the most important parameters affecting the public attitude towards wind power.

Conclusions and Implications/Policy Suggestions - Cross Sectional Studies

Pedersen & Waye (2008) The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines

- Response to wind turbine noise was significantly related to exposure (SPL A-weighted SPL in dB).
- **There is support to the hypothesis that there is more to annoyance than sound levels** (SPL) and that intrusiveness and sound characteristics also contribute.
- **Only a small % of people who could hear the wind turbines became very annoyed**.
- The prevalence of annoyance was higher among people living in more natural environments and among those who lived in areas previously considered naturally quiet.
- **A negative attitude about the visual impact of the wind turbines on the landscape was equally associated with annoyance as was the A weighted SPLs.**
- Respondents who were the most annoyed were also the most stressed (self-reported and measured)

Pedersen & Larsman (2008) The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines

- The probability of perception of and/or annoyance with wind turbine noise would be large in a landscape where the wind turbines are easily visibly distinguished. Thus it is possible that an "asthetic respsonse, rather than a multi-sensory effect, is one of the main factors influencing response to wind turbine noise. Wind turbines in a flat landscape are not just easily detected, but could also be appraised as incongruent with the environment" (p388). "Residents in these areas had possibly chosen the environment for qualities such as quietness and beautiful scenery, and would not appraise wind turbines as congruent with their expectations of the living environment" (p288).
- **Perceptions that wind turbines have a negative impact on the scenery increases the probability of noise annoyance regardless of A-weighted sound levels.**
- Thus, it is important to take visual attitudes (towards the noise source) into account during an environmental assessment.

<u>Pedersen & Waye (2007) Wind turbine noise, annoyance, and self-reported health and well-being in different living environments.</u>

- It is possible that the model used for calculating the sound underestimated the A-weighted SPL

- Seeing one or more wind turbines increased the odds of perceiving sound from the wind turbines and being annoyed.

- A negative attitude about wind turbines in general but particularly about their impact on the visual landscape increases the odds of being annoyed.

- **In this study – no Adverse Health Effects other than annoyance could be directly connected to wind turbine noise.**

- There is a need to consider the unique (local) environment when planning a new wind farm – to avoid adverse health effects.

- The influence of local area factors on noise should be considered in future research.

- **In planning wind farms, it would help (decrease stress/annoyance) by providing residents with relevant information and possibilities to communicate with the developers and authorities** (Note: those who discussed and sought information experienced less strain.)

- Future research should: a) take into account individual factors known to moderate the dose-response relationship; and b) explore the influence of dissimilar environments.

<u>Pedersen & Waye (2004) Perception and annoyance due to wind turbine noise – a dose–response relationship.</u>

- A significant **Dose-Response Relationship between SPL (dBA) from wind turbine noise annoyance was found**.

- Prevalence of noise annoyance was higher than expected (when comparing to other setting/noise sources). One factor that could explain the different dose-response relationships (wind turbine versus other noise sources) is that the wind turbine study was in a rural environment where low background level noises allow increased perception of wind turbine noise. Thus, the wind turbine noise is not easily masked or blended into normal ambient (background) noise.

- **Further studies are needed**, including more Rs in upper sound categories – before sound conclusions can be reached.

- There is a **need to explore the influence of individual and contextual parameters**.

Kaldellis & Kavadias (2004) Evaluation of Greek Wind Parks Visual Impact. "The Public Attitude".

- In order to support the sustained development, more attention should be paid on the visual incorporation in the local landscape.

- The visual intrusion of existing or new wind farms should be analyzed and amended.

Warren C, Lumsden C, O'Dowd S, Birnie R. 'Green on Green': public perception of wind power in Scotland and Ireland. *J Environ Planning Management.* 2005;48(6):853-875.

Overview
The authors report on two case studies conducted in 2003 in Scotland and Ireland at existing and approved wind farm sites.

Background
Previous research has found that those who are 'anti-wind turbine' perceive the turbines as being much noisier and intrusive than those pro-turbine, regardless of how loud they actually are.

Purpose
The authors tested three 'counter-intuitive' findings from previous research: 'temporal effects' (i.e. attitudes are more favourable *after* construction), 'spatial effects' (i.e. attitudes are more favourable *closer* to the turbines) and 'NIMBY-ism' (i.e. that NIMBY syndrome lacks adequate explanatory power).

Methods
Face-to-face, in-home surveys were conducted using a pilot-refined questionnaire. Two locations were chosen in Scotland, one with an existing farm and another that had an approved construction. Two zones at each location were defined: 1-5 km and 5-10 km. Household selection was systematic, with every third house selected within a settlement with a random starting point. In Ireland, two locations were chosen with two existing wind farms in close proximity to each. There three zones were used at each location, adding a 10-20 km zone. In each zone, the largest population centre was sampled. Scotland n = 115. Ireland n = 240.

Results
Only one respondent (of 16 negative responses) at the existing site in Scotland cited noise as a negative factor. There is 88% overall support for the site. 24% of residents altered their attitudes towards the turbines after installation (positively), with 15% of those being because the turbines produced no noise.

In Ireland, there were a high number of people who reported expecting negative impacts from the turbines, with 59% of respondents citing noise (among other factors). However, 73% of respondents felt their fears were never realized, either because they have not arisen or because they have become used to the turbines. Only 11% of all respondents reported being able to hear the turbines, with 75% of those 11% reporting that the sound did not disturb them or it was background noise.

Conclusions
The "results support earlier work which has found that opposition to wind farms arises in part from exaggerated perceptions of likely impact, and that the experience of living near a wind farm frequently dispels these fears." "Visual and noise impacts turn out to be less than commonly anticipated."

Waye KP, Ohrstrom E (2002). Psycho-Acoustic Characters of relevance for Annoyance of Wind Turbine Noise.

Overview
The purpose of the study was to evaluate the relative annoyance between noises from different wind turbines and to see if it were plausible that observed relationships would reflect differences between different wind turbines in real life situations and hence help with technical solutions.

Methods

Subjects: 25 university students (13 women, 12 men) were recruited and had a hearing test. All were considered to have normal hearing levels.

Noise Exposure:

- Noise was recorded from 5 of the most frequently used mid-sized wind turbines in Sweden. Noisewas recorded at 25, 100, 200, and sometimes 300 or 400m at wind speeds of 7-10 m/s.

- Recordings at **100m** were used for the experiment where subjects were exposed to the noise at times of 3 minutes and 10 minutes at levels of 40 decebels A-weighted.

Outcome Measures: i) annoyance, ii) relative annoyance, iii) length of time they were **aware** of the noise during 10m exposures, and perceptions of: a) loudness, b) sharpness, c) roughness, d) fluctuation strength, e) tonality, and f) modulation.

Instruments:
Subjects responded to 4 sets of questionnaires:
Questionnaire A – evaluated attitude towards wind turbine noise (administered pre-test).
Questionnaire B – evaluated annoyance and awareness of the wind turbine noise.
Questionnaire C – subjects rated perception and annoyance.
Questionnaire D – subjects rated relative annoyance of the five noises from the different wind turbines (from least to most).

Analysis:
Differences between subjective ratings of the noises were evaluated using ANOVA. Tests of significance for separate noises were done using Duncan new multiple-range test. Analysis of relationships between variables were done using Pearson's correlation coefficient. All tests were two tailed and a p-value of <0.05 was considered statistically significant.

Results

- Noise from one type of wind turbine was significantly more annoying compared to two other types of WTs.
- A significant difference was found in the rating of awareness between noises from different types of wind turbines.
- The % of subject who were aware of the wind turbine sound (often to nearly the whole time or the whole time) ranged from 28%-40% depending upon the WT type.
- Ratings of ‘lapping’, ‘swishing’, ‘whistling’, and ‘uneven’ were significantly different between the noises
- Most annoying noises reported were: swishing, lapping and whistling. Least annoying noises were: grinding and low frequency.
- Annoyance was significantly correlated to ‘lapping and whistling’ (swishing did not reach significance).
- Awareness was significantly correlated to lapping.
- Unlike other studies – there was no significant relationship between subjects’ attitude to, or opinion of WTs and annoyance of WT noise.

Conclusions and Implications/Policy Suggestions – Experiment Studies

- Subjects in this study were not residents near local WT Farms. This may explain why the results regarding opinions of wind turbines were not associated with annoyance as has been observed in other studies.

- There may be a need to establish standardized definitions for: a) different sounds reported; and possibly for b) physical symptoms reported.

- Lapping, swishing and whistling can be hypothesized to be easily noticed and potentially annoying sounds, while low frequency and grinding can be hypothesized to be related to less intrusive and potentially less annoying sound. The authors suggest: These descriptors should be identified in acoustical terms and further analyzed in interactive studies.

WIND TURBINES AND HEALTH, PUBLISHED – CASE STUDY, KEY INFORMANT & GROUNDED THEORY

Three studies were identified that were a fit for this category:

Pedersen, Hallberg & Waye. (2007). Living in the vicinity of wind turbines: A grounded theory study.

Gross. (2007). Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance.

Alves-Pereira & Castelo Branco. (2007) On the Impact of Infrasound and Low Frequency Noise on Public Health – Two Cases of Residential Exposure.

The Pedersen and Gross studies addressed psycho-social aspects, human responses and attitudes and perceptions about wind farms and will be summarized together. The Alves-Pereira case study presents ‘vibroacoustic disease’ and will addressed independently in this section and more comprehensively in Appendix 5.

Gross C. (2007) Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance.

Pedersen, E., Hallberg, L.M., & Waye, K.P.. (2007) Living in the vicinity of wind turbines: A grounded theory study.

Purpose

In a **case study** of key informants, Gross evaluated aspects of plans to develop a 69 wind turbine installation in Australia. The study explored whether the application of procedural justice (as principles of fairness) can increase acceptance of the outcome of a development proposal within a community, as well as the general viability of the model as a community consultation approach.

The purpose of the **Pedersen et al., grounded theory study** was to "gain a deeper understanding of how people living in the vicinity of wind turbines perceive and are affected by turbines. Respondents were asked about the community consultation process.

Methods

A town (Taralga) in Australia was chosen for its recently proposed wind farm and the contentious reception said proposal received. An initial analysis of the submissions to the planning authority during the developer's consultation period was done, with nearly 25% mentioning community divisions. It was decided to focus on the consultation process itself, and not the actual wind turbine proposal. Gross conducted cross-disciplinary research using an adaptive theory approach that included semi-structured interviews with selected members of the community that had a population of about 370. These individuals were selected using a snowball methodology. A total of 12 interviews were conducted with all participants unaware of the final outcome of the development proposal, as it was still being decided upon.

Pedersen et al., used a constant comparative method for discovering grounded theory. They conducted in-depth interviews with 15 informants who live within 600m of wind turbines in a wind farm with 40 turbines. Subjects were specifically selected from different noise exposure sound pressure level (SPL) categories: a) <32.5 dBA, b) 32.5-35.0 dBA, c) 35.0-37.5 dBA, d) 37.5-40.0 dBA, e) >40.0 with over 50% of the subject living in the higher SPL level ($\geq$ 37.5 dBA) categories. Respondents were asked what they thought of wind turbines when first erected, what they thought now, and how they would describe the implications of living near them now.

Results

Gross (2007) found that:

- **The community was very divided and with high tensions.**
- Issues raise by those opposed were: secrecy, too little too late, misleading to some, deficient information, unanswered questions and lack of appropriate consultation which Gross suggested seemed to facilitate the opposition groups.
- Problems resulted in financial winners and losers, social division, no open discussion, letters to the newspaper and changed opinions.
- **If people have an initial positive or neutral perception of wind turbines but find the process to be unfair – they are more likely to perceive the outcome as unfair/not legitimate.**
- The "legitimacy of the outcome [was viewed as] synonymous with accepting the outcome and being satisfied with it."

Pedersen et al., (2007) found that:

- Some Respondents in this study reported annoyance at SPL levels lower that what would typically not cause annoyance from road traffic and other sources.

- Two main stimuli identified by Rs were: i) noise, and ii) flicker. Rs indicated that the noise could not be compared to other sources of disturbances.

- All respondents indicated they were exposed to audible and visual stimuli from the wind turbines.

- The reported experiences/consequences differed enough to place people into two categories that emerged: **1) Intrusion into Privacy**; and **2) Outside my Territory**. It appears that personal values about living their living environment is what decided which category was the appropriate fit for the respondent.

- <u>Respondents who fit into the Intrusion category:</u>
    a. Appeared to place more value on their home environment as a peaceful quiet place where they create a home versus just live in it and where they would not be exposed to both known and unknown risks.
    b. Saw the home as a place to rest (*a protected zone which was removed by the wind turbines*) and that was away from the busy world.
    c. Expressed feelings of violation, helplessness, lack of influence or control, being subject to injustice (from local officials and wind turbine), not being believed (about their experiences).
    d. <u>Felt that wind turbines were an intrusion on their privacy.</u>
    e. **Were more likely to express feelings of anger, uneasiness, fatigue and negative emotions and that this affected well-being and quality of life.**
    f. **Felt they did not have enough input/influence regarding the planning of the wind farms** and that they were misled regarding the impact of the wind turbines on them (when they signed the agreement). They also described bad experiences treated disrespectfully when dealing with govt officials.

- <u>Respondents who fit into the **Outside My Territory** category</u>
    a. Were more likely to consider the countryside to be a place for economic growth and technical achievement. **They believed that if one chose to live in the country, one must accept disturbances typical of the countryside such as: flies, odor from farms and thus also noise and shadows from wind turbines.** They felt land owners had the right to decide how to use their land thus the right to erect wind turbines. These respondents expressed that wind turbines were of no concern because they were "***outside of my territory***".

    b. Noticed the noise and flickering light and the wind direction but generally did not think of them (otherwise) even though the noise could be heard. "It doesn't bother us – you can hear it if you want to".

    c. Indicated the exposure from the WT could easily be mentally shut out and thought of as not relevant. They described themselves as more tolerant than their neighbors in the **Intrusion c**ategory. Their perception was that those in the Intrusion category had too high demands of their living environment.

    d. **Often described wind turbines in a positive sense** such as using them to notice wind direction for deciding where to place BBQs in the garden. WTs were perceived as neutral or ugly but necessary devices.

Conclusions and Implications/Policy Suggestions

Gross (2007)
Improved or more acceptable outcomes are more likely if: a) consultation is conducted openly and starts early, b) issues are answered fully, c) all community voices are heard and not drowned by the opposing voice and d) if a general community consensus is reached. Gross suggested that a fairer process leads to better community discussion and is less likely to result in social conflict, damaged relationships and a sense of winners and losers in the community.

Pedersen, Hallberg & Waye. (2007).

- Since audible and visual stimuli from wind turbines cause annoyance among some people, wind turbines could be considered to be environmental stressors.

- Living near WTs affects different people differently.

- **Those in the *Intrusion Group* may be more *Territorial* in nature** in that they rely heavily on physical boundaries physical markers and boundaries put up around and inside their primary territory to stop intrusion from the outside. (Note – this group appeared to spend more effort decorating/personalizing their homes and gardens - the authors suggested this was like 'marking their territories' used more fences, bushes.)

- **The authors also suggested that another way to understand differences between the two groups (annoyed and not annoyed) was to use the Cognitive Stress Theory (Lazarus and Folkman 1984) and to focus on the individual's interpretation of the meaning of environmental events**. (This study found that respondents in the two categories had different values about their living environments (economic growth VS peace/quiet/rest).

- Little is known about the long-term consequences on health of low-level ambient stressors and that given the lack of ability to control the wind turbine stressor could pose a mental load over time that could have a negative impact on health and well-being.

- Responses to flicker are not well known and need more research.

- Wind turbine characteristics make their impact (on the area/residents) different from other noise sources such as road traffic. The sound from WTs is amplitude-modulated (varies with rhythmically and intensity of rotor blades). In addition, the WTs are very large, and placed in the rural landscape that has low background noise. These differences suggest that studies from other settings (i.e.,road traffic in urban settings) cannot be generalized.

- Bad experiences when contacting authorities were commonly described by those who were negatively affected by WTs.

- **The possible association between 'territoriality' characteristics and annoyance from WTs should be further studied.**

- **Future studies should focus on how to plan and develop WT farms so that they do not intrude on peoples' living environments and lead to unnecessary adverse effects.**

Alves-Pereira & Castelo Branco. (2007)
<u>On the Impact of Infrasound and Low Frequency Noise on Public Health – Two Cases of Residential Exposure.</u>
[Note – See appendix 4 for a more comprehensive evaluation of vibroacoustic disease and a possible link to wind turbines. In short, the international medical and research communities do not appear to have accepted VAD as a pathological entity. In addition, the VAD researchers did not make a diagnosis of VAD in the family exposed to wind turbines; however, they concluded the wind turbine family would someday develop VAD based upon their conclusions from the non-wind turbine location.]

<u>Paper Overview</u>
Authors present background information on what they believe causes Vibroacoustic Disease (**VAD**). They suggest that infrasound and low frequency noise (<500Hz) causes body cells and tissues to vibrate which causes a non-inflammatory response where the cells/tissues produce collagen which is the organisms attempt to reinforce structural integrity. The authors indicate that exposure to infrasound and low frequency noise (**ILFN**) causes thickening of walls of blood vessels and that this can be observed through echochardiography and that exposure to ILFN is associated with cardiovascular diseases (e.g., coronary heart disease, atherosclerosis and other conditions associated with thickening of blood vessel walls and blood flow restriction).

The authors then present two cases of residential exposure to **ILFN**. The two locations included a non-wind farm location where the researchers had diagnosed VAD in one family and a second location with Wind Turbines that had similar levels of low frequency noise **but where the researchers did not make a diagnosis of VAD and instead suggested it would occur someday if the residents continued living at the location.**

<u>Purpose</u>
This case study paper reports the results of two cases of residential exposure to infrasound and low frequency noise.

<u>Methods</u>
Included in the study were two families. One family resided near a grain elevator (the reported source of ILFN) and a second family residing near a wind farm with 4 wind turbines located between 322m and 643m (322m, 540m, 580m, 643m) from the home. [Note the wind turbines had only been operational for several months.]

The authors measured infrasound levels ($\leq$ 20 Hz) for different frequencies (Hz: 6.3, 8, 10, 12.5, 16, and 20) at the two different locations. They indicated that measurements were taken at different times using different equipment.

The authors also conducted health histories and health symptom evaluations in both families for symptoms they report to be associated with vibroacoustic disease.

<u>Results</u>
Sound levels - The unweighted ILFN levels reported at the two locations by Alves-Pereira & Castelo Branco are indicated below. The levels are slightly higher at the wind turbine residence.

Hz	**dB** Grain Elevator	**dB** Wind Turbines
6.3	**45**	***53***
8	**52**	***56***
10	**51**	***58***
12.5	**42**	***47***
16	**41**	***56***
20	**36**	***53***

Health Results

- Grain Elevator Family - Authors indicate this family consisted of mother, father and 10-yr old son. The authors state the **Father was asymptomatic *but that he complained of concentration problems, and irritability***. They reported that the **Mother** has: late-onset epilepsy, body aches, headaches, an episode of tachycardia with feelings of faintness (EKG revealed no abnormalities). They also reported that the **Son** suffers from asthma, had pneumonia at 8 months and ear surgery at 3 years, was diagnosed with late onset epilepsy at age 5 yrs, and had nose bleeds that later stopped. The authors stated that echocardiography, indicated that all three subjects had thickening of cardiovascular structures normally seen in VAD patients (e.g., pericardium and mitral valve) and made a finding that VAD existed in this family.

- Wind Turbine Family – This family consisted of two children (girl 8 & boy 12 years) and mother and father. The authors reported that the 12 year old boy had been experiencing a decrease in memory and attention skills at school. They did not find evidence of VAD (i.e., thickening of cardiovascular structures) in any family member and did not make a diagnoses of VAD.

Conclusions and Implications/Policy Suggestions – Vibroacoustic Disease Case Study

- **The authors concluded that the wind turbine family members would someday develop VAD because their ILFN exposure levels were higher than the exposure levels of the Grain Elevator family** who the researchers had previous made a diagnoses of VAD.

- **Studies investigating the effects of noise exposure on public health that do not take into account the entire spectrum of acoustical energy are misleading** and may be scientifically unsound.

- The acoustical spectrum should be further segmented and the dBA unit should be abolished from ILFN assessments.

Wind Turbines and Health, Published Peer Reviewed – Other Research

Six papers were identified that were a fit for this category. A review of the titles (see below) will indicate that these papers were a 'loose' fit for the peer reviewed research category. They were included because they met two or more of the following criteria: a) addressed some aspect of the relationship between wind turbines and possible adverse health consequences; b) were published in peer reviewed journals; and c) included evidence informed data, opinions or conclusions. Main results and policy suggestions will be summarized for each paper.

Bastasch M, van Dam J, Søndergaard B, Rogers A. (2006). Wind Turbine Noise – An Overview

Dixaut G. Vernez D, Fevrier C, Rumeau M, Thibier M, Berengier M. et al. (2008). Wind turbines and noise: Is there a minimal siting distance?

Harding G, Harding P, Wilkins A. (2008) Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them.

Kaldellis JK, Kavadias KA, Paliatsos AG. (2003) Environment impacts of wind energy applications: "Myth or reality?"

Keith S, Michaud D, Bly S. (2008) A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act.

Leventhall G. (2006) Infrasound from wind turbines – fact, fiction or deception.

Nash R, Martin A, Carney D, Krishman K. (2006) Wind farms as possible tourist attractions.

<u>Dixaut G et al. (2008). Wind turbines and noise: Is there a minimal siting distance?</u>

<u>Background</u>

The authors report a study that was conducted by the French Agency for Environmental and Occupational Health Safety (AFSSET) and the French Environment and Energy Management Agency (ADEME) that was in response to **<u>public concerns</u>** about potential environmental and health impacts of wind turbines. ***The authors indicate that those concerns are what led the French National Academy of Medicine to temporarily recommend a minimal distance of 1,500 metres between wind turbines (>2.5MW) and residences***.

The author indicate that two main noise regulation strategies exist in different countries: i) acceptance levels based on absolute noise (including ambient background and other sources); and ii) acceptance levels based on emergence (the contribution of a specific source to the ambient level). They indicated that ‘Absolute levels’ are used in some countries (e.g. Germany, Denmark, Greece and Sweden) and that a combination of both absolute and relative levels are used in other countries (e.g. England, Australia, New Zealand and France). They also point out that French regulations are quite restrictive and set at an emergence limit of 3 dB(A) at night.

<u>Methods</u>

A work group of experts in acoustics, metrology, and health effects were formed to review available data from various countries including data on measured noise levels in residential areas. In addition, regional authorities were interviewed (42% response rate of 97 regional authorities) to get data on setback distances and management practices. The researchers also conducted simulations to assess noise levels induced by wind farms in different topographical locations and under different meteorological conditions.

<u>Results and Conclusions</u>

- Complaints from residents reported for 10% of wind parks.
- Lack of direct health effects.
- The numerical simulations indicated that noise emergence induced at 1500m remains weak and generally below 3 dBA.
- Mean current setback distance was 650m.
- ***The setting of a precautionary distance of 1500m does not seem relevant.***

<u>Harding G, Harding P, Wilkins A. (2008) Wind turbines, flicker, and photosensitive epilepsy</u>

<u>Purpose</u>
Harding et al., **addressed the issue of 'shadow flicker'** and the concerns associated with the possibility that wind turbines could cause seizures.

<u>Background information</u>
The authors indicated that both sunlight and televisions can be precipitants of photosensitive seizures and that photosensitive seizures occur in 1 in 4,000 people.
They also indicated that large wind turbines rotate between 30-60 rpm and that at 60rpm can produce flicker at a rate of $\geq$3Hz (would be 3 flashes per second from WTs) and that exposure to flicker of a WT is determined by hub height and diameter of blades, the height of the sun and direction of the blades relative to the observer.

<u>Conclusions and Implications/Policy Suggestions – Shadow Flicker & Seizures</u>

- Analyses indicate that flicker from WTs is potentially a problem at considerable observation distances.
- WTs that interrupt sun light at frequencies greater than 3 Hz may possess potential risk of inducing photosensitive seizures.
- At 3Hz and less, cumulative risk should be 1.7 per 100,000 of the *photosensitive population*
- Keep rotation speeds to a minimum and in WTs with 3 blades, ensure that speed of rotation is not greater than 60rpm.

<u>Keith et al. (2008) A proposal for evaluating the potential health effects of wind turbine noise…</u>

<u>Purpose</u>
The **paper provides proposals for criteria for evaluating potential health effects of wind turbine** noise and the rationale behind the suggestions.

<u>Background</u>

- Authors indicate that Canada's wind capacity doubled in 2006 (to 1459 MW) and is projected to increase to 10,000 MW by 2015.
- The Canadian Environmental Assessment Act (CEAA) requires certain projects with federal government triggers, such as federally funded WT projects, to undergo an environmental assessment before receiving federal government approval. The intent of this process is to ensure that the projects are not likely to cause significant adverse environmental effects. However, <u>it is the responsible authorities' decision as to whether a project fulfills this intent.</u> (Environmental effects may include **Health Effects** from project related noise.)
- Health Canada provides advice relating to the effects on human health that is based upon well accepted scientific evidence.
- There is no general national policy for environmental noise that could be applied to WT noise in Canada.
- Buildings constructed to older Canadian residential standards attenuate exterior noise by at least 20dB with windows closed. The authors also point out that the WHO used the 15dB reduction for a windows slightly open situation.

- Noise Guidelines:
    a. **<u>South Australian</u>** environment Protection Agency, (2007) **35-43dBA** depending upon the measured background sound level.

    b. <u>International Guidelines</u>: a) **Denmark** = **40dBA** at 8 m/s, b) **UK** night time = **45dBA** at 8 m/s with increase to 54 dBA at 12 m/s. UK day time Leq = 37-42 dBA for Quiet Zones with increases up to 54 dBA for 12 m/s.

    c. **Canada** noise guidelines (not WT noise specific): **i) Quebec 40–45 dBA** depending upon Zone 1 (isolated fingle family dwellings, schools , hospitals or other teaching/health /convalescent institutions) or Zone 2 (multi-family dwellings, mobile home parks, institutions or camp grounds); **ii) Nova Scotia** = **Leq 55 dBA** night time; **iii) Manitoba** = **Leq 50 dBA**)

    d. **Canadian WT specific guidelines**: a) ***<u>Ontario</u>*** (limit increases w wind speed) i) <6 m/s = 40 dBA, ii) 11 m/s = 53 dBA); b) ***<u>Alberta</u>*** = **40 dBA** nighttime at 6-9 m/s; and c) ***<u>British Columbia</u>*** = **40 dBA** at a residence or lands residentially zoned at 8-10 m/s.

- Authors introduced the term: "**Percentage High Annoyance (%HA)**" and indicated the proposed changes are based upon projected-changes in High Annoyance.

- Modern WTs are not associated with audible low frequency or infrasound noise. The McKenzie Report (Hayes McKenzie, 2006) evaluated 3 WT farms in the UK and found that infrasound was well below the threshold for audibility, and that although low frequency noise may have been just above the threshold of audibility, it was less than the low frequency noise from local traffic noise.

- Ontario is the only province that specifies an adjustment of 5dBA if the WT project contains '*audible multi-frequency beating' however – the authors point out that at this time this does not apply to Ontario WTs.*

<u>Policy Suggestions and Conclusions for Evaluating Potential Health Effects of WT Noise</u>

- At a height of 1.5 m – in quiet rural settings – <u>sound level should not exceed 45dBA</u> at residences and that the predicted sound level should be based upon the wind speed yielding the maximum sound power from the WT. The authors propose noise mitigation should be enacted if predicted noise (Leq = ave day and ave night) from WTs would exceed 45dBA. Authors propose that the same limit be set for both day and night.

- **Utilize a 'cautious approach' to predict WT noise.**

- The authors suggest that "to decide which mitigation criterion should be recommended by Health Canada to responsible authorities, an evaluation method for the potential health effects of WT noise is needed. There is no general national policy for environmental noise that could be applied to WT noise in Canada.

- **Authors argue that a <u>Leq of 45 dBA</u> is consistent with the WHO recommendations that equivalent sound levels indoors not exceed 30dBA** for continuous background noise for a good night's sleep.

- Project sound levels should be adjusted by 10 dBA in quiet rural areas. (Annoyance reactions are expected to be higher in quiet rural areas because there is a greater expectation and value placed on peace and quiet.)

- Although modern WTs are not associated with 'audible tonal noise', each WT project needs to be assessed for tonal sound and that if tonal noise is present, the proposed criterion level of 45 dBA will need to be reduced.

- American National Standards Institute (ANSI) – specifies that in the 63 Hz band, moderately noticeable vibrations are associated with a sound level of 70 dB (or 44 dBA). Therefore, a 45 dBA limit in quiet rural areas should adequately protect against low frequency noise impacts from WTs.

- The authors refer to previous research that has shown a relationship between annoyance of aircraft noise and fear of aircraft crashes and then suggest that a similar relationship may exist for some living close to WTs because of the immense size the WTs that can be over 5 times the height of the house..

- Use a worst case scenario (i.e., assume maximum noise at a given wind speed) by illustrating that wind speed at the ground level can be much less that at hub height (1.4 – 2.6 time greater) and that consequently that WT noise will not be masked as well by ambient noise – or that WT noise will be well above the background sound level.

- *The authors indicate that: "an increase in community reaction can occur if an intruding noise, which was supposed to be inaudible or barely perceptible, is readily heard by the community".* Thus they suggest that environmental assessments avoid statements that suggest WTs are inaudible, or that changes of up to 5dB are either not, or barely noticeable.

Nash R, Martin A, Carney D, Krishman K. (2006) Wind farms as possible tourist attractions.

Overview

The authors reported the results from different European surveys that addressed public opinions about wind farms.

Results

- A Mori poll commissioned by the Scottish Executive (in 2002) indicated 'overwhelming support for wind generation' and that only 12% of the respondents thought the wind farms spoiled the landscape.

- In addition, when asked if the wind farms had a positive or negative effect on their impression of Argyll as a place to visit: a) 55% said generally or completely positive; b) 32% were ambivalent; and c) 8% said a negative effect.

- In 13 different studies in the UK that evaluated public attitudes about wind power of people living close to the sites or proposed sites (Total N = 3,549), all studies demonstrated that the majority of residents were in favour of wind power.

- The authors suggest that wind farms across the world have proved to be attractive to tourists and cited a California example where millions of tourists take rides through the areas in electric cars. The authors illustrated a common concern that (by the 'anti-development lobby) that wind farms drive tourists away and argued against this by providing a NZ example (Tararua) where the wind farm brought in tourists and has since diversified to accommodate more tourists with an interest in the site.

Kaldellis JK et al. (2003) Environment impacts of wind energy applications: “Myth or reality?”

Background

The authors indicated that wind energy is the fastest growing energy sector for electricity productions in many European countries and that wind turbine projects have provoked serious reactions from local people. This was a position paper on the impact of wind turbines on the environment. Noise and visual impact were discussed. The authors site previous research that found that a negative view of wind turbines on the visual landscape is a major factor in opposition to wind farms.

Technical information on noise levels was presented:

- As wind speed approaches 6-7 m/s the noise from wind in the leaves/trees/shrubs will mask the noise of wind turbines.
- Sound intensity drops with the square of the distance from the sound source.
- At 40m from the base of a wind turbine generating 100dBA the measured sound would be 60 dBA (corresponding to a clothes dryer).
- At 170m the sound would be 44 dBA.
- If two wind turbines are equal distance from the receptor, the sound energy will double and increase the level by 3dBA.
- It will take 10 wind turbines at equal distance from the receptor for the person to perceive the loudness to have doubled. (For example a farm of 10 wind turbines with the closest located 500m would result in a sound level of 42 dBA.)
- Two different origins of sound emissions from WTs 1) mechanical noise 2) aerodynamic noise with aerodynamic noise being the most significant from larger wind turbines. For most existing commercial WTs most significant source of noise is noise from the blades.

Conclusions & Policy Suggestions

- Wind energy is cost-effective.
- Wind energy application can impose unnecessary annoyance on humans.
- ***“It is a common belief that wind turbines are not inherently dangerous. Therefore, every aspect of a wind plant should convey the sense that wind energy is more benign than other forms of energy. Of course, wind industry should continue placing the same effort on being a good neighbor as on being aerodynamic efficient, in order not only to maintain but also to increase public acceptance of wind energy…”***

Bastasch M, et al. (2006). Wind Turbine Noise – An Overview

Overview

The article provides an overview/synthesis of the literature on wind turbine noise, measurement, regulation and research on annoyance.

Background Information

Sound measurement guidelines: come from the International Energy Agency (IEA). International standard IEC 61400 of the International Electrotechnical Commission is the typical standard (Parts 11 and 14).

There is much confusion among non-experts (e.g. legislation drafters, turbine opponents) about the 10 meter wind speed reference height stipulated in these guidelines. It does not refer to measuring wind speed at that height, nor the height of the measuring apparatus, but is merely for standardization purposes. [Note – reports about noise levels and standards very frequently indicate the noise was measured or calculated for a height of 10 metres from the ground.]

There is further confusion, since turbines are taller now than when the guidelines were written (from 50m to 80-100m or higher) so the 10m wind speed height is probably inappropriate in most cases "site specific values" must be adjusted for, which is commonly neglected.

Tonal values are also accounted for in the standard, as is a way of combining multiple test results across a farm for 95% confidence intervals. This standard does *not* cover amplitude variation or low frequency noise.

Turbines produce *aerodynamic* and *mechanical* noise. Noise generated by a typical turbine is 96-108 dB(A). *Mechanical* noise is generated by "the gearbox, cooling fans, the generator, the power converter, hydraulic pumps, the yaw motor and bearings". Technology is used to reduce this source of noise. *Aerodynamic* noise strongly correlates to tip speed. By controlling tip speed and blade angles noise can be reduced, usually reducing power output.

Noise annoyance

The authors indicated that "Annoyance from noise is not related to the noise levels themselves" and cite some of the literature (Fields, [1993]; Wolsink, [1993]; Pederson and Waye, [2005]) that provided evidence of a week relationship between annoyance and sound levels:

- Fields (1993), found a weak relation between annoyance and noise levels, but found annoyance related to perceptions and attitudes towards the noise source.

- Wolsink, et al. (1993): 564 people, SPL of 30-40 dB (A) from turbines; 6% were annoyed with weak relationship to SPL. Perceptions and attitudes towards the noise source were related to annoyance, which decreased over time.

- References Pederson and Waye (2005) <LINK>: 518 people, 6 levels SPL. Relation between increasing SPL and annoyance. Annoyance with wind turbines increases more quickly than with other industrial noise sources. Again, perceptions and attitudes towards the noise source were related to higher levels of annoyance

Infrasound and low frequency noise

- The research suggests that modern turbines do emit infrasound, but at levels below the minimum threshold of perception for most of the population, and well below the threshold for any adverse effects.
- Infrasound (sub 20 Hz) has both natural (.001 Hz – 2 Hz) and man-made sources. We experience infrasound as changes in static pressure, masking of higher frequency sound and vibrations.
- The human perception threshold increases as the sound frequency decreases thus small differences can have a highly variable impact on annoyance in different people.
- Infrasound can cause “fatigue, apathy, abdominal symptoms, or hypertension” at about 115 dB with the pain threshold at abouat 120 dB (10Hz).
- 24 hour exposure to 120-130 dB infrasound will cause physiological damage
- The authors indicate that: “It is important to reiterate, however, that *there is no evidence of adverse effects below 90 dB*” and that the noise of the wind turbine blades (the ‘swish’) is not low frequency noise.

<u>Conclusions and Policy Suggestions</u>

- Noise guidelines should be wind turbine-specific, given their special nature.
- The authors suggest that most of the propagation models currently used (including ISO9613-2) are not entirely accurate and that the most useful model is the Nord2000.
- Background noise levels should be measured pre-installation.
- More careful planning could help reduce negative attitudes amongst locals towards wind turbine projects (and thus future annoyance).
- Wind turbine noise can be perceived as annoying, particularly when negative attitudes toward wind turbines already exist.
- By focusing on infrasound and low frequency noise, turbine opponents are losing credibility and may be missing factors that can improve matters.
- The authors cite the findings of the 42nd IEA Topic Expert meeting on turbines, which recommends a collaborative planning approach (the European community-based approach) as opposed to the ‘hierarchical’ approach to development.

<u>Leventhall G. (2006) Infrasound from wind turbines – fact, fiction or deception.</u>

<u>Overview</u>

The author presents technical information about 'infrasound' and discusses how the media and other sources have misused and misunderstood what is infrasound. The author indicates that statement on infrasound from 'objectors' has caused avoidable distress in residents near wind turbines and served to divert attention from the main noise source caused by the repeating sound of blades interacting with the tower.

<u>Background and Technical Information</u>

- Author states it has been shown that there is insignificant Infrasound from WTs and that there is normally little low frequency noise.

- The author also states that the common assumption that **Infrasound** is <u>inaudible</u> is incorrect (and probably is based upon the descriptor).

  The author points out the misunderstanding between Infrasound and Low Frequency Noise has continued and illustrates how over time the misuse of the term Infrasound has crept into use by people who object to WTs and that this may have caused harm by detracting from noise sources (i.e., low frequency swish – swish noise) that need to be studied. For example, the author cites a 1994 newspaper article that suggested WTs are a health hazard because of the low-frequency noise they emit.

- The author states that frequencies below 40 Hz can't be distinguished from background noise due to wind but that back ground noise and WT noise separate above 40 Hz.

- Modern WTs produce pulses which analyze as Infrasound, but at low levels 50-70 dB below, typically well below the hearing threshold. Jackobson (2004) concluded Infrasound can be neglected in the assessment of WT noise (Jakobsen 2004).

- The fluctuations of WT noise (swish-swish) are a very low frequency modulation of the aerodynamic noise, which is typically in the region of 500-1000 Hz. (Paul's note – this is well above the Infrasound frequencies).

- The author indicates that a common definition for Infrasound is incorrect: "acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16Hz)" and indicates that sound remains audible below 16 Hz and as low as 4 Hz for exposure in an acoustic chamber.

<u>Conclusions and Policy Suggestions</u>

- Infrasound from WTs is below the audible threshold and of no consequence.

- Low frequency noise is not usually a problem except under conditions of unusual turbulent air flow.

- The problem noise from WTs is the fluctuating swish which may be mistaken for Infrasound – but it is in the normal audio range of 500-1000Hz

- It is the swish noise on which attention should be focus in order to reduce it or obtain a proper estimate of its effects.

- Claims of harm from infrasound are possibly harmful, should they lead to unnecessary fears. The author suggests that residents near a wind farm may be less tolerant of WT noise (thus experience anxiety/stress) as a result of incorrect statements about Infrasound from WTs.

- Attention should not be directed at Infrasound but at the audio frequency fluctuating swish-swish (often mistaken as infrasound), which is what some find disturbing depending upon its level.

- Although the needs of sensitive people need to be considered – limits should not necessarily be set to satisfy the most sensitive.

Devlin E. Factors affecting public acceptance of wind turbines in Sweden. *Wind Eng*. 2005;29(6):503-511.

Overview
A non-systematic review of the literature concerning wind turbines in Sweden.

Results
"Those who are irritated by the turbine's visual intrusion will be further annoyed by the turbine's sound level which will be construed as unacceptable noise. This only relates to a small minority of the neighbouring community."
A Swedish commission found visual impact the most troublesome factor.
Communities where there is a perceived need for turbines will better accept noise and visual intrusion.
Three studies all found that those who work the land are more amenable to turbines than seasonal users of the land.
Financial gain (locally) is extremely important in turbine acceptance.

SUMMARY OF WIND TURBINES AND HEALTH - PUBLISHED PEER REVIEWED RESEARCH

What do we know from the peer reviewed literature?

- **Evidence Base - A review of papers in this category clearly reveals that there is a small evidence base of the relationship between exposure to wind turbines and health effects.** The strongest evidence appears to focus on the relationships between noise levels and the pathway through individual characteristics (e.g., perception and attitudes) to annoyance.

- **No evidence was found that demonstrated a dose-response causal relationship between noise emitted from wind turbines and adverse health effects.**

- A French study (French Agency for Environmental and Occupational Health Safety) was conducted in response to the recommendation from the French Academy of Medicine that until a study was completed that a 1,500 set-back distance be used. **The conclusion of the subsequent French Study was that the precautionary distance of 1,500 metres was not warranted.**

- Alves-Pereira & Castelo Branco claimed the family residing near wind turbines would someday develop vibroacoustic disease; however, their research consisted of a single case study that cannot be used to make claims of causality. In addition, we remind the reader that they did not find vibroacoustic disease in their subjects and also that the international medical and research community does not appear to have recognized vibroacoustic disease as a pathological entity.

- A dose-response relationship between noise and annoyance exists with more people being annoyed when exposed to higher noise levels. The total percentage of those exposed who are highly or fairly annoyed is low. Pederson & Waye, (2008, 2007) reported 84 of the total sample of 1095 or 7.7% being fairly to highly annoyed and for those exposed to <37.5 dBA it was less than 5%. However, percentages increases rapidly for those exposed to SPLs in categories above 40 dBA. with reported percentages of fairly to highly annoyed ranging from %15 (Pederson & Waye, 2007) to 36% (Pedersen & Waye, 2004). It may be worth noting that in the 2007 study only 2% of the respondents (20/754) were exposed to SPLs above 40dBA.

- Annoyance and sleep disturbances were associated with a dose-response with increases observed at higher SPLs and those who are more annoyed are more likely to report higher stress levels.

- **Multiple studies found that visual impact (i.e., a negative perception of how WTs affect the view) and negative attitudes about WTs in general were also correlated with annoyance with the effect being as strong as noise levels. <u>The research also indicates a relationship between annoyance and self-reported stress but not between SPL and stress. This suggests that stress (and the outcomes of stress) in those individuals is a result of how they process and deal with unwanted stimuli but not a direct result of the actual exposure.</u>**

- The evidence suggests that additional factors that affect the acceptance of industrial wind farms and annoyance include perceptions of the purpose of the land, perceptions of intrusiveness and how fair or equitable local residents feel about the process which resulted in the decision to develop the wind farm.

- People become annoyed by wind turbine noise at lower levels than for other outdoor transportation related noises such as aircraft, road traffic and railways.

- Evidence supports the contention that negative fears are normally overstated and/or tend to dissipate after the turbines have been installed.

- Noise is cited as an annoying factor by a very, very small percentage of those living near wind turbines. Visual intrusion and other disruptions are far more likely to be cited as an annoyance, and even then these are a small minority.

<u>What do we need to know?</u>

- ***In the peer reviewed literature there is no evidence that exposure to wind turbines directly causes ill health. However, the evidence base is: small, self-reported, based on modeled not measured A-weighted exposure levels, and did not measure or estimate unweighted low frequency noise SPLs.*** Given this, additional research is needed that evaluates health outcomes associated with exposure to wind turbines. We recognize that many industry, academic and public health experts state that this is not needed because the exposure levels (emissions) from wind turbines do not justify the need. And per the results in the following sections (See sections 2-5 in this document) we agree that the wind turbine and additional noise and health evidence base points in this direction. However, "<u>no evidence of harm is not the same as evidence of no harm".</u> And until this research is conducted it is very likely that the increasing vocal opposition groups will continue to reject the assertions from industry, government and Public Health that wind turbines do not cause ill health effects.

- Research should be conducted at multiple wind farms with different geographic, population, and wind farm characteristics. Unweighted sound exposure levels should be measured (not modeled) at all residences before and after the wind farms are operational. SPLs should be measured at multiple times under different conditions. Individual characteristics and attitudes should be documented and self-reported, clinical and administrative data should be collected in randomized samples of exposed and non-exposed residents. A primary aim of the studies would be to evaluate whether any observed dose-response relationships exist between noise exposures and both measured and self-reported health outcomes.

- We need to know more about the relationship between individual characteristics and the likelihood of becoming highly annoyed by visual and noise exposures to wind turbines. This includes more knowledge about the local political decision-making process and the relationships between the local government, the developers and community residents.

- We need to know more about the actual respondents who report being annoyed and how likely this is to occur under different conditions.

- The evidence indicates that people become annoyed by wind turbine noise at lower levels than for other outdoor transportation related noises such as aircraft, road traffic and railways. However, when reviewing the dose response curves (See figure in the Pederson and Way, 2004 section) it is interesting to note that annoyance also seems to be related to when the noise source was introduced over time with Railways first and least annoying followed by Road Traffic, Aircraft and then more recently industrial WTs as the most annoying. Given this, would the curve for WTs be the same in 30-50 years?

- We need to learn more about what can be done to decrease the probability of annoyance in the general population and sleep disturbances and stress in those who become highly annoyed. This also includes the need for a better understanding of local characteristics and how to increase acceptance of the development and implementations of wind farms.

Category 1 References – Research: Wind Turbines and Health, Published Peer Reviewed

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Waye KP, Ohrstrom E. Psycho-Acoustic Characters of relevance for Annoyance of Wind Turbine Noise. *Journal of Sound and Vibration.* 2002;250(1):65-73.

2) Wind Turbines and Health - Grey/Self-Published Research

Grey Literature historically has been considered to consist of the following documents: scientific and technical reports, government documents, theses, conference abstracts, and working papers from research groups or committees. Thus, these documents often came from sources closely related to academic or scientific entities that did not have a specific political agenda. This suggests that; although these types of documents were not published in peer reviewed scientific journals, there was some degree scientific rigor. However, with the increased use of the internet, the definition of Grey Literature has broadened somewhat. This is because it is now very easy for almost anyone to self-publish and make a document available on the internet which can then be posted in one or multiple websites. The main criteria for this category were that the paper has a research component that addressed the results or hypothesized health impacts associated with exposure wind turbines. It was not our intent to complete an exhaustive review of all available grey literature documents particularly given that we chose to include opinion/synthesis documents that supported assertions with available evidence. In addition, we were constrained by both time and human resources.

Thirty-two documents were identified for full review for this category. A preliminary theme that emerged was that documents could be separated into two broad categories: i) Case studies and other papers that support the conclusion of negative health effects; and ii) Other papers that do not support or suggest adverse health effects. The results will be summarized by category. Full references are found at the end of this section.

Year/Author: Case Study/Other papers that support or suggest adverse health effects

2009 Pierpont N.
2006 Pierpont N.
2005 Pierpont N.
2005 Pierpont N.
2007 Harry A.
2010 Krogh C, Gillis et al.
2009 Nissenbaum M.
2007 Frey B, Hadden P.
2009 McMurtry R.
2007 Alves-Pereira M, Castelo Branco N
2007 Alves-Pereira M, Castelo Branco N
2007 Phipps R. et al.
2007 Phipps.
2009 Kleiber C, Colling D.
2007 Stewart J.
2007 Kamperman G, James R.
2009 Horner B, James R, Jeffery R et al.

Year/Author: Other papers that do not support or suggest adverse health effects

2005 National Academy of Medicine – France
2008 Van den Berg F, Pedersen E, Bouma J, Bakker R.
2003 Pedersen E, Halmstad H.I.
2008 Pedersen E, Bouma J, Bakker R, Van den Berg F.
2006 Pedersen E, Waye K.
2009 Minnesota Department of Health
2006 Hayes McKenzie Partnership Ltd.
2008 Chatham-Kent Public Health Unit.
2009 Rideout K, Bos C.

2006 Rogers A.
2006 Rogers A.
2005 Rogers A.
2007 Moorehouse A, Hayes M, von Hunerbein S, Piper B, Adams M.
2009 Colby D, Dobie R, Leventhall G, Lipscomb D, McCunney R, Seilo M, Sondergaar B.

Case Study/Other Papers that Support or Suggest Adverse Health Effects

Pierpont N

Pierpont N (2009). Wind Turbine Syndrome. A report on a natural experiment. Santa Fe, NM:K-Selected Books,
Pierpont N. (2005) Health, hazard, and quality of life near wind power installations. How close is too close?
Pierpont N. (2005) Noisy Wind and Hot Air. Wind Turbine Syndrome.
Pierpont N. (2006) Wind Turbine Syndrome: Noise, shadow flicker and health. 2006.

Overview

Nina Pierpont is a physician who introduced the term 'Wind Turbine Syndrome' after she observed a cluster of symptoms that people experienced who lived near wind farms. The 2009 'report on a natural experiment' provides information on the author's case series study (methods, results and conclusions) whereas the 2005-2006 documents provide background information and examples to support her claim that wind turbine syndrome exists and that exposure to wind turbines at the current setback distances causes illness in residents. The results, conclusions and policy suggestions of the four documents will be summarized together with a focus on the 2009 case series study (methods and results).

Background Information

- The author introduced the term **Wind Turbine Syndrome** which she describes as: *"a complex of symptoms which start when local turbines go into operation and resolve when the turbines are off or when the person is out of the area"* .

- **Symptoms the author suggests are caused by exposure to wind turbines include**: a) sleep disturbances; b) headaches (increased frequency, intensity or duration); c) tinnitus; d) balance & equilibrium disturbances; e) internal quivering, vibration, pulsation; f) agitation, anxiety, alarm, and irratibility; g) tachychardia; h) nausea; i) concentrations and memory problems h) decline in school performance; i) Irritability/anger; and j) fatique & decreased motivation.

- The author also introduced the term Visceral Vibratory Vestibular Disturbance (VVVD) which she describes as "internal quivering, vibration, or pulsations and the associated complex of agitation, anxiety, alarm, irratibility, tachychardia, nausea, and sleep disturbance".

- **Hypothesis for Wind Turbine Syndrome Aetiology -** Pierpont suggests that low frequency noise from wind turbines trick the body's balance system into thinking it is moving and relates the process to something similar to "seasickness". She references van den Berg (2006) where he reported 68-90 dB at 750m (10 Hz) and up to 60 dB (10-100 Hz) infrasound and low frequency noise levels from wind turbines. The author suggests **Wind Turbine Syndrome is associated with the Vestibular System – by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in diff body locations.** That "low frequency noise or vibration too weak to hear can still stimulate the human vestibular system; opening the door for symptoms that she calls Wind Turbine Syndrome". In addition to noise affecting the balance system, the author also suggests that since the eyes are involved – that shadow flicker 'adds' to the balance disturbance.

- The author also suggests that 20%-30% of the population is susceptible to the symptoms of wind turbine syndrome and that risk factors include: pre-existing migraine disorder, hearing loss, or those with a compensated balance problem. Pierpont also suggests the health impact from noise studies is under stated because vulnerable populations (elderly, sick, chronic medical conditions, depression, mental illness, developmental disabilities, babies and young) are requently underrepresented and are more sensitive to the effects of chronic noise exposure.

- The author states that wind turbine syndrome is not the same as vibroacoustic disease (VAD) described by the Portuguese researchers Alves-Pereira and Castelo Branco.

- The author indicates that in New York state noise standards indicate limits of 6 dBA for noise increases over ambient levels and that noise from wind turbines at night time is often perceived as louder because of characteristics that include still, cool air at ground level and that sound travels further at night.

<u>Pierpont N (2009) Wind Turbine Syndrome. A report on a natural experiment</u>

<u>Purpose</u>
In her 294 page book, the author indicates that the purpose of her study was to: "establish a case definition for the consistent, frequently debilitating, set of symptoms experienced by while living near wind turbine installations, and to place this symptom complex within the context of known pathophysiology".

Pierpont also indicates that individual attitudes effect whether noise is wanted or unwanted and that this affects annoyance. However, she rejects the possibility that symptoms are psyco-somatic (associated with other anxiety) and clearly believes they are caused by the noise from wind turbines.

<u>Methods</u>
Pierpont reports her study design was a **<u>case series of *affected* families</u>, interviewed by telephone. She used a broad-based, structured interview including a narrative account, symptom checklist, past medical and psychiatric history, personal and social history, selected elements of family history, and review of systems**.

Sample Selection
Pierpont indicates her final sample ***size as 37*** people. Pierpont recruited **10 'affected' families from five countries** (Canada, UK, Ireland, Italy & USA). In the methods section (p 38) Pierpont does not illustrate how the 'affected families' from the 5 different countries were identified. Subjects ranged in age from <1 Year to 70-79. Seven of the 37 subjects were 6 years or under with 4 being 3 years or under.

[*Note – in the methods section of her book, page 38, Pierpont does not describe how the 10 affected families from the 5 different countries were identified. However, being labeled as 'affected' suggests that a family member had already concluded that the wind turbines were associated negative health outcomes.*]

Subject Eligibility Criteria
The author indicated that families were selected to conform to criteria indicated below. (Later in her book, page 220, Pierpont further clarifies her criteria by indicating that at "least one family member was severely affected by living near turbines".

- Severity of symptoms of at least one family member.

- Presence of a "post-exposure" condition, in which the family had either left the affected home or spent periods of time away.

- Quality of observation, memory, and expression, so that interviewed people were able to state clearly, consistently, and in detail what had happened to them under what conditions and at what time.

- Residence near recently erected turbines (placed in operation 2004-2007).

- Short time span between moving out and the interview, if exposure had already ended (6 weeks maximum).

- Family actions in response to turbine noise showing how serious and debilitating the symptoms were (moving out, purchasing a second home, leaving home for months, renovating house, sleeping in root cellar). (Page 39)

Sample Size and Interview Methods
Pierpont interviewed 23 adult and teenage members of 10 families. However, she collected data on other family members using the primary respondent as their proxy to report data and answer questions on their behalf. Thus to achieve her sample size of 37, Pierpont collected data on 14 additional people in the 'affected homes' using the primary respondent as a proxy.

Respondents and Proxy Respondents were provided with a check list of possible symptoms were asked questions about symptoms and were asked to report them for periods: a) before exposure, b) during exposure, and c) at times away from exposure. Respondents were also asked about intensity of symptoms.

Exposure
Pierpont does not report weighted or unweighted sound measurements at each of the 10 residences. Reported distances from the homes ranged from 350m – 1500m with an average of 738. (It was unclear how these were measured.) The number of wind turbines in the wind farms ranged from 8-40 with an average of 21. Exposure time (time the wind turbines were operational) ranged from 5-21 months with an average of 8.7 months.

Results
Pierpont found that many subjects reported health symptoms that they believe appeared or increased following exposure to the wind turbines. Examples are summarized below.

- Sleep disturbances (32/37subjects)
- Increased frequency, intensity or duration of headaches (19/37 subjects)
- Tinnitus & ear symptoms – new or worse (14/37 subjects)
- Balance & equilibrium disturbances (16/37 subjects)
- Internal quivering, vibration, pulsation (11/37 subjects)
- Visceral vibratory vestibular disturbance (14/37 subjects)
- Concentrations and memory (ages 4 and older) (20/34 subjects)
- Decline or increase in school performance when exposed or non-exposed (7/10 children & teens)
- Irritability/anger (28/37 subjects)
- Fatigue & decreased motivation (21/37 subjects)

Pierpont also reported that:

- Symptoms typically appeared immediately or within the 1st month after exposure (the wind turbines were operational).

- Symptoms were correlated with particular sounds from the turbine installations, rate of turbine spin, or whether the turbines were turned towards, away from, or sideways relative to their homes.

- Wind turbine noise was more disturbing than other noises such as from trains.

- Risk factors for *Increased* *Tinnitus & ear sensations* included: previous noise exposure, tinnitus prior to exposure, and previous hearing loss.

- Subjects believed their symptoms were caused by: noise, vibration and/or by the moving blades and that symptoms were associated with wind direction and strength and sound characteristics.

- Respondents indicated that symptoms went away when they were away from the wind turbines.

- Other symptoms reported to be worsened during exposure to the wind turbines included: asthma, pneumonia, pleurisy, stroke,& changes in coagulation or blood sugar

Conclusions and Policy Suggestions

- Setbacks: Pierpont indicates that her and other studies suggest the following **minimum set back distances should be between 1.5km and 3.5km depending** upon the terrain or proximity to hospitals and residences. Current set back limits in the USA and other countries (305 – 457 m) are not based upon research on safety and health.

- Sound Measurement: **C-weighting is a more appropriate approach to measuring environmental noise (compared to the A-weighting standard) with low-frequency components, such as noise from wind turbines**.

- Risk factors: Those suffering from Wind Turbine Syndrome have a ‘compensated balance problem’. These people have been able to compensate for their balance problem by being more dependent upon the visual channel or the somato-sensory channel before they were exposed to the Wind Turbines. However, exposure to Wind Turbines creates further stimuli or causes additional distortion that hurts the ability to compensate and consequently affects balance.

- Research needs:
  - i) Studies that compare exposed to not exposed.
  - ii) Case series by neurotologists.
  - iii) **Studies that evaluate the relationships between: sound frequencies, sound intensity, and vibration with subjects’ symptoms**.
  - iv) Research on the effects of low frequency noise and vibration on the human vestibular system
  - v) Research should begin with a study of symptoms and not on noise levels. She suggests symptom clusters should be the reference point not noise levels. **We need to measure noise levels when symptoms are and are not present**.

Harry A. (2007) Wind Turbines, Noise and Health

Overview

Harry reports the results of a study (n=39) of people who lived 300-2000 metres from wind turbines in several sites in UK-Wales, Cornwall & North England. **Respondents who self-identified as suffering health symptoms as a result of exposure to the Wind Turbines were recruited for this case study.**

Background

The author is a physician living in the UK. She indicated that she realized there may be a problem associated with wind turbines when she was introduced to a family that resided about 400m from wind turbines and that reported to be suffering from poor sleep, headaches, stress and anxiety symptoms when the wind was blowing in certain directions.

Methods

Sample and Questionnaires - Questionnaires were sent to 42 adults (≥ 18 years) who were described as: "people already known to be suffering from problems which they felt was due to their proximity to WTs. [*Note – we could not find information on how these people were identified and recruited.*] The questionnaire was set up so that the person could respond 'yes' or 'no' to a check list of symptoms they experienced.

Survey questions addressed:

- Distance from property to nearest WT
- Length of time living at residence
- Self reported health status change after exposure ("Do you feel that your health has in any way been affected since the erection of these turbines?)
- Self reported symptoms affected after exposure (If yes (to question iii) – "Do you feel that since living near a wind turbine/turbines you have experienced excess of the following symptoms: headaches, palpitations, excess tiredness, stress, anxiety, tinnitus, hearing problems, sleep disturbances, migraines, depression, other?
- Whether the Respondent approached their doctor regarding their symptoms.
- If quality of life had been altered since living near the Wind Turbines.

Exposure

Harry did not report weighted or unweighted sound measurements at the residences.
Reported distances from the homes ranged from 300m – 1600m with an average of 643m.

Results

- Harry indicated that surveys were provided to people known to be suffering from problems they felt were due to the wind turbines. However, she indicates in a figure that 81% reported their health had been affected since the erection of the wind turbines.

- 73% reported that their Quality of Life had been altered since the erection of WTs.

- 76% reported they had seen an MD because of their symptoms.

- Of the Respondents answering yes to adverse health effects, the percent reporting different symptoms were: i) tired-80%; ii) lack of sleep-75%; iii) headache-71%; iv) stress – 60%; v) anxiety-53%; vi) migraines-27%; vii) depressed-23%; viii) tinnitus-21%; ix) hearing loss-18%; x) palpatations-17%.

- A main theme in the additional comments from respondents was the issue of noise as the main irritant/problem. Other themes that emerged as irritants included: flicker, loss of control, and impact on the visual landscape.

Krogh C, Gillis L, Kouwen N. (2010)
<u>A self-reporting survey: adverse health effects with industrial wind turbines and the need for vigilance.</u>
<u>Overview</u>
The authors report the results of an Ontario survey that has been ongoing since 2009. In the available March, 2010 report, 132 Ontario residents had responded. Surveys similar to those used by Harry (2007) were sent to people living near wind farms who responded to Health Survey Contact Flyers about wind turbines that were distributed in "areas affected by wind turbines". **In the abstract the authors refer to the survey respondents as** "**Victims**" and indicate the following: "Victims report disturbed living conditions and loss of quality of life and enjoyment of their homes and property, and financial loss due to the negative impact to the health of their families….. Comments from the victims are included in this report."

<u>Methods</u>
[*Note – it was difficult to find information in grey literature documents about the methods used for this survey. Much of what is included in this methods section is based upon a personal communication on June 12, 2009 between our research assistant and M. Anderson (Wind Concerns Ontario) who was familiar with the study.*]

Sample and Questionnaire

- Health Survey Contact Flyers were distributed in "areas affected by wind turbine complexes". Information in flyers included statements such as: "victims suffering from adverse health effects from wind turbine complexes are hesitant to report due to the manner in which their reports have been discounted".

- People who responded to the flyers were sent a survey that 'reproduced' that used by Dr. Amada Harry in the UK (See above: Harry, 2007). No restrictions were placed upon the survey distribution with the exception that respondents were fluent in English and without cognitive impairment. The survey was also available online.

- More than one 'affected' adult in the home could respond by filling out separate questionnaires.

- In the March 2010 report, 132 respondents had completed the surveys. Although the authors do not indicate the total number of residences and the dates the surveys were returned, the report does list respondent number and reported distance from the wind turbines. In the table provided there were 31 instances of respondent data where the reported distances to the wind turbines were exactly same for two or more respondents (range 2 – 5) that totaled 76 with a 2.5 average. This suggests that there may have been up to 31 residences where more than one self selected person responded to the survey.

Exposure
<u>Krogh et al., did report weighted or unweighted sound measurements at the residences</u>.
Reported distances from the homes ranged from 300m – 5000m with an average of 643m.
Fourteen percent (14%) reported residing less than 500m.

Exposure Levels - The authors did not report sound levels (SPLs) measured at the different residences. Thus, the only measure of exposure is the reported distance to the nearest wind turbine which on average was almost the same for those reporting health effects attributed to the wind turbines and those reporting no health effects. **(Health Effects average = 816.1m, No Health Effects Average = 820.6m)**

Results

Self-reported No Health Effects Group

- The authors report that 26/132 respondents (19.7%) indicated that they did not believe their health had been affected since the erection of the wind turbines.

- An **analysis of the data provided in the report indicates the average self-reported distance from the residences to the nearest wind turbine for the 'No Health Effects' group was 820.6 metres**.

Self-reported Health Effects Group

- The authors report that 106/132 respondents (80.3%) indicated that they believed their health had been affected since the erection of the wind turbines.

- Symptoms reported (attributed to the wind turbines) were that same as those used in the Amanda Harry survey and ranged from respondents reporting yes to 2 to all of: headaches, palpitations, excessive tiredness, stress, anxiety, tinnitus, hearing problems, sleep disturbance, migraines depression and other.

- 101/105 (96.2%) reported altered quality of life and 42/88 (47.7%, 18 non responses for this question) reported they had approached their doctor regarding their symptoms.

- An **analysis of the data provided in the report indicates the average self-reported distance from the residences to the nearest wind turbine for the 'Health Effects' group was 816.1 metres.**

Conclusions and Policy Suggestions

- **The authors suggest the number of people in Ontario reporting adverse health effects due industrial wind turbines continues to rise.**

- The authors refer to residents living near wind turbines as 'victims' who report disturbed living conditions and loss of quality of life due to the negative health impact on their families.

Nissenbaum M. (2009) Mars Hill Wind Turbine Project Health Effects: Preliminary Findings

Overview

PowerPoint presentation to the Maine Medical Association on health effects of particular wind turbine development by local doctor Michael A. Nissenbaum.

Background Information

- Nissenbaum indicates the Mars Hill Wind Project consists of 28 GE 1.5sl/sle turbines with an 80m hub height and about 119m blade tips. At a wind speed of 6-8m/s the turbines are reported to produce a noise level of 103-104 dB (A) with a tonal value of + 4 dB (A). The wind farm became fully operational in March 2007.

- 20 homes located North & East of turbines; 35 adults & 16 children live within 1036m (3400ft).

- The Department of Environmental Protection allowed *a variance from the noise standards* for the farm, finding that in four locations the sound level would be 45-50 dB (A) (nighttime). Further, the measured average was in fact 52.5 dB (A) which included downtime.

Methods

The author interviewed 15 adults (41-75 years) residing within 3,400 feet from the wind farm.
The questionnaire asked for pre-existing medical conditions (or diagnoses) and medications, and post-turbine medical conditions (or diagnoses) and medications (or dose changes).

It asked about the frequency/severity prior to and after turbine, whether it improves while away, whether they have seen a doctor and gotten a new prescription or change in dosage for a list of symptoms: sleep disturbance (difficulty falling asleep, waking up middle of night), headaches, migraines, dizziness, ears ringing, balance problems, unusual body sensations, weight gain/loss, palpitations, changes in appetite, feelings of stress, feelings of anger, feelings of hopelessness, feelings of anxiety, feelings of irritability, feelings of depression and other.

Additional questions ask about quality of life being altered and whether they have considered moving (and why they haven't, if they have).

Exposure

- Nissenbaum did report weighted or unweighted sound measurements at the different residences. However, on slide 29 he reports a stated noise variance of 45-50 dBA (from the wind farm operators) and that night time readings of 52.5 dBA had been reported.

- Reported distances to the nearest turbines ranged from 1,200 – 3,400 feet (average = 2,500 ft).

Results

• Sleep Disturbances	14/15 (13/14 discussed with doctor; 12/13 offered prescription)
• Headache (increased)	8/15 (6/15 new onset headaches, 2/15 increased migraine frequency)
• Dizziness	3/15
• Tinnitus	1/15
• Hypertension	3/15 new diagnoses, 1/15 condition worsened
• Weight Change	6/15 since turned on (5/6 are gains)
• Psychiatric Symptomatology	a) stress 11/15, b) anger 13/15, c) anxiety 6/15, d) irritability 4/15, e) hopelessness 11/15, f) depression 8/11 [7 new].
• Decreased Quality of Live	15/15
• Thought of moving	15/15

Conclusions and Policy Suggestions

- **Although the study has methodological weaknesses, the author indicates the result to be 'alarming'**.
- Nissenbaum proposes a moratorium on all development until the proper medical research can be undertaken, both locally and internationally. Or an alternative: the use of siting setbacks used in non-US jurisdictions and the use of C-weighting measurements.
- **There should be the adoption of a 'code of conduct' for developers**
- Quality of life should take priority over development.
- Suggests that since Maine has a vast unpopulated hinterland that there is little need to situate wind farms in close proximity to residential communities.
- Indicated epidemiological studies would be problematic if Good neighbor and lease-holder gag clauses exist in land leases.

McMurtry R. (2009)
<u>Deputation to the Standing Committee on General Government Regarding Bill C-150. April 22, 2009.</u>

<u>Overview</u>
This document is the text of a presentation given by Dr. Robert McMurtry where he presents information on regulations in Canada, low frequency noise and wind turbines and reported adverse health events. He concludes with a proposal for a well-designed epidemiological study.

<u>Background Information</u>
McMurtry indicates that (at the time) national regulations in Canada for set-back distances from a residence do not exist and that Provincial Ministry of the Environment regulations are flawed.

The author suggests low frequency noise is an issue, that there is growing public interest and that A-weighting underestimate sound pressure levels of noise and that C-weighting should be used. He also suggests the evidence on low frequency noise is sufficiently strong to warrant immediate concern but that there are crucial differences of opinion.

McMurtry reported that there were many reports of adverse health effects and cited the case studies by Dr. Nina Pierpont, Dr. Amanda Harry, Dr. Michael Nisssenbaum and the Ontario study led by Carmen Krogh and Lorrie Gillis. (*See preceding summaries*)

<u>Conclusions and Policy Suggestions</u>
The author concludes that **there are conflicting claims about possible health risks of low frequency noise from wind turbines and suggests the way to address the issue is to conduct a well-designed epidemiological study to be conducted by 'arms-length' investigators.** McMurtry also suggests sound engineers are brought in to measure low frequency noise levels near wind farms.

<u>Alves-Pereira M, Castelo Branco N. (2007)</u>
i) In-home wind turbine noise *is* conducive to vibroacoustic disease. Second International Meeting on Wind Turbine Noise. Lyon France. September. 2007
ii) Public health noise exposure: the <u>importance of low frequency noise. INTER-NOISE. Isntanbul, Turkey. August. 2007.</u>

<u>Overview</u>
These two documents represent the published materials from two international conferences in 2007: a) INTER-NOISE 2007 in Istanbul, Turkey; and b) Second International Meeting on Wind Turbine Noise in Lyon France. The authors present the results of a case study in which the authors describe vibroacoustic disease and where they conclude that low frequency noise from wind turbines can lead to severe health problems.

Note - These two documents present the information from the same study published in 2007:
Alves-Pereira M, Castelo Branco NAA. On the Impact of Infrasound and Low Frequency Noise on Public Health – Two Cases of Residential Exposure. *Rev. Lusofona de Ciencias e Technologias da Saude.* 2007;(4)2:186-200.

This paper was summarized earlier in the results section titled: **<u>1) Research – Wind Turbines and Health, Published Peer Reviewed.</u>** In addition, a more comprehensive evaluation of the suggested link between vibroacoustic disease and emissions from wind turbines is presented in Appendix 6.
Given this, these two papers will not be summarized in this section.

Phipps R, Amati M, McCoard S, Fisher R. (2007)
<u>Visual and Noise Effects Reported by Residents Living Close to Manawato Wind Farms: *Preliminary Survey Results*.</u>

Phipps R. (2007) Evidence of Robyn Phipps, In the Matter of Moturimu Wind Farm Application heard <u>before the Joint Commissioners 8th-26th March, 2007, Palmerston North. 2007.</u>

<u>Overview</u>
Research done on New Zealand wind farms with the objective of investigating noise and visual effects on local residents from wind turbines in the Manwatu and Taraua regions. The first document presents preliminary results; whereas, the second document reports results from a later date.

<u>Methods</u>
A four-page, self-reporting survey was sent to 1,100 residences located within 3km of existing wind farms. Questions were asked about the distance to the nearest wind turbine, whether they could see turbines from the home, visual impacts, **<u>noise impacts</u>**, financial gain from the wind farms, effects on television, radio and phone, and whether they had complained or considered complaining about the wind farm effects. Respondents were also asked quality of life questions.
[*Note – The authors asked if the respondents could hear the wind turbines (i.e., noise impact); however, they did not ask questions about annoyance or self reported health outcomes*.]

<u>Results</u>
- The survey had a 56% response rate (614/1100)
- The proportion of respondents who could hear the WTs decreased progressively with distance.
- 42% reported sleep disturbances
- 72% of the respondents reported hearing the WTs. Other perception data:

% reporting hearing WT	distance
45% residing	0-2 km
52%	2-2.5km
36%	2.5-5.3km
52%	5-9.5km
20%	10km

- Noise from WTs reduced quality of life: a) Never 68%, b) Occasionally 17.8%, c) Frequently 12.8%, d) Most of the time 1.7%.

- Nose from the WTs means we close window more that we would like: a) Never 73.5%, b) Occasionally 13.6%, d) Frequently 12.3%, d) Most of the time 0.6%.

<u>Conclusions and Policy Suggestions</u>
- The results indicate that wind farms have significant noise influences upon large number of people in the area and that number of people affected by noise may be underestimated.

- The 55% response rate suggests strong local interest in the topic.

<u>Kleiber C, Colling D. (2009) Modern Wind Turbines Generate Dangerously 'Dirty' Electricity. April, 2009.</u>

<u>Background</u>
The authors site the Ripley Wind Farm in Ontario (Enercon E82 turbines) and that residents have reported: ringing in the ears, headaches, sleeplessness, dangerously elevated blood pressure (requiring medication), heart palpitations, itching in the ears, eye watering, earaches, and pressure on the chest causing them to fight to breathe. They also indicate that some report that symptoms disappear when they leave and that four residents had to move and that <u>there is no radio reception under or near the power lines from the wind turbines because ther is too much interference and that local farmers report getting headaches driving along the power lines.</u>

The authors cite three sources [peer-reviewed] that associate "electrical pollution" with similar symptoms and refer to it as "radio wave sickness". The authors indicate that even exposure to small amounts of high frequencies" can cause symptoms and that this exposure is associated with increased risk of cancer and that symptoms are affected by frequencies, body-type and individual height.

<u>Results</u>
The authors show figures of waveform measurements that were taken at a residence before and after the wind turbines were operational which they report demonstrates that wind turbines are "extremely electrically polluting".

<u>Conclusions and Policy Suggestions</u>
The authors conclude: "In order to eliminate the electrical pollution problem wreaking havoc on the health of people living in proximity to wind farms, the inverters need to be properly filtered at each wind turbine and all collections lines from the wind turbines to the substation should be buried. There also needs to be a proper neutral system installed to handle the high frequency return current."

<u>Stewart J. (2006) Location, Location, Location: An investigation into wind farms and noise by the Noise Association.</u>

<u>Overview</u>
Review of how wind turbines work, official noise guidelines, wind turbine noise, reported health effects and new research conducted by The Noise Association of the UK.

<u>Background Information</u>

- Britain targets producing 10% of electricity from renewable sources by 2010. Britain subsidizes the industry and has plans to have 60-70% of the wind turbines to be located off short. As of 2005, there were over 100 wind farms in Britain, 19 under construction, 62 with consent and 150 in the proposal stages.

- The Department of Trade and Industry published the ETSU-R-97 guidelines and the Scottish Office Environment Department published the PAN45 guidelines. These are the guidelines used to assess noise impact by planning evaluators:

  a) Daytime: outside property levels should not exceed 35-40 dB (A) or background + 5 dB(A), whichever is greater.
  b) Nighttime: outside property levels should not exceed 43 dB (A) or background + 5 dB(A), whichever is greater.
  c) A penalty is applied for tonal sound

- MORI (Scotland) survey: surveyed people living within 20km of operation wind farms. Less than 0.5% of respondents mentioned wind farms unless prompted. 20% said they had a positive impact, 7% negative, and 1% said they were noisy.

Technical Information

- The author indicates that modern turbines are quieter than 'early 1990s' turbines. He also indicates that since the newer turbines are much taller that the standard practice of using 10m wind speeds may lead to inaccuracies and an underestimation of wind speeds

- Noise is defined as 'unwanted' sound. A 1 dB change is just perceptible, a 3 dB change is clearly perceptible, a 10 dB change is perceived as doubling

- Stewart indicates: a) that there is "some controversy" over the use of just A-weighted measures, with "some acousticians" lobbying for additional use of C-weighting; b) that 35 dB is "within the limit where noise is officially considered to be a problem for most people; and c) Pedersen & Waye found that noise complaints from wind farms (at least at levels above 35 dB) are proportionally higher than noise complaints about other sources of noise.

- Mentions that wind turbines produce low frequency noise, particularly in turbulent conditions. Low-frequency 'noise' is between 0-150/200 Hz and infrasound is 0-20 Hz and it travels further than normal sound. It also penetrates buildings more than normal sound and can be hard to trace (it can also 'embed' itself in walls).

- Stewart suggests that "many acousticians" say C-weighting is more appropriate than A-weighting to assess low frequency noise, citing the WHO guidelines that dB (C) be used when the difference between dB(A) and dB(C) measurements are in excess of 10 dB. He also indicates that some argue this should happen only with a 20 dB level difference. Cites Leventhall who suggested that A-weighting may not show the annoying characteristics of low-frequency noise.

- Cite a study that found 20 Hz is audible at 80 dB (at the absolute lowest) and 4 Hz is 107 dB and anecdotal evidence by a "low-frequency noise sufferer" that this is because of brain signal interference (the adverse effects of this). They further cite that 10 Hz is audible at 97 dB, 30 Hz is 60 dB, 40 Hz is 56 dB, 60 Hz is 39 dB, 80 Hz is 37 dB and 100 Hz is 23 dB, all on average (with standard dev about 6 dB).

- Cites research for military that measured infrasound from wind turbines and its ability to travel large distances fromthe turbines (10 miles), but found that measurements taken near the wind turbines produced unproblematic amounts of infrasound for humans (at 100m the levels were well below hearing thresholds).

Results

- The author summarizes results from his work and other studies.

- Steward cites a EU study' (Wolsinki et al. 1993) of residents exposed to experienced 35 dB and which reported that 6.4% of in the German/Holland sample were annoyed by the noise; whereas, in Denmark 11% reported being rather/very annoyed.

- Pedersen & Waye (2002) found no annoyance below 32.5 dB(A) $L_{A\,eq,}$ 20% between 37.5-40 dB(A) and 36% above 40 dB(A). For noise sensitive people, no difference below 35 dB (A), but they became annoyed quicker above.

- British Wind Energy Association 1994: 250 local residents near a 12 turbine farm 6 months after operational. 83% were not concerned or not very concerned about noise.

- Steward indicated that “all the European studies found that there was a statistically significant link between noise annoyance and annoyance at the flicker effect created by the blades of the turbines”. He also said: “these studies suggest that, while some people relatively close to wind farms do not consider noise to be a major problem, it is a big concern for others”

- Stewart Study
  a) Conducted own measurements at three wind farms (two in England, one in Wales. Found that at 10 Hz, the loudest measurement C-weighted was 75 dB – well under the hearing threshold. At 20 Hz, the loudest measurement was 82 dB, but most was within 40-70 dB. This means very few people will hear this sound. Concluded: “the findings suggest that at 20Hz, the very upper range of the infrasound range, there might be a problem for a few people in very specific circumstances, but that infrasound noise from wind turbines will not be heard by most people”.

  b) Low frequency findings: 40Hz was between 22dB and 77 dB (C-weighted); 60Hz was between 15dB and 80dB with most between 40-70dB (C-weighted); 125Hz was between 20dB and 74dB with most between 40-60dB (C-weighted) (added “this indicates that at 125Hz, the low frequency content of the ‘swish’ sound is audible”)

  c) About the measurements: “all taken within about one and a half miles of the turbines”

  d) “I t was usually just when people were downwind and the air was turbulent that low frequency formed a significant part of the noise”.

  e) Indoor measurements at a house in Wales that had been complaining about turbine noise: 10Hz 44-48dB; 20Hz 40-48dB; 60Hz 44-63dB (sometimes perceptible); 100Hz 42-52 (sometimes perceptible) (add “which indicates that the ‘swish’ sound is being heard, containing a low-frequency content” [Results indicate that at times the residents would be able to ‘hear’ some low-frequency noise (at the higher end) but no infrasound.

  f) Stewart reported that there is a low-frequency content in the noise from wind farms that can be heard. It is most marked at the higher range of low-frequency. He suggested this means that it is likely it is difficult to separate it out from the ‘swish, swish’ sound that causes most complaints, but also that it could increase annoyance from the swish sound. He also suggests that the low-frequency content of wind turbines is likely to cause ‘low-frequency noise sufferers’ a problem. The problem may be no greater, though, than many of them would experience from other potential sources of low-frequency noise, such as air-conditioning or central heating. But it could be amplified in the small number of cases where it resonates with the walls of a building

Conclusions

- Wind farm noise affects different people differently. The evidence suggests there is rarely a problem at distances 1-1.5 miles.

- Noise is not a problem for many people living close to WTs; however, for those who are annoyed, it is overwhelmingly the ‘swish, swish’ noise that is the problem.

- For those who cannot shut out the noise, factors such as shadow flicker may make the noise more intrusive than other noises of similar dB levels.

- Wt noise can be a problem in rural areas with low ambient background noise.

- Infrasound from WTs is too low to be heard by most people.

- Low frequency may form part of the audible ‘swish’ noise heard by people and may cause problems for people sensitive to low frequency noise. But low frequency noise from WTs is no greater than the low-frequency component found in several other noise sources. It may be underestimated by ‘A’ weighted measurements (versus using ‘C’ weighting).

- Symptoms some people complain about are similar to those associated with ‘vibroacoustic disease’. This suggests a unique combination of noise (includes low frequencies) and strobing effects, is having a physical effect on some people. [*Note – See Appendix for more information on vibroacoustic disease.*]

- Modern WTs are quieter, but there is evidence that the noise they emit is being underestimated because measurements continue to be taken at a height of 10m from the ground which underestimates wind speed at the 100m height of the WTs.

Policy Suggestions

- Site WTs no closer than 1 mile from the nearest dwelling

- Only locate wind farms where the ‘swish swish’ noise will not cause problems.

- The Wind Power Industry needs to recognize that WTs do cause significant noise problems for some people.

- Government guidelines for wind farm locations should be revised to take into account the more intrusive nature of the noise in areas with low back ground noise levels.

- The debate on WTs should recognize that the infrasound content of WT noise is too low for most people to hear. People should not exaggerate the audibility of the low-frequency of the noise.

- Guidelines should require the use of ‘C’ weighting and ‘G’ weighting for infrasound as well as ‘A’ weighting when measuring noise from WTs.

- **Health Research** – More research is needed to test the claims that WTs affect health. There should be a short moratorium on the installation of the large, modern WTs until this research has been conducted. .

Kamperman G, James R. (2008) The 'How To' Guide to Siting Wind Turbines to Prevent Health Risks from Sound.

Overview
The authors indicate that the purpose of their paper was to outline a rational, evidence-based set of criteria for industrial wind turbine siting in rural communities. This document was prepared for Wind-watch.org which is an organization that clearly is opposed to large wind farms and which supports the assertion of negative health effects. The authors: a) summarize the results of a literature review; b) propose citing criteria; c) propose sound limits; d) discuss how to include their criteria in noise ordinances; and e) suggest measurement procedures. The authors reviewed the literature from some case and other studies relating to health from the following authors summarized previously in this report: Pierpont N, Harry A, Frey et al., Phipps R, and Pedersen E.

Background Information
Authors indicate that complaint about noise from WTs are common and that this raises questions about existing guidelines. The also suggest that recent research that suggests "significant health effects are associated with living too close to modern industrial WTs".

Current information suggests that the models (set back models/guidelines) should not be used for making siting decisions until the known errors regarding predicting sound levels and tolerances are applied to the results.

Author's cite noise limits in other countries illustrated below. *[Note – we assume these to be limits measured at the receptor site (e.g., the residence) and not at the source, given that most modern wind turbine produce around 100 dBA at the hub.]*

- Australia: the higher of 35 dBA or L_{90} + 5 dBA
- Denmark: 40 dBA
- France: L_{90} + 3 (night) and L_{90} + 5 (day)
- Germany: 40 dBA
- Holland: 40 dBA
- United Kingdom: 40 dBA (day) and 43 dBA (night) or L_{90} + 5 dBA
- Illinois: 55 dBA (day) and 51 dBA (night)
- Wisconsin: 50 dBA
- Michigan: 55 dBA

The authors also provide information from the WHO on low frequency noise as a health concern. [Note – they did not indicate the noise levels (SPLs) at which the WHO suggests to be a risk threshold and compare these to known emmissons from wind turbines.] The follow

"The World Health Organization recognizes the special place of low frequency noise as an environmental problem. Its publication "Community Noise" (Berglund et al., 2000) makes a number of references to low frequency noise, some of which are as follows:

• "It should be noted that low frequency noise… can disturb rest and sleep even at low sound levels.

• For noise with a large proportion of low frequency sounds a still lower guideline (than 30dBA) is recommended.

• When prominent low frequency components are present, noise measures based on A-weighting are inappropriate.

• Since A-weighting underestimates the sound pressure level of noise with low frequency components, a better assessment
of health effects would be to use C-weighting."
• It should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health." WHO also states: "The evidence on low frequency noise is sufficiently strong to warrant immediate concern. Available at http://www.who.int/docstore/peh/noise/guidelines2.html" (p14)

Problem Example - The authors illustrate the following problem where guideline allow turbines to be located so as to produce maximum sound levels of 45 dBA with the assumption that the tone and context of the noise compatible with the quiet rural community setting. The authors point out that this does not acknowledge the dramatic change this will be for the noise environment of nearby families who live in areas with existing night-time background levels of 20 to 30 dBA.

Result – Health Impact

The authors summarized the results from previous studies and reported that not all people are affected equally with children, the elderly and those with pre-existing medical conditions to be a higher risk. Symptoms reported in this document include: sleep disturbances, headache, ringing in the ears, dizziness, nausea, irritability, and problems with memory, concentration, and problem solving. [*Note - most of the studies the authors reference were not reported in peer reviewed medical journals.]*

Conclusions and Suggestions

The author's indicated that previously installed WTs in Europe and other countries were less than 1 MW capacity and had hub heights under 61 metres and that many of those are reaching the end of their useful life and will be replaced with the larger 1.5 to 3 MW units such as those being implemented in North America. Given this, the authors suggest their concepts and recommendations regarding siting wind turbines are also applicable abroad.

Frey B, Hadden P. (2006) Noise Radiation from Wind Turbines Installed Near Homes: Effects on Health. With annotated review of the research and related issues.

Overview

The 137 pp paper addresses issues relating to WTs and health: a) personal experiences; b) acoustics; c) health effects; d) human rights. It includes many individual comments, anecdotal evidence, and excerpts from government documents or peer reviewed literature.

[Note: As evidenced from information in the abstract, it was very clear from the start that the authors believed WTs caused negative health consequences to residents and that the purpose of this report was to support that hypothesis.]

From the abstract: "Wind turbines are large industrial structures that create obtrusive environmental noise pollution when built too close to dwellings. This annotated review of evidence and research by experts considers the impact of industrial-scale wind turbines suffered by those living nearby. First, the paper includes the comments by some of the families affected by wind turbines, … Next, the paper reviews the health effects that may result from the acoustic radiation caused by wind turbines,… These injuries are considered in the context of Human Rights, .. Furthermore, the paper considers the consequent devaluation of a dwelling as a measure of part of the damage that arises when wind turbines are sited too close to a dwelling, causing acoustic radiation and consequent adverse health responses.

Background Information

- Inaudible sound can still affect the body – it can unbalance the natural function of the body. The authors refer to the effect of low frequency noise and site how the military has used it to disperse crowds.

- Authors provide information where measured sound levels (in a stable atmosphere) fluctuated 4-6 dB and site GP van den Berg who indicated that Atmospheric stability has a significant effect on wind turbine sound especially for modern tall turbines.

- The materials that homes are built of (e.g., wood, stone, brick) and how homes are built affect how much outside sound is filtered out.

- Authors indicate that humans can detect low frequency noise (LFN) that we can not necessarily hear and present LFN (infrasound) measurements at two WT farms: a) 50dB at 10-20Hz; and b) 70dB at ≤ 20Hz.

- The authors site the WHO guidelines for Community Noise and suggest that since A-weighting underestimates sound pressure levels of low frequency noise, that C-weighting should be used.

Results

The authors presented the results of interview statement made by wind farm residents who were clearly annoyed by the noise emissions from the wind turbines and presented information on their experiences and perceptions. Authors suggest the possibility of or presented comments from residents regarding a variety of perceived impacts of WTs that included: annoyance, inability to get away from source of annoyance, annoyance worse at night, balance problems/nausea/vision problems caused by low frequency noise, sleep disturbances, stress increases, indigestion, ulcers, heartburn, sense of pressure in heart, symptoms similar to sea or car sickness.

Authors site studies that found LFN (40-50 dBA) was perceived as annoying and adversely affected performance particularly of mentally demanding tasks. The mentioned referred to WHO Community Noise guidelines that indicate sleep disturbances begin at SPLs of 30dBA.

Authors presented information that suggested Migraine sufferers were at increased risk when exposed to WT emissions including strobe effect and sound.

The authors present a quote from the WHO Guidelines for Community Noise (1999) indicated below. [*Note – lacking was adequate information on noise level (SPL) risk thresholds for the specific health outcomes, although the authors indicated 30dBA indoors for sleep and 50-55 dBA for annoyance outdoors*]

> "The potential health effects of community noise include hearing impairment; startle and defense reactions; aural pain; ear discomfort; speech interference; sleep disturbance; cardiovascular effects; performance reduction; and annoyance responses. These health effects, in turn, can lead to social handicap; reduced productivity; decreased performance in learning; absenteeism in the workplace and school; increased drug use; and accidents. In addition to health effects of community noise, other impacts are important such as loss of property value." (p61)

The authors presented information on low frequency noise (LFN) and vibration and indicated that there are: "… four physical factors of primary importance in determining the human response to vibration: the intensity, the frequency, the duration, (exposure time) and the direction of the vibration." And quoted a reference used by Berglund et al. (1996): "It has been suggested that at very low frequencies human detection does not occur through hearing in the normal sense. Rather, detection results from nonlinearities of conduction in the middle and inner ear which generate harmonic distortion in the higher, more easily audible frequency range (von Gierke and Nixon 1976)." **This information was to support the argument that studies on the effects of low frequency noise shouldn't focus only on what people can hear**.

Results from the Harry (2006) and Pierpont (2009) case studies were presented (Note –these were summarized earlier in this document). The authors also presented the results from other noise and health (non-wind turbine) studies.

Conclusions

- On page 86, the authors provide the following: "Thus, the evidence strongly supports those who complain of adverse health effects when living within close proximity of wind turbines, particularly the impacts from noise and shadow flicker/strobe effects. Their symptoms parallel those found in other areas of research into the physiologic and medical impact of noise on people. Various noise characters, low frequency noise, infrasound, and shadow flicker, all delivered with a pulsating character, over a prolonged period, pose health risks when developers site wind turbines too close to homes."

- The environmental noise pollution from wind turbines built too close to dwellings causes serious discomfort, and often health injury, to families.

- They also conclude that a safe buffer zone of at least 2km should exist between family dwellings and industrial wind turbines of up to 2MW installed capacity, with greater separation for a wind turbine greater than 2MW installed capacity.

- Locating wind turbines close to families demands a precision, accuracy, and certainty of acoustic prediction and calculation that is just not available to the wind energy engineers and acousticians.

- Research links noise to adverse health effects, e.g., sleep deprivation and headache. Sleep deprivation itself may lead to physiologic affects, such as a rise in cortisol levels, a sign of physiologic stress, as well as headache, mood changes, and inability to concentrate.

Policy Suggestions

- The Government would be prudent to institute an immediate and mandatory minimum buffer of 2km between a dwelling and an industrial wind turbine, and with greater separation from a dwelling for a wind turbine with greater than 2MW installed capacity.

- There is a need for a multidisciplinary team of experts – independent of the wind energy industry – to assess clinically and to investigate epidemiologically, the health impacts on people where industrial wind turbines have been located too close to their dwellings.

Horner B et al. (2010) Wind Energy Industry Acknowledgement of Adverse Health Effects. Part 1 Conclusion and Executive Summary. An Analysis of the American/Canadian Wind; energy Association sponsored "Wind Turbine Sound and Health Effects An Expert Panel Review, December 2009".

Overview
This 46 page document was a critical response to the 2009 document by Colby et al., (Colby D, Dobie R, Leventhall G, Lipscomb D, McCunney R, Seilo M, Sondergaar B. *Wind Turbine Sound and Health Effects An Expert Panel Review.*) prepared for American Wind Energy Association and Canadian Wind Energy Association. The main conclusion presented in that document was that: "There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects." The authors of the 2009 report did indicate that a small minority of those exposed to wind turbines report annoyance and stress associated with noise perception.

Purpose & Methods
The authors clearly indicate their stance about adverse health effects and wind turbines at the beginning of the document with the following: "*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.*"
The authors also suggest the conclusions made by the 'expert panel' in the 2009 Colby et al., document were not supported and indicate that their critique would consist of a "point – counter point" format.

Background Information
Horner et al., report that the World Health Organization identifies annoyance and sleep disturbance as adverse health effects and that some of the health risks of sleep disturbance include: fatigue, memory difficulties, concentration problems, mood disorders, cardiovascular, respiratory, renal, gastrointestinal, musculoskeletal disorders, impaired immune system function and increased risk of mortality.

Research – The authors cited a November 2009 decision by the Japanese Ministry of Environment to announce a four year study into the effects of wind farms on health and a similar 2009 decision by members of the Maine Medical Association which called for an independent health study.

The authors also reported the conclusions of the Nissenbaum (Maine) study which were 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.

Results
[*Note – the main purpose of this document was to be very critical of the process and conclusions of the 2009 Colby et al., document. Most of the pages in the document consisted of point by point evaluations and criticisms of the information used, points made and conclusions of the Colby et al., document. It is outside the scope of this project to evaluate each point.]*

Annoyance - One of the main results identified in this document related to differences in opinion regarding whether or not annoyance was considered to be an adverse health effect. For example Horner et al., quote the following statement by Colby et al.,:

> "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 authors then reference a Health Canada and WHO documents that indicate:

- "The most common effect of community noise is annoyance, which is considered an adverse health effect by the World Health Organization".
- "Sleep disturbance and annoyance are the first effects of night noise and can lead to mental disorders.

Infrasound and Low Frequency Noise – The authors do not state that low frequency noise emissions from wind turbines cause ill health. However, they clearly disagree with Colby et al., and state "there is no settled medical science on this issue as yet."

Conclusions

Adverse health effects - The authors state: "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."

Low frequency noise - Horner et al., also conclude that infrasound and low frequency noise can cause adverse health effects (as evidenced by many peer reviewed studies). They state this is more likely when the noise is dynamically modulated. Thus, they conclude that 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.

Research needs - Independent third party studies must be undertaken to establish the incidence and prevalence of adverse health effects relating to wind turbines.

WIND TURBINES AND HEALTH - GREY/SELF PUBLISHED (CONTINUED)

Other Papers that do not support or suggest adverse health effects

National Academy of Medicine – France. (2005) The impact of operating wind turbines on human health. Report and recommendations group.

Overview

This report is a synthesis of technical information and background information about complaints about wind farms and about hypothetical risks of exposure to wind turbine noise emissions.

[*Note – this document is often cited by groups with serious concerns about wind farms and current set-back regulations. Documents from these groups often suggest that the recommendation from this academy of a 1,500 metre setback provides proof or at least very strong support for adverse health effects and would likely argue that this summary should be in the preceding section. However, upon a closer review it was decided that this document was a better fit for this category of grey/self-published literature. For example, the document indicates that the 1,500 setback was not based on the Academy's conclusion that enough evidence was available to conclude that current exposure (based upon set-back standards) to wind turbines directly caused ill health but more so because there was little research existed and thus that there was "little data on wind potential dangers to humans". The Academy intended their recommendation to be temporary until the research had been conducted.*]

Background Information

The authors suggest that the possible impact of wind farms on humans has not been addressed or regulated adequately and that in the scientific literature very little data on the likelihood of harm to humans was available.

They also indicated that historical health complaints reported in the available (clinical) studies were problematic because of a "complete lack of any methodological bias are rare in the literature".

The authors indicated that some property owners see the value of their property go down and that this sense of unfairness amplifies the noise nuisance which the Academy reported to be the most common grievance and which also caused disturbed sleep. The report also illustrated other symptoms people have reported they 'blamed' on wind turbines which the Academy referred to as "less precise, less well described and consist of subjective events (headache, fatigue, feeling drunk) sometimes objective (vomiting, insomnia, palpitations)."

The authors indicate that rumors and concerns about infrasound have been widely disseminated. The Academy reports that beyond a few metres from the wind turbines that the infrasound becomes inaudible and that it has no impact on human health.

The Academy indicates that the possibility of noise nuisance from wind turbines has been minimized and that specific assessment had not been regulated. They illustrated known health effects of noise from other settings such as: sleep disruption, stress, hypertension and myocardial infarction. The Academy then indicated that it was legitimate to extrapolate some of the same risks associated to noise from other settings (e.g., airports) to wind but that an epidemiological study was needed because the wind and airports are two very different noise sources.

<u>Conclusions</u>

- The production of infrasound by the wind is in their immediate vicinity, well analyzed and very mild; it is safe for humans.

- There are no proven risks of visual stimulation (shadow flicker).

- The real risks of linked to a possible chronic acoustic trauma (physiological) where the impact is related to the distance.

<u>Policy Suggestions</u>

- The Academy suggested that a minimum safe distance must be defined "even if the distance is specific to each location".

- **Research** – "To demonstrate the possible harmful effects of wind noise for humans, the Academy considers it essential that companies are two types of studies including:
  a) The development of a procedure realizing the registration over a long period of several weeks, the noise induced by wind turbines in homes, and its analysis at different scales in order to apply this expertise to the populations concerned.
  b) An epidemiological study possible health effects of the wind noise on populations that are correlated with distance implantation of these devices, and the results of the measures proposed above."

- **<u>Pending the results</u> of these studies, the Academy recommended that the government ("as a precaution") suspended the construction of wind turbines with a capacity exceeding 2.5 MW located within <u>1,500 feet</u> of homes**.

[*Note – the document we have was translated from French to English. Earlier in the document the suggested 'set-back distance ' was set at 1,500 metres not the 1,500 feet as was indicated in the conclusion section of the document. We assume the recommendation to be 1,500 metres*.]

Van den Berg F, Pedersen E, Bouma J, Bakker R. (2008) WINDFARMperception: Visual and acoustic impact of wind turbine farms on residents

Overview

The report is a detailed statistical analysis about various factors and how they relate to wind turbine annoyance and health outcomes. The study looked at how people perceived the wind farm in their living environment (e.g., sight and sound). It consisted of a postal survey (n = 725, 37% response rate) of Dutch residents.

Methods

Study Group – the study group was selected from all residents in the Netherlands who resided within 2.5 km from a wind turbine with a capacity of 500 MW or more. Respondents were exposed to sound levels between 20 dBA – 54 dBA at distances ranging from 17 m to 2.1 km. 14% of the respondents received economic benefits from the wind turbines. This group tended to live closer to the wind turbines, were higher educated, less old and considered healthier compared to the other respondents.

Sample - 50375 addresses were identified and subdivided into the three environment types (quiet countryside, countryside with main road, build-up area). Based upon modeling, the residences were placed in four exposure groups: 1) 25-30, 2) 30-35, 3) 35-40, and 4) 40-45 dB(A) with an equal number of individuals in each exposure group and at least 50 respondents each. The resulted in a study sample of about 2,000. The preselected minimum required response rate was set at 30%. Residents living near wind turbines for less than one year were excluded.

Sound Exposure Measurement - Use three different models: 'Dutch' model (HRMI), ISO 9613.2 and the 'simple' model (e.g. NZS6808,) The 'Dutch' and ISO estimates are similar, except at very long distances (air absorption values differ); the 'simple' model overestimates at small distances and underestimates at long distances.

Power mode was always assumed to be highest (greatest sound output). Sound was calculated to *all* turbines around the address, including the excluded small turbines.

Assumptions: Receiver height of 5m ('ear' level if bedroom on ground floor; if standing (2m) then levels are 0.1 dB lower), ground absorption at 100% (if no absorption, sound levels are 1.4 dB higher at receiver) , no reflection or shielding of sound (given the nature of rural development)

Visual Exposure – Vertical angle and visual impact were evaluated. The Vertical angle is between the horizontal at the receiver and the line between receiver and hub. The Visual impact is the fraction of total field of view (half sphere above horizon) covered by the turbine (schematized as a rectangle).

Questionnaire - The researchers modified the instrument used by Pedersen in Swedish studies (translated to Dutch) and added sections on health, the environment, from the General Health Questionnaire (GHQ) and on quality of life. Environmental questions were added to mask the main survey purpose (e.g. questions on road noise were added). Wind turbine noise was assessed in five different questions, which showed a high internal consistency on Cronbach's alpha .

The questionnaire addressed: attitude towards WTs, impact of WTs on landscape, noise sensitivity, self-reported health, well being and sleep, and stress. Rs were classified into groups based upon 5dB sound level categories. Dose-response relationships were reported based upon the proportion of Rs who 'noticed' or 'were annoyed' by the noise. Associations between moderating factors and response were tested statistically with binary logistic regression and adjusted for possible confounders.

Analyses – The researchers developed a theoretical model relating exposure to response. Exposure (sound level, distance, vertical angle, fraction of view) influences response (perception, annoyance, occurrence, sound character), but is moderated by physical factors (visibility, urbanization, type of house, background sound level) and individual factors (age and gender, economical benefit from wind turbines, education level and employment, living conditions, attitude and noise sensitivity). The response generates effects such as health, psychological distress, stress, and sleep quality.

Results

Non-respondent Analysis

In a random sample of 200 non-respondents, (95 responded, 47.5% response rate) the authors reported no statistically significant differences in annoyance between the two groups (i.e., previous responders and non-respondents).

Wind Turbine Annoyance

Annoyed by Blinking shadows indoors (n = 669)
69% do not notice (464/669)
14% notice but not annoyed (91/669)
11% slightly annoyed (75/669)
3% rather annoyed (20/669)
3% very annoyed (19/669)

Annoyed by Sound of rotor blades (n=661)
65% almost never (430/661)
9% at least once in past year (57/661)
9% at least once in past month (67/661)
7% at least once in past week (45/661)
10% almost daily (69/661)

Annoyed by Sound outdoors (n=708)
40% do not notice (284/708)
37% notice but not annoyed (259/708)
13% slightly annoyed (92/708)
6% rather annoyed (44/708)
4% very annoyed (29/708)

Annoyed by Sound indoors (n=699)
67% do not notice (465/699)
20% notice but not annoyed (139/699)
8% slightly annoyed (54/699)
3% rather annoyed (21/699)
3% very annoyed (20/699)

Dose-Response, Annoyance and Financial Benefits

- SPL (noise levels in 5 dB intervals) *is* correlated with annoyance (5-point scale), and this increase is statistically significant until 40 dB and it declines above 45 dB (<30 dB = 2.2%, 30-35 = 7.5%, 35-40 = 17.6%, 40-45 = 18.3%, **>45 = 12.3%**). If those who benefit economically are excluded, proportions of annoyance are larger (20% at 35-40, 25% at 40-45 and 28.6% at >45 (of 21 respondents).

- **Financial benefits from turbines was significantly correlated with less annoyance** (Those in the >45 dBA exposure category were receiving financial benefits.) There was no difference in the ability to hear the sound between respondents that benefited economically from wind turbines and those who did not, but there was a clear difference in annoyance between the two groups. Very few people among those who benefited economically reported annoyance with sound from wind turbines.

- After controlling for SPL, gender, age and economic benefits: being able to see a turbine was strongly associated with annoyance.

- Increasing age (non-isolated) was associated with annoyance; whereas, gender (non-isolated) was *not* found to be associated.

- Attitude towards turbines and self reported noise sensitivity were positively associated with annoyance.

Health Effect Results

- **Chronic disease, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease and migraine** were ***not*** **associated** with **sound levels**

- Psychological distress, stress and difficulty falling asleep were *not* associated with sound levels

- Sleep interruption *is* associated with sound levels. At >45 dB sleep interruption was significantly higher than at other sound levels and background noise was positively associated with interruption

- **Chronic disease, high blood pressure, tinnitus, hearing impairment, cardiovascular disease and migraine were** ***not*** **associated** with turbine **annoyance**

- Diabetes associated with turbine annoyance

- Stress, difficulties falling asleep and sleep interruption *are* associated with turbine annoyance

Conclusions

Hearing wind turbines

- The probability to hear wind turbines increased with increasing levels of wind turbine sound, irrespective of the appreciation of the sound by respondents.

- Not having wind turbines visible from the dwelling and high levels of background (road traffic) sound decreased the probability of hearing wind turbine sound, though the influence of background sound is small.

- Wind turbines were perceived as louder when the wind was blowing from the wind turbine towards the dwelling, and less loud vice versa.

- Wind turbines were perceived as louder when the wind was strong and less loud with a weak or no wind. However, more respondents thought it was louder than less loud at night, even though at night wind speeds are on average lower.

Annoyance from wind turbine sound

- Of the exposures from wind turbines, noise was the most annoying.

- The probability of being annoyed by wind turbine sound increased with increasing levels of wind turbine sound.

- The most common description of the wind turbine sound was swishing/lashing; a description that was associated with noise annoyance: annoyance is more probable for respondents that gave this description than for those who did not.

- Benefiting economically from wind turbines, not having wind turbines visible from the dwelling and living in a rural area with a main road (in comparison with a built-up area) decreased the probability of being annoyed by wind turbine sound.

- Although the presence of background sound from road traffic made wind turbine sound less noticeable, higher levels of background sound did not reduce the probability of being annoyed.

- Annoyance with wind turbine noise was associated with a negative attitude towards wind turbines in general and the impact of wind turbines on the landscape.

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.

Sound exposure, annoyance and a pathway to stress
"Respondents who reported that they were annoyed by wind turbine sound were more likely to also be psychologically distressed, reporting symptoms of stress and having difficulties to fall asleep. It appears that these symptoms occur when people are annoyed, but it does not matter at what sound level this annoyance occurs. The study design does not allow conclusions on what is the cause and what is the effect. A plausible explanation of the observed association is that wind turbine sound leads to annoyance for some people; annoyance that in turn possibly hinders psycho-physiological restoration and increases the level of stress. However, it cannot be excluded that some people that are under stress or strain for other reasons than wind turbine sound more easily react negatively when exposed to the sound and hence become annoyed." (p 57-58)

<u>Policy Suggestions</u>

- Research is needed to distinguish between the two directions of cause and effect (annoyance and psycho-physiological distress)

- The observed relationship between diabetes and annoyance should be investigated.

- Wind turbine noise is more annoying than other noises sources (swishing is what annoys people most – amplitude modulation). Thus the authors suggest, sound should receive more attention during planning and mitigation measures should be considered. 1

- Giving residents a sense of control in wind turbines may help mitigate annoyance, as the 'health farmers', those living closest to turbines, are just as likely to hear them and see them (and are in fact exposed to higher noise levels) and yet are less likely to be annoyed.

- It is possible that better integrating wind turbines into the landscape will reduce annoyance.

- No empirical evidence has been found to support the claim that roadways 'mask' the sound of wind turbines, as annoyance is not effected by background noise. This deserves more investigation.

<u>Pedersen, E. & Halmstad, H.I. (2003) Noise annoyance from wind turbines: A review.</u>
<u>Overview</u>
The paper was a Narrative Review of literature on the present knowledge on perception and annoyance of noise from wind turbines in residential areas (& recreational areas). It also summarized the regulations from some European countries.

<u>Background Information</u>

- Some countries have based their Wind Turbine noise regulations upon different principles. (E.g., based upon studies from a different noise source.)

- Other settings: in the USA SPL at night time in suburban areas is above 40 dBA; 30-40dBA along a river in the Grand Canyon; and 10-20 dBA along a remote trail in a park.

- Other settings - a) In a USA study (Fidell et al, 1996) found that respondents engaged in outdoor (wilderness) recreation, were highly annoyed at a 7 dBA lower level than what would be tolerable in a residential setting; and b) in Norway (Krog et al, 2000) evaluated annoyance to military aircraft in recreational areas and found that annoyance increased with age, exposure/duration. They also found that those who had a more negative attitude about military aircraft were more likely to judge their experience as less positive.

- In other settings- evidence exists that noise from aircraft and road traffic are associated with psychosocial or psychosomatic nuisance. However the effects appear related to individual factors (sensitivity to noise and capacity to cope with stress) and to annoyance rather than Sound Pressure Level.

- Passchier-Vermeer observed that the threshold for hypertension and ischaemic heart disease was 70 dBA outdoors (Passchier-Vermeer, 2002)

- Other settings – Rylander (1999) in a review of traffic noise effects, found there was no research that indicated that environmental noise could provoke psychiatric disease.

<u>Guidelines in other countries (Maximum or recommended)</u>

Sweden	40 dBA (outside residences) measured at 8 m/s and 10 m height
Denmark	40-45 dBA (outside residences) 40 dBA for sensitive* areas. (*e.g., institutions, gardens, recreation)
Germany	35-70 dBA (night time) 35=hospital & health resorts, 40 = residential, 45= mixed residential/industrial, 70=industrial
Netherlands	40 dBA at 10 m/s and 50 dBA at 12 m/s (evenings = 45 dBA)
England	WT noise should be no more than 5 dBA above the background noise for day and night with fixed limits of 43 dBA for night time. England considers 35 dBA to be the threshold for sleep disturbances.

<u>Results</u>

- There is no scientific evidence that the noise at levels created by WTs could cause health problems other than annoyance.

- Interference with communication and noise induced hearing loss is not an issue with WTs because noise levels are too low.

- No studies have been found that explored the cardiovascular and psycho-physiological effects, performance reduction effects and effects on social behavioral effects from WTs. {SEE WHO info above].

- Annoyance (however) should be considered to be an undesired effect on health and well-being.

- Transferring the results from studies in outdoor areas in other setting (non WT) – there is no evidence that noise from Wind Turbines could cause Cardiovascular Disease or psycho-physiological effects.

Conclusions

- Noise from WTs is not well studied (compared to noise from traffic)

- Since the number of studies were low – no general conclusions could be drawn; however, the evidence suggests: a) annoyance is correlated to exposure (increased dB, greater proportion report annoyance); b) annoyance occurs to a higher degree at low noise levels compared to when annoyance begins from other sources such as traffic; and c) annoyance is influenced by visual impact on the landscape.

- WT noise does not directly cause any physical health problems. However, there is enough data to conclude WT noise could induce sleep disturbances or stress-related symptoms.

- WT noise is not easily masked by background noise particularly in some topographical settings.

- Individual factors are of importance to annoyance. People seeking quiet may be more likely to be annoyed by any sound.

- **The visual impact of WTs may be the dominant source of annoyance.**

Policy Suggestions

- The SPL of the intruding sound must be compared to the SPL of the background noise.

- WHO Guidelines for community noise lists effects to be considered when setting community noise levels: interference with communication; noise induced hearing loss; sleep disturbance effects; cardiovascular and psycho-physiological effects; performance reduction effects; annoyance responses; and effects on social behavior (Berglund et al., 1999).

- Annoyance should be considered to be an undesired effect on health and well-being.

- Stress can result from annoyance and needs to be further studied in WT settings.

- The WHO guidelines for community noise recommend that outdoor noise levels in living areas should not exceed 45 dBA at night. [Schewela 1998] The authors suggest the noise exposure from WTs is not known to exceed this limit.

Pedersen E, Waye K. (2006) Exploring Perception and Annoyance Due to Wind Turbine Noise in Dissimilar Living Environment.

Overview

The document represents results presented at a Euronoise conference and is based upon a cross sectional study conducted in Sweden.

Methods

The authors conducted a cross sectional study in seven study areas where each location had at least on e 600 KW or larger wind turbine. study areas included: a) complex ground – suburban and rural areas; b) flat ground – agricultural and suburban areas. Inclusion criteria included exposure levels of >30 dBA. Noise levels were calculated using the Swedish EPA guidelines.

1,309 surveys were sent to one randomized person in each residence. Response Rate = 58.4%.

Exposure categories

SPL	n	% of Total
<32.5dB	361	47.19
32.5-35.0 dB	209	27.32
35.0-37.5 dB	104	13.59
37.5-40. dB	71	9.28
>40.0 dB	20	2.61
	N=765	100%

Results

- The proportion of Respondents who could hear and were annoyed by WT noise was higher among those who could see one or more WTs.

- People living in agricultural (compared to suburban) areas were more likely to have higher degrees of perception and annoyance.

  For SPL (sound level) categories under 40 dBA – the proportion of those who both noticed and were annoyed ranged from 3%-6%.

- 15% (3 of 20) of those living above 40dBA were annoyed

- No differences in perception and annoyance between complex and flat ground were observed except for the >40dB category.

- A larger proportions of Rs in Agricultural settings were annoyed by WT noise compared to Suburban Respondents

Conclusions

Urban rural differences may be a result of: a) different sound propagation calculations that didn't take into account local barriers; b) variations in the background SPLs between agricultural and suburban areas; c) the variation in the visibility of WTs influencing the rate of noise annoyance; and d) residents personal values of their living environment due to the level of urbanization in the area (e.g., rural vs suburban).

Pedersen E, Bouma J, Bakker R, Van Den Berg F. (2008) Response to wind turbine noise in the Netherlands.

This document came from conference proceedings and is a report of the study summarized earlier in this report: Van den Berg F, Pedersen E, Bouma J, Bakker R. (2008) WINDFARMperception: Visual and acoustic impact of wind turbine farms on residents. *Thus, the results will not be duplicated again in this section.*

Chatham-Kent Public Health Unit. (2008) The Health Impact of Wind; Turbines: A Review of the Current Literature.

Overview
Report is Narrative review of the published, white and grey literature on Wind Turbines and Health. The purpose was to identify the impact of WTs on both human health and safety.

Background Information
Health Hazard Definition - The Workplace Safety and Insurance Board of Ontario defines a health hazard as something the results in an injury, illness, or disease.

World Capacity - The authors report that an estimated 68,000 wind turbines have been installed worldwide over the last 25 years.

Setback Distance - Minimum setback distance in the Chatham-Kent area is 600m from any residential or institutional zone.

Comparable Noise Levels - Authors report the following noise levels: a) audible sound created by a wind turbine, measured at 350 meters, is approximately 35-45 dB(A); b) rural night-time background noise is 20-40 dB(A); c) a jet airplane at 250 meters is 105 dB(A); and d) an urban residential environment is 58-62 dB(A). Wind on its own, as it interacts with the environment, produces levels up to 35 dB (A).

Health and Safety Issues – The authors identify the main health and safety issues associated with WTs to be: a) blade and structure failure; b) icing (ice chunks flinging from blades); c) noise emissions; d) shadow flicker; and e) construction injuries.

Results
- Authors suggest there are no recorded injuries to the public caused by WTs. However they indicate that lightning strikes may pose the greatest potential for blade or turbine breakage.

- The health impact of the noise created by wind turbines has been studied and debated for decades with no definitive evidence supporting harm to the human ear.

- A 2006, Howe Gastmeier Chapnik engineering completed an independent study on infrasound associated with Canadian wind farms and found that wind farms generate infrasound but at levels not perceptible to the human ear. The authors also report that international studies have also found that infrasound generated by wind
- turbines is not known to be harmful to human health.

- Epilepsy and Shadow Flicker - Modern wind turbines rotate at a frequency between 1 and 1.75 hertz which is well below the risk threshold frequency known to affect individuals with epilepsy (i.e., 2.5-3 Hz).

Conclusions
- **Dr. Pierpont Case Study -** The literature search utilized by Chatham-Kent Public Health for the Chatham-Kent report, revealed no articles or research papers by Nina Pierpont published in scientific or peer reviewed journals. Several of the studies Dr. Pierpont has conducted are case studies, meaning they are a documentation of an individual's account of a situation or experience. One cannot discount the information, yet it is prudent that generalizations from such limited data are avoided.

- Wind power has been in use around the world for decades with very little human impact.

- Despite copious literature from experts in government, manufacturers of wind turbines, and support groups both for and against wind power, very little scientific evidence exists on the health effects of wind turbines.

- *"In summary, as long as the Ministry of Environment Guidelines forlocation criteria of wind farms are followed, it is my opinion that there will be negligible adverse health impacts on Chatham-Kent citizens. Although opposition to wind farms on aesthetic grounds is a legitimate point of view, opposition to wind farms on the basis of potential adverse health consequences is not justified by the evidence."(p17)*

<u>Policy Suggestions</u>

Noise Concerns

- Ensure and enforce adherence to Chatham-Kent municipal setbacks.

- Sound assessment by an acoustical consultant is obtained on an as needed basis

Shadow Flicker

- Landscape screening is preserved or designed after installation of wind turbine to decrease flicker impact to neighbouring land.

- Window treatments as required for neighbouring lands

<u>Rideout K, Bos C. (2009) Wind turbines and health. What's the evidence?</u>

<u>Overview</u>

The document was a presentation by two researchers from the National Collaborating Centre for Environmental Health.

<u>Background Information</u>

- **Projected Growth in Canada -** The authors indicate that there are 90 wind farms in Canada, generating 2369MW (1% of national energy needs) and that Nova Scotia Renewable Energy Standards require 5% renewable by 2010 and 10% by 2013. The also indicate that between 2009 and 2013 PEI plans to increase capacity from 72 MW to 500 MW.

- Wind turbines: are 80m tall, have 40m blades, generate 2MW, operate in 4-25m/s winds, spin at 15rpm and have a tip speed of 62.8m/s

- Define low frequency as below 200 Hz and infrasound as below 20 Hz; Humans are most sensitive to noise between 1000 and 20,000 Hz

- **Blade Failure -** Dutch data (1980-2001): partial/full blade failure rates from 1/2,400 to 1/20,000 /year

- **Main Public Health Concerns -** sound (noise levels/intensity, low frequency noise, variation); EMF exposure; Shadow flicker; Aesthetics; Icing; Structural failure; Safety; and Environmental impacts. Infrasound is the most controversial and the uneven "swoosh swoosh" noise is perceived as more annoying than a steady "white noise".

Results/Health Impact

- **Low Frequency Noise -** There is no published data to support claims of adverse health effects of low frequency sound at low pressure (below 20Hz and 110 dB)

- **Shadow flicker** – a) lasts a very short time period under the necessary conditions (~30 mins); b) is most pronounced close to turbine (within 300m); c) dizziness and disorientation can result from disagreement between visual cues and inner ear (migraine suffers in particular); d) no evidence of adverse health effects but there is an aesthetic or nuisance effect.

- **Shadow flicker and epilepsy** – a) people with epilepsy are not usually light sensitive (~5%); b) sensitivity is at 16-25Hz; c) the Epilepsy Foundation warns flicker frequency greater than 10Hz may trigger seizures; and d) modern turbines fall within 0.5-1Hz

Conclusions

Sound – a) perceptions vary; b) no evidence of noise-induced health effects at levels emitted by wind turbines; c) stress and sleep disturbance are possible.

EMF & Power Cables – WTs emissions are lower thatn other electricity generation.

Shadow Flicker – a) can be minimized by careful siting, zoning, and screening; and b) is not in the frequency range that can induce seizures.

Health Effects – there is minimal evidence for health effects but health concerns are valid and must be addressed.

Minnesota Department of Health. (2009) *Public Health Impacts of Wind Turbines.*

Overview

This document provides a literature review, types of health concerns (variables), background on health and noise, and an evaluation of the studies by Harry, Phipps and Pierpont. The paper is a response to two proposed WT farms both with over 134 wind turbines.

Background Information

- Newer turbines have upwind rotor blades, minimizing low frequency "infrasound" (i.e., air pressure changes at frequencies below 20-100 Hz that are inaudible).

- The ear is sensitive to only a relatively narrow frequency range of air pressure changes: those between approximately 20 and 20,000 HZ. Loudness increases as the logarithm of air pressure, and it is convenient to relate loudness to a reference air pressure (in dyne/cm2 or pascals) in tenths of logarithmic units (decibels; dB).

- **Low frequency noise and the vestibular system**
  a) The vestibular system reacts to changes in head and body orientation in space, and is necessary for maintenance of equilibrium and postural reflexes, for performance of rapid and intricate body movements, and for stabilizing visual images (via the vestibulo-ocular reflex) as the direction of movement changes (Guyton, 1991). Like the cochlea, the vestibular apparatus reacts to pressure changes at a range of frequencies; optimal frequencies are lower than for hearing. (Todd et al.,2008). These investigators found maximal sensitivity at 100 Hz, with some sensitivity down to 12.5 Hz.

b) While vestibular system activation is not directly felt, activation may give rise to a variety of sensations: vertigo, as the eye muscles make compensatory adjustments to rapid angular motion, and a variety of unpleasant sensations related to internal organs.

c) The vestibular system interacts with the autonomic nervous system, which regulates internal body organs.

d) Sensations and effects correlated with intense vestibular activation include nausea and vomiting and cardiac arrhythmia, blood pressure changes and breathing changes. While these effects are induced by relatively intense stimulation, it is also true that A-weighted sound measurements attuned to auditory sensitivity, will underweight low frequencies for which the vestibular system is much more sensitive.

e) Activation of the vestibular system does not always give rise to unpleasant sensations. However, it is not known what stimulus intensities are generally required for autonomic activation at relatively low frequencies, and it is likely that there is considerable human variability and capacity to adapt to vestibular challenges.

f) The wavelength of low frequency sound is very long (e.g., 40 Hz in air at sea level and room temperature is 8.6 meters) and are not effectively attenuated by walls and windows of most homes or vehicles. It is possible that there are rooms within buildings exposed to low frequency sound or noise where some frequencies may be amplified by resonance (e.g. ½ wavelength, ¼ wavelength) within the structure.

g) Low frequency sound can cause vibrations within a building at higher, more audible frequencies as well as throbbing or rumbling.

h) **Measuring low noise -** The World Health Organization (WHO, 1999) suggests that A-weighting noise that has a large low frequency component is not reliable assessment of loudness. C-weighting has been recommended for artillery noise, but a linear, unweighted scale may be even better at predicting a reaction (Berglund et al., 1996).

i) **Sound attenuation** – Sound decays at a rate of about -6 dB per doubling of distance. However, low frequency noise from WTs decays at a lower rate at long distances, about -3 dB per doubling of distance in the downwind direction (Shepherd and Hubbard, 1991).

j) The **WHO** (1999) recommends 30 dB (A) indoors as a limit for "a good night's sleep". However, they also suggest that guidance for noise with predominating low frequencies be less than 30 dB (A).

Results

Human Response to Low Frequency Stimulation

- There is no consensus whether sensitivity below 20 Hz is by a similar or different mechanism than sensitivity and hearing above 20 Hz. Possible mechanisms of sensation caused by low frequencies include bone conduction at the applied frequencies, as well as amplification of the base frequency and/or harmonics by the auditory apparatus (eardrum and ossicles) in the ear. Sensory thresholds are relatively continuous, suggesting (but not proving) a similar mechanism above and below 20 Hz. Cochlear sensitivity to infrasound (< 20 Hz) is considerably less than cochlear sensitivity to audible frequencies.

- Møller and Pedersen (2004) reviewed human sensitivity at low and infrasonic frequencies – results include: i) When whole-body pressure-field sensitivity is compared with ear-only (earphone) sensitivity, the results are very similar. These data suggest that the threshold sensitivity for low frequency is through the ear and not vestibular; ii) Individual responses to LFN vary dramatically, therefore the sensitivity response of individuals to different low frequency stimulation may be difficult to predict.

- Noise has also been shown to impact sleep and sleep patterns, and one study demonstrated impacts from low frequency noise in the range of <u>72 to 85 dB(A) on chronic insomnia</u>

- Authors quote the WHO - "There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects" (WHO, 1999).

- The difference, in dB, between soft (acceptable) and loud (annoying) noise is much less at low frequency

Annoyance and Rhythmic Modulation (<u>Amplitude Modulation</u> or frequency modulation)

- Rhythmic modulation of noise, especially low frequency noise, has been found to be more annoying than steady noise (Bradley, 1994; Holmberg et al., 1997).

- One form of rhythmic modulation of aerodynamic noise that can be noticeable very near to a WT is a distance-to-blade effect. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade passes and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise at about once per second (1 Hz). On the ground, about 500 feet directly downwind from the turbine, the distance-to-blade can cause a difference in sound pressure of about 2 dB between the *tip* of the blade at its farthest point and the *tip* of the blade at its nearest point (48 meter blades, 70 meter tower).

- If the receptor is <u>500 feet from the turbine</u> base, in line with the blade rotation or up to 60° off line, the difference in sound pressure from the *tip* of the blade at its farthest and nearest point can be about <u>4-5 dB, an audible difference.</u>

- A blade angle that is not properly tuned to the wind speed (or wind direction) will make more noise than a properly tuned blade. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise.

- Aerodynamic noise from a wind turbine may be underestimated during planning. One source of error is that most meteorological wind speed measurements noted in wind farm literature are taken at 10 meters above the ground. Wind speed above this elevation, in the area of the wind turbine rotor, is then calculated using established modeling relationships. In one study (van den Berg, 2004) it was determined that the wind speeds at the hub at night were up to 2.6 times higher than modeled. Subsequently, it was found that noise levels were <u>*15 dB higher than anticipated*</u>.

- A number of reports have included discussion of aerodynamic modulation (van den Berg, 2005; UK Department of Transport and Industry, 2006; UK Department for Business Enterprise and Regulatory Reform, 2007; van den Berg, 2008). They suggest that ***aerodynamic modulation is typically underestimated*** when noise estimates are calculated.

- Individual Sensitivity - Human sensitivity to sound, especially to low frequency sound, is variable. Individuals have different ranges of frequency sensitivity to audible sound; different thresholds for each frequency of audible sound; different vestibular sensitivities and reactions to vestibular activation; and different sensitivity to vibration. People will exhibit variable levels of annoyance and tolerance for different frequencies.

Conclusions

- Low frequency noise is primarily a problem that may affect some people in their homes, especially at night.
- 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.
- The Minnesota nighttime standard of 50 dB (A) not to be exceeded more than 50% of the time in a given hour, appears to underweight penetration of low frequency noise into dwellings.
- Some "models may under-predict wind speed that will be encountered when the turbine is erected. Higher wind speed will result in noise exceeding model predictions."
- Flicker can be eliminated by placement of wind turbines outside of the path of the sun as viewed from areas of concern, or by appropriate setbacks.
- Prediction of complaint likelihood during project planning depends on: 1) good noise modeling including characterization of potential sources of aerodynamic modulation noise and characterization of nighttime wind conditions and noise; 2) shadow flicker modeling; 3) visibility of the wind turbines; and 4) interests of nearby residents and community.

Policy Suggestions

The authors suggested the following regarding proposals to develop wind farms:

- WT noise estimates should include cumulative impacts (40-50 dB(A) isopleths) of all wind turbines
- Isopleths for dB(C) - dB(A) greater than 10 dB should also be determined to evaluate the low frequency noise component
- Potential impacts from shadow flicker and turbine visibility should be evaluated.
- Any noise criteria beyond current state standards used for placement of wind turbines should reflect priorities and attitudes of the community.

Moorehouse A, Hayes M, et al. (2007) Research into Aerodynamic Modulation of Wind Turbine Noise

Overview and Purpose

This report is based upon a study commissioned by DEFRA (Department for Environment, Food and Rural Affairs). It followed a report by the Hayes McKenzie Partnership to DTI in 2005 which reported that low frequency noise emission from windfarms were investigated and which concluded that the complaints were not caused by low frequency noise, but by amplitude modulation of aerodynamic noise (AM) from the wind turbines.

The aims of the study were to ascertain the prevalence of AM on UK wind farm sites, to try to gain a better understanding of the likely causes, and to establish whether further research into AM is required.

Methods
The researchers: a) conducted a survey of local authorities; b) investigates sites with Amplitude Modulation complaints; c) conducted a literature search; and d) surveyed WT manufactures.

Background Information
International Guidelines - German regulations (1999) provide different limits for different areas (industrial, mixed, residential, sensitive) Dutch regulations (2001) provide wind speed-dependant limits of 40 dB(A) night, 45 dB(A) evening and 50 dB(A) day

Turbines & Aerodynamic Sound

- Amplitude Modulation (AM) refers to aerodynamic noise “with a greater than normal degree of regular fluctuation at blade passing frequency, typically once per second”.

- The authors indicate that the first report: i) recorded indoor AM levels of 3 to 5 dB(A) in the 200 – 800 Hz range; and ii) external modulation of 3 to 4 dB(A) could produce up to 7 to 9 dB(A) indoors.

- Sources of aerodynamic noise: inflow turbulence (air flow into blades), trailing edge/boundary layer noise (air flow across blades, which is most common source of noise), tip noise, blunt trailing edge noise (not significant with modern turbines).

- Stalling a turbine produces 10dB spikes in noise, although this method of regulation is rare in modern turbines.

- Imperfections in the blade are known to produce tonal noise, usually resulting from operation damage.

- Large eddies produce low frequency noise and small eddies generate higher frequencies.

- Aerodynamic noise is largely broadband – blade swish though is not steady and modulates at the blade-passing frequency (once per second).

- Modulation of a few dB is usually acceptable, although it is not clear why modulation increases with some turbines (in downwind turbines this would have been the thump as the blade passed the tower wake).

- The authors suspect that inconsistent wind speed across the rotor is the likely culprit of AM and cite van den Berg who postulates that the variation between the top and bottom of the rotor in wind speed varies in calm conditions significantly and thus the wind speed varies cyclically

- Large wind shear (low ground speed with high hub speed) creates conditions of highly audible aerodynamic noise given the low background noise.

Results

- The researchers had a 100% response rate from the 133 wind farms they contacted.

- 27/133 wind farms have received formal complaints since 1991 (3 = ave # complaints)

- AM was found to be a problem at 4/27 of the locations, a possible factor at 9/27, and not a factor at 14/27 (with one location considered too recent to properly assess).

- Weather data agrees strongly with complaint logs (i.e., atmospheric conditions, wind speeds & direction).

Conclusions and Policy Suggestions

- About 20% of the wind farms have been subjects of complaints.

- Conditions associated with AM might occur between about 7% and 15% of the time.

- Authors conclude that the reason AM noise travels far from the turbine in some conditions is not well understood, despite van den Berg's preliminary hypotheses.

- Complaints are not controlled and thus complaints can serve as proxy for other opposition, and thus not all complaints indicate adverse outcomes, and the absence of complaints does not always indicate a lack of problems. (E.g., Traffic noise generates lower volume of complaints given the perceived likelihood of a changed outcome. The authors speculate this might be reverse regarding wind turbines.)

- Further study of the production and propagation of AM noise is needed to provide guidelines to ameliorate AM (beyond stopping the turbine).

- Receptor locations should be the site of measurement (or an additional site of measurement) for AM

- Prediction models are not completely reliable as "the complexity of turbulent flows" is not well understood.

Rogers A, Manwell J, Wright S. (2006) Wind Turbine Acoustic Noise.

Overview

This document is 'white paper' prepared for the Department of Mechanical and Industrial Engineering at the University of Massachusetts at Amherst on wind turbine noise issues.

Background Information

Wind Turbine Noise

- Technology changes have resulted in much quieter WTs; however, WT noise still is a public concern.

- Sound turns into noise when it is unwanted. This is subjective and depends on amplitude and duration.

- WT sound is a function of wind speed, turbine design, distance and ambient sound levels. Propagation is a function of the sound source characteristics (directivity, height), distance, air absorption, reflection and absorption by the ground and nearby objects and weather effects such as changes of wind speed and temperature with height.

- The authors describe a study which found background noise in a high school area was 42-48 dB (A) in wind speeds of 2-4 m/s (5-9 mph). In another location, a background noise assessment at a Madison Windpower project was 25 dB(A) at calm wind and 42 dB (A) at 5.4 m/s (12mph).

- The authors cites two sources that WT sound from large modern WTs tends to increase more slowly with increased wind speed than does ambient (background) wind generated sound. Thus noise issues are more common at lower wind speeds.

- Small wind turbines (less than 30 kW) are generally louder than large wind turbines and WTs from the 90s and on are significantly quieter than 80s turbines. Noise from a 2 MW turbine totaling 102.2 dB(A).

Sound & Sound Measurement Filters

A-weighting for medium intensity sounds; B-weighting for medium-loud; C-weighting for loud and low-frequency; G-weighting for infrasound

- L_{90} is the sound level exceeded 90% of the time and is considered the 'background' level
- $L_{A\ eq}$ is the average SPL over the measurement period
- L_{dn} is the 24 hour average, found by adding 10 dB to levels measure between 10 p.m. and 7 a.m.

A 6 dB increase is equivalent to moving half the distance towards a sound source. A 10 dB increase is subjectively heard as an approximate doubling in loudness.

Low frequency noise and Infrasound

Low frequency noise is typically defined as between 10 – 200 Hz (at the bottom of our perception). Infrasound is typically defined as being below 20 Hz (below most perception). It is pervasive and comes from ambient air turbulence, ventilation units, waves on the seashore, distant explosions, traffic, aircraft and other machinery. It propagates farther than higher frequencies.

International Noise Limits

- **Denmark** – 40/45 residential/rural

- **Germany** – residential 55/40 day/night; rural 50/35 day/night

- **Netherlands** - residential 45/35 day/night; rural 40/30 day/night

- **Massachusetts** – new noise can't be > 10 dB(A) $_{L90}$ over ambient baseline and pure tones (octave band) may not exceed 3 dBA over the two adjacent octave bands. (Measurements are to be made at the property line or at any inhabited buildings located within the property.)

Results – Health Impact

- The authors suggest that: "In general, the effects of noise on people can be classified into three general categories: 1. Subjective effects including annoyance, nuisance, dissatisfaction; 2. Interference with activities such as speech, sleep, and learning; 3. Physiological effects such as anxiety, tinnitus, or hearing loss."

- Communities are more sensitive to nighttime sound levels.

- Infrasound primary invokes annoyance and varies with the characteristics of the sound: static pressure buildup, masking of higher frequencies, rattling of furniture.

- Infrasound produces no adverse effects at $\leq$90 dB. At 115 dB it can cause fatigue, apathy, abdominal symptoms, hypertension. The pain threshold is at 120 dB (10 Hz) and prolonged exposure to 120 – 130 dB will cause physiological damage.

Conclusion and Policy Suggestions

- When a wind turbine is proposed near a sensitive receptor, a sound assessment study is appropriate consisting of four parts: i) ambient background sound levels in the wind conditions turbine will operate; ii) prediction & measurement of turbine sound levels near the site; iii)sound propagation model selection; and iv) comparison of sound pressure levels (SPLs).

- Incentives should only be awarded to manufactures that provide sound data (IEC standards) or for sites where sound is not an issue

- Community noise standards are important to ensure livable communities. Wind turbines must be held to comply with these regulations. Wind turbines need not be held to additional levels of regulations.

- Blanket setbacks for small wind turbines should not be pre-determined, but evaluated on an individual basis.

- Sound levels (SPLs) must be taken into account when siting turbines. When the distance is within three times the blade-tip height of the turbine, a noise study should be performed and publicized.

Rogers A. (2005) Infrasound and Psychoacoustics.

Overview

The document is a presentation at the Renewable Energy Research Laboratory, University of Massachusetts at Amherst.

Background Information

- Infrasound is sound at < 20Hz. Natural sources include from ambient air & waves. Human sources include vehicles, machinery, wind turbines and ventilation units.

- **Measuring Sound - i**) **A-weighting** (approximates response of human ear to sounds of medium intensity & used to assess environmental and occupational noise); ii) **C-Weighting** (approximates response of human ear to loud sounds); and iii) **G-weighting** (designed for infrasound).

- **Human perception of Infrasound -** i) can be perceived below 20Hz; ii) ear = primary sensory channel; iii) at 2-100Hz perception is both auditory and tactile; iv) tonality lost at 16-18 Hz; and v) because of long wavelengths ability to detect direction is weak.

- Human perception thresholds (for Infrasound) are high (E.g., about 100dB (G) at 10 Hz).

- Sound from WTs diminishes with distance and blurs with multiple WTs.

- The noticeable swish–swish noise from WTs is amplitude modulation at blade passing frequencies of higher frequency blade tip turbulence and does not contain low frequencies

Results - Health Impact & Annoyance

- Annoyance from Infrasound associated w sound intensity/variations with time, number of events, time of day. Infrasound annoyance mechanisms include: feeling of static pressure, periodic masking effects, door & window rattle

- No reliable evidence that infrasound below the hearing threshold produces physiological or psychological effects
  Infrasound is only dangerous if it is too load and there is no evidence of adverse effects of infrasound below 90 dB(G)

- Fatigue, apathy, abdominal symptoms and hypertension reported after 115 dB; whereas, the pain threshold is about 120 dB(G) at 10 Hz and where exposure above 120-130 dB can cause physiological damage.

- The author illustrated an example of a 19 Turbine Wind Farm where the infrasound would not be detectible by anyone at 400m.

- **Community Noise Meta-analysis Study -** The author cited a meta-analysis of 136 Community Noise Studies (Fields 1993) which found that noise annoyance is related to: i) noise sensitivity, ii) fear of danger from noise source, iii) attitudes toward noise prevention, iv) attitudes about importance of noise source, and v) annoyance with non-noise aspects of noise source. Additional findings were that: a) annoyance was often only weakly related to noise levels; and b) even at low noise levels a small % of people were highly annoyed and annoyance was related to noise levels.

- **Other studies** – The author also cited studies by Wolsink et al., (1993) and Pedersen and Waye (2005) which found that only a small percentage of people were annoyed by WT and that a dose-response existed (higher percentages of people were annoyed at higher levels of noise. The studies also found that other non-noise factors were also associated with annoyance such as: visual intrusion, age of the wind farm (longer operation was associated with less annoyance), self-reported noise sensitivity, attitudes about WTs, perceptions of the countryside, lack of control and feelings of injustice.

Conclusions and Policy Suggestons

- High levels (i.e. dB) of low freq sound are needed for perception

- Infrasound is emitted from modern WTs, but it is not a problem.

- Annoyance from WTs are a function of noise level and attitudes toward other aspects of WTs

- Annoyance from WT noise increases more rapidly, as SPL increases, compared to other industrial noise sources.

- Careful work at the planning stage may help mitigate some noise concerns.

Rogers A. (2006) Wind Turbine Noise, Infrasound and Noise Perception.

Overview

The document is a presentation at the Renewable Energy Research Laboratory, University of Massachusetts at Amherst.

Background Information

- Human hearing range is about 20-20,000 Hz; whereas Infrasound is <20 Hz (Highest piano key = 4186 Hz, Low C = 33Hz)

- Sound is measured using units of decibels (dB). The dB scale is logarithmic: i) doubling the distance WTs reduces SPL 6dB; ii) 2 WTs produce 3dB more than 1; iii) a 10dB increase is perceived as doubling loudness.

- A-weighting is the standard method to compensate for sensitivity of human ear.

- Sound Power Level (SPL) = measure of the *source* strength (90-105 dB(A) typical for WTs). *Sound Pressure Level* = measure of the level at ***receptor*** (e.g., neighbor, microphone). Typically <45 dBA for WTs

- L_{Aeq} = A-weighted equivalent (average) over a period of time. L_{90} = noise level exceeded 90% of the time.

- L_{dn} or DNL = day-night level, where night level is weighted more severely.

- dB level examples provided: i) forest 18-20; ii) living room 40; iii)business office 60-65; iv) street traffic 80-84; v) 100m from Jet take off 125.

- WT noise sources are mechanical and blades (aerodynamic). WT noise levels have decreased significantly since the 1980s and new technology has significantly decreased the SPL from the newer larger WTs.

- International standards exist for measuring WT sound – this data can be used to determine sound levels at a site.

- Predicting noise levels at different distances from the WT is routinely done using: a) blade tip height, b) WT power level, and c) a propagation model (distance, sound absorption by ground cover, frequency, wind direction, background noise &terrain effects). Computer models can provide calculated SPLs and maps of equal-noise contours

- Massachusetts Noise regulations – New source must be < or = 10dBA over L90 levels. Pure tones, measured in octave bands can only be 3 dB(A) over adjacent bands.

- Infrasound = sounds < 20 Hz natural sources include air turbulence, waves (.001 to 2 Hz) is measured w G-weighted

- Down wind turbines (old not used any more) produce more noise. All modern WTs have up-wind rotors.

- Background noise: a) masks WT noise; b) increases with wind speed; and c) typical levels are 30-45dB(A)

Results - Health Impact & Annoyance

- Infrasound is perceived as a mixture of auditory and tactile sensations w the ear as primary sensory organ.

- No reliable evidence exists that infrasound below the hearing threshold produces physiological or psychological effects.

- The author presented two examples from locations with 850 kW and 1.3 MW wind turbines. In both locations all Infrasound levels were below human perception at distances of 80 and 100 m from the WTs.

- Rogers sited Wolsink et al., (1993) – where574 respondents were exposed to 30-40 dB (A). In that study only 6% of Rs were annoyed. Variables related to annoyance included: stress from turbine noise, daily hassles, visual intrusion and age of WT site (where annoyance decreased with age of operation).

Conclusions and Policy Suggestions

- High levels of low frequency sound are required for perception.

- The ear is the most sensitive receptor of infrasound.

- Infrasound is emitted from modern WTs, but it is not a problem.

- Annoyance from WTs increases more rapidly, as sound level increases, than for other industrial noise sources.

- Allowance should be made for varying human sensitivity to sound; and b) manufacturing/operational variations in sound levels.

- It is possible to address the subjective factors of WT annoyance during the planning process. Careful planning at this phase may help.

- Compliance with regulations does not mean complaints will not be made.

Hayes Mckenzie Partnership Ltd. (2006) The Measurement of Low Frequency Noise at Three UK Wind Farms.

Overview

The paper reports a study that measured noise levels at 3 WT farms where low frequency noise from WTs had been identified by neighbours as a source of annoyance.

Background Information

- **Of 126 wind farms operating in the UK, 5 have reports of low frequency noise problems** – thus such complaints are the exception versus a general problem which exists for all WT farms.

- The authors reference the "Community Noise" document prepared for the WHO which states that there is: "no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects".

- (Infrasound = <20 Hz, Low Frequency Noise = 20-500 Hz)

- LFN is associated w inflow turbulence of air into the rotor disc. High frequency sounds are better absorbed over distances compared to LFN.

- Infrasound Exposure Levels – a) running exposes one to infrasound levels of 90-95 dB at 2-6 Hz; whereas: b) child on a swing = 120 dB at 1 Hz.

- Infrasound noise (<20 Hz) can still be heard although tonality is lost below 16-18 Hz.

- Over land there is a genera reduction of 6 dB for each doubling of distance. (re: LFN and infrasound)

- At 200-300 m from WTs, the high-frequency swish is heard. However over longer distances the high frequency noises are absorbed by the atmosphere such that the spectrum becomes biased towards the low frequencies. Thus, in quiet environments, WT noise that is audible at greater distances will be heard more as a low frequency rumble versus the swish.

- **Hearing sensitivity** - a) the older population is about 6-7 dB less sensitive than the younger pop; b) the top 10% most sensitive have thresholds about 10-12 dB below the average; c) the top 5% most sensitive have hearing thresholds 2 dB below the top 10% [thus is 12-14 below the ave].

Technical Information

- G weighting is specifically designed for infrasound. G-weighted levels of 95-100 dB(G) is close to the perception threshold level. Whereas, for environmental noise it is normal to use the sound level meter A-weighting which gradually reduces the significance of frequencies below 1000 Hz.

- **Noise levels & averaging**
  a) Averaging is done over time to better represent noise levels experienced and to account for fluctuations. The Equivalent Level = an energy average defined as the value of the SPL in dBs of continuous steady sound that within a specified time interval, ‘T’, has the same mean-squared SP as the sound that varies with time.
  b) ($L_{eq.\,T}$); where L eq is the equivalent continuous SPL (noise level) determined over a time interval T = T2 – T1.
  c) L_{nn} percentile levels may be defined as the SPL which is exceeded for n% of the time during the measurement time period, T. Example L_{90} would be the sound level exceeded for over 90% of the Time whereas Leq would be the SPL average over the Time period.

Methods

Study Locations - Three Wind farms with complaints about low frequency noise were identified.

Site 1 – Was commissioned in 1999 and had 7 pitch regulated WTs. Residents complained of a thumping noise that resulted in headaches and pressure sensations in the head.

Site 2 – Was commissioned in 2001 and had 16 stall regulated WTs. Residents complained of roaring bumping, whoosh, thumping noise that causes headaches and tiredness due to lack of sleep.

Site 3 – Was commissioned in 2002, had 3 stall regulated 1.3 MW WTs. Residents complained of low frequency noise from the WTs and tonal noise from the WTs.

Exposure Measurement
To assess levels of infrasound and LFN exposure at the 3 WT farms: researchers used a "0kdB 4-channel Harmonie System" with the use of low frequency microphones and preamplifiers. Measurements were performed at internal and external locations at each of the receptor locations where LFN has been described by the occupants. Microphones were located at positions where it was considered to be the most audible when the noise occurred.

SPL measurements and ground borne vibration were measured at one location where the occupants indicated the sound was coming up through the ground.

Free field noise measurements were also conducted. These allow the assessment of noise at the receptor location, external to the building. (Due to wind induced noise – these were only taken for frequencies above 10 Hz.)

<u>Results – Annoyance & Health Impact</u>

- The authors reference the "Community Noise" document prepared for the WHO which states that there is: "no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects".

- The authors indicate that studies have shown that people who complain about LFNs do not have lower hearing thresholds (i.e., do not hear sound at lower levels) compared to those who did not complain. However, the Salford Study found that the people who 'suffered from LFN' would generally set the acceptable level at 10dB above their hearing threshold whereas the non-sufferers would set it at about 20dB above their hearing threshold. [*Thus, suffers do not hear at lower levels, they appear to be more sensitive relative to their own hearing levels.*]

- The authors reference the literature and indicated that at 1000Hz SPL increases of 10dB are perceived as a doubling of sound levels. Whereas, at 20Hz, 5.2dB are perceived as a doubling of sound levels.

Site 1
Investigations indicated that noise was audible in several rooms in the house in which residents complained of a thumping noise that resulted in headaches and pressure sensations. The authors also reported that after the implementation of a Noise Reduction Management System that the LFN had been substantially reduced; however, wind turbine noise was still audible in the garden area and was most intrusive when wind came from the east.

During the study period – the residents turned on the recording equipment at 4:00 am when they stated the noise woke them up and they were unable to get back to sleep. An analysis of the sound revealed that the acoustic energy at 20 Hz was 20dB below the threshold of hearing (20dB below the DEFRA night-time LFM criterion and 28 dB below the perception threshold defined by Watanabe and Moller.)

The analysis also revealed that at times when the SPL levels crossed or came very close to the threshold of hearing (or DEFRA criterion), they coincided with the movement of a motor vehicle along a road located to the south-west and the time in which one of the residents awakened. Approximately 10 minutes later the resident went back to bed and sound analysis revealed snoring which the authors indicated: "At 400-500 Hz, measured noise levels exceed the ISO Threshold Criterion by 10-15 dB."

The authors reported that the analysis of the recordings indicated that it was the motor vehicle and not the wind turbine noise that caused the resident to awaken; but that once awake both the audible noise from the wind farm and their partner may have caused the person to have difficulty returning to sleep.

Site 2

At this location the resident was told to use the recording equipment to record the noise when it was considered to be a problem. During the one month study period the resident turned on the equipment twice. During those time periods WT noise was clearly audible within the dwelling (windows were open). The analysis indicated that the source was "modulation of the aerodynamic noise associated with the movement of the turbine blades through the air" and was likely to be at 250 Hz thus not low frequency noise. [*Note – this is often called Amplitude Modulation.*]

Site 3

Occupants in two residences complained of LFN and tonal noises. Equipment was set up for 6 weeks. Once in the 6 week period residents in one of the locations report LFN associated w the WTs.

Analysis of the recordings (made both in and outside) indicated a clear source of audible LFN at both measurement site. BUT – it was associated with the use of the washing machine on spin cycle. Reductions in LFN levels coincided with closing of a door. Noise measured outside started at 06:48:25 and ended at 07:05:25. Indoor SPLs went up or down depending upon the residents opening or closing doors. The researchers concluded that the tonal signature indicated that the noise could not have been generated by the WTs.

General Results

- **Low Frequency Noise -** The measurements at all 3 WT sites indicated that LFN is measurable but below the DEFRA Night time Low Frequency Noise Criterion. Internal levels (measured in rooms with windows closed) did not exceed 20dB.

- **Traffic and WT Noise -** WT noise may result in internal noise level that is just above the threshold of audibility, as defined within ISO 226. This means that the LFN from WTs could be audible within a dwelling. However, at all the measurement sites, low frequency noise associated with traffic movement along local roads has been found to be greater than from the wind farm.

- **Audible Modulation:** The common cause of complaints associated with WT noise at all 3 wind farms is not associated with LFN, but is the audible modulation (AM) of the aerodynamic noise, especially at night. The authors indicated that the internal noise levels associated with the AM were not considered loud enough to awaken residents but that this could result in difficulties returning to sleep.

- **Perception of the problem -** The authors also stated that it was not uncommon for residents to identify Wind Farms as the cause of awakening – "although noise levels and the measurements/recordings indicate to the contrary".

Conclusions

- Infrasound noise emissions from WTs are significantly below the recognized threshold of perception for acoustic energy within this frequency range. "Even assuming that most sensitive members of the population have a hearing threshold which is 12dB lower than the median hearing threshold, measured infrasound levels are well below this criterion".

- Infrasound from modern WTs is not a source which will result in noise levels which may be injurious to health.

- Little data exists of low frequency noise measurements within dwellings associated with modern WTs. Most guidance for WT noise assessment is based upon noise criterion applied externally to a dwelling or receptor location. However, LFN complaints are often associated with the perception of noise within buildings.

- The lack of wind induced masking noise, which normally would be the result of wind induced turbulence, serves to make the ear more sensitive to Low Frequency sources when indoors.

<u>Policy Suggestions</u>

- Audible Modulation – the authors indicated that since this can be heard and is considered an annoyance, that it needs further assessment and that in the presence of high levels of aerodynamic modulation a correction for the presence of the acoustic feature should be considered.

- For reported LFN problems – unattended measurements may be required to determine the presence of any LFN and that recordings should be made continuously for a minimum period of 3 days.

- Audible Modulation (the main source of annoyance) there is increased risk of AM for sites where stable atmospheric conditions may occur at night. The authors also indicate that AM differences can be as much as 3-6 dBA. Thus approaches to decrease this should be considered.]

- The authors indicate a guideline that suggests a 5dB correction should be applied if one of the following occur: i) the noise contains a distinguishable, discrete continuous note (whine, his, screech, hum, etc); ii) the noise contains distinct impulses (banks, clicks, clatters or thumps); and iii) the noise is irregular enough to attract attention. **The authors suggest that this correction may be needed for periods of high modulation (AM) such as at night time when the potential for stable atmospheric conditions is greatest.**

Colby D, Dobie R, Leventhall G, Lipscomb D, McCunney R, Seilo M, Sondergaar B. (2009)
<u>Wind Turbine Sound and Health Effects An Expert Panel Review.</u>

<u>Overview and Objectives</u>
This 85 page document was report prepared for the American Wind Energy Association (AWEA) and the Canadian Wind Energy Association (CanWEA). The authors indicate that the AWEA and CanWEA, assembled a panel of independent experts to address concerns that the sounds emitted from wind turbines cause adverse health consequences. "The objective of the panel was to provide an authoritative reference document for the use of legislators, regulators, and people simply wanting to make sense of the conflicting information about wind turbine sound."

<u>Methods</u>
The authors indicated a three step methodology:

Step 1 – Expert Panel: CanWEA and AWEA identifies panel members (described as independent experts) with expertise in the following areas: audiology, acoustics, otolaryngology, occupational/environmental medicine, and public health.

Step 2 – Literature Review: Panel members conducted a Pub Med literature search under the heading "Wind Turbines and Health Effects" to research and address peer-reviewed literature. An additional search on "vibroacoustic disease" was also performed. In addition, non-peer reviewed sources were also identified.

Step 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.

<u>Research Questions</u>

Key questions addressed by the panel members are illustrated below:

1. How do wind turbine operations affect human auditory response?
2. How do we determine the loudness and frequency of sound and its effects on the human ear?
3. How do wind turbines produce sound?
4. How is sound measured and tested?
5. What is vibration?
6. What type of exposure to wind turbines is more likely to be perceived by humans (low frequency sound, infrasound or vibration)?
7. Can sounds in the low frequency range, most notably the infrasonic range, adversely affect human health?
8. Can sounds below the hearing level affect health?
9. How does the human vestibular system respond to sound?
10. What are the potential adverse effects and health implications of sound exposure?
11. What does scientific literature say about wind turbines, low frequency sound, and infrasound?

Background Information

Environmental Noise - In order to compare to wind turbine emission, the authors presented A-weighed noise levels measured in the environment:

Source	dB(A)
Jet takeoff (200 feet)	120
Auto horn (3 feet)	110
Jet takeoff (1000 feet)	100
Shout (0.5 feet)	100
N.Y. subway station	90
Freeway traffic (50 feet)	70 to 80
Air conditioning unit (20 feet)	60
Light auto traffic (50 feet)	50
Living room	40
Library	30

Wind Turbine Noise

- **Source -** A 100-meter-diameter blade, rotating once every three seconds, has a tip velocity of just over 100 meters per second. Aerodynamic sound (the main sound from WTs) is "caused by the interaction of the turbine blade with the turbulence produced both adjacent to it (turbulent boundary layer) and in its near wake".

- **Amplitude Modulation** – The authors report that it is recognized that sound can be higher during the downward motion of the blade and can occur once per second and that this is called Amplitude Modulation. The authors acknowledge that the cause of Amplitude Modulation is not well known. [*Note – this is the 'swish swish' noise that is often the source of complaints.*]
understood.

- **Measured sound levels -** The authors report that sound levels of 50dBA at 1,500 feet would be a conservative estimate for modern wind turbines.

- **Low Frequency Noise -** Low frequency sound associated with wind turbines has attracted attention. The authors indicate this is because the A-weighting scale that is used for occupational and environmental regulatory compliance does not work well with sounds that have prominently low frequency components. The authors also indicated that for some there is the perception that "there is something special, sinister, and harmful about low frequency sound" which the authors argue is not the case.

Vibration & the Vestibular System

- The authors point out that it has been postulated that adverse health effects have been caused by vibration from low frequency noise generated from wind turbines. On page 3-10 the authors then present an example and argue that if the vibrations were entering the body via the ground and through the feet that this could be possible. They then argue that since the low frequency noise is in the air and affects all sides of the human body that "there is no resultant force on the suspended system and it does not vibrate or resonate". The authors then report that this information demonstrates a major flaw in the hypothesis of "Wind Turbine Syndrome" presented by Dr. Nina Pierpont.

- The authors report that the vestibular system of the body: a) plays a major role in maintaining a person's sense of balance; b) responds to pressure changes (sound pressure, i.e., decibels) at various frequencies; and c) at high levels ($\geq$ 140 dBA) low frequency noise exposure can cause nausea and changes in respiration and blood pressure.

- Head vibration resulting from low frequency sound has been suggested as a possible cause of a variety of symptoms that some hypothesize as being associated with wind turbines.

Sound Exposure and Adverse Health Effects

- The authors indicate that the effects of sound are directly dependent upon the sound levels. They also indicate that higher frequency noise present a greater health risk compared to lower frequencies. Examples of known adverse health effects presented included: a) speech interference, b) hearing loss, c) task interference, d) annoyance, and e) sleep disturbance.

- It has been hypothesized that that chronic noise exposure might lead to chronic health problems such as hypertension and heart disease. The authors indicate that this has been the subject of hundreds of contradictory studies of highly variable quality.

- The authors report that Annoyance is not an adverse health effect or a disease and that it is a subjective response that varies among people to different sounds.

- The authors report that no scientific studies have evaluated health effects from low frequency noise generated from wind turbines. They indicate that sources include wind, rivers, waterfalls, road traffic, aircraft and industry. Based upon information from the American FDA, the authors suggest that exposure to levels in the 70dB range is considered safe.

- Studies in Europe by Pedersen et al., Wolsink et al., and Pedersen and Waye, have demonstrated a dose-response between increasing noise levels and noise annoyance. These studies also found that there also were strong correlations between individual characteristics/perceptions and annoyance (e.g., a negative attitude of wind turbines and/or their impact on the visual landscape.) These studies found that a small percentage of the people were annoyed (5% in the 35-40 dB exposure category) and that the % annoyed increased for higher exposure categories (e.g. 18% at 40-50 dBA).

Results

Infrasound, Low-Frequency Sound, Annoyance & Health

- 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 authors also cited Jakobsen (2004) concluded that infrasound from wind turbines does not present a health concern.

- Under many conditions, low frequency sound below about 40 Hz cannot be distinguished from environmental background sound from the wind itself.

- 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. If so, city dwelling would be impossible due to the similar levels of ambient sound levels normally present in urban environments.

- Hearing sensitivity is not the deciding factor with respect to annoyance. Individual factors also influence annoyance.

- 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.

- Nocebo Effect – The authors describe the 'Nocebo Effect' which they describe as: "an adverse outcome, a worsening of mental or physical health, based on fear or belief in adverse effects" and which is basically the opposite of the placebo effect. The authors describe predisposing factors believed to be associated with this 'effect' (e.g. expectations of adverse effects; conditioning from prior experiences; and psychological characteristics such as anxiety, depression and the tendency to somatise) and a range of symptoms that can result (e.g., drowsiness, nausea, fatigue, insomnia, headache, weakness, dizziness, and difficulty concentrating) and finish by pointing out that this basket of symptoms are the same as those described by Pierpont in her wind turbine syndrome hypothesis.

Vibroacoustic Disease and Wind Turbine Syndrome

Vibroacoustic Disease and Wind Turbine Syndrome are reported to be linked to low frequency noise emissions from wind turbines. The authors indicated that reviews of the reports raised critical concerns about the validity of conclusions made by the authors of those reports. Critical issues included: a) the level of sound exposure associated with the putative health effects; b) the lack of diagnostic specificity associated with the health effects reported, and c) the lack of a control group in the analysis.

<u>Vibroacoustic disease</u>

- VAD is described by the VAD researchers (Alves-Pereira and Castelo Branco) as a whole-body, multi-system entity, caused by chronic exposure to large pressure amplitude and low frequency sound and where the primary diagnostic criterion is thickening of cardiovascular structures, such as cardiac muscle and blood vessels.

- Colby et al., pointed out that the VAD concept was developed by examining people at high levels of exposure and that originally the VAD team indicated $\geq$ 90 dB risk threshold. Colby et al., then indicated that there is an "enormous decibel difference between the sound exposure of aircraft technicians and the sound exposure of people who live near wind turbines" and reported that animal experiments have found that at least 13 weeks of continuous exposure to 100dB of low frequency noise were required to produce symptoms described to be associated with VAD.

- Two main criticisms of the paper where Alves-Pereira and Castelo Branco concluded a family living near WTs would someday develop VAD were: a) that the study was a case series "which are of virtually no value in understanding potential causal associations between exposure to a potential hazard"; and b) that the 50 dB decrease in the risk threshold (90 dB to 40dB wind turbine exposure) meant that it would take (100,000 years for the wind turbine dose to equal that of one year of the higher level sound.

- The authors concluded that there was no foundation to support the hypothesis that exposure to sub-threshold, low levels of infrasound leads to vibroacoustic disease.

Wind Turbine Syndrome
Colby et al., report that Wind Turbine Syndrome is based upon the hypotheses: i) that low levels of wind turbines emission (infrasound) affect the vestibular system; and b) that infrasound also causes internal vibrations. Pierpont then argues that the combined effect confuses the position and motion detectors in the body which then results in a variety of adverse symptoms.

On page 4-8, Colby et al., provided information to support their conclusions that the two hypotheses were based on information that had been misinterpreted an

Interpreting Studies and Reports
In this section the authors provide an overview of how research studies can be used to determine definitive links between exposure and adverse health outcomes directly caused by that exposure.

[Note - It appears that the authors included this section in response to the case studies that are widely reported on the internet and which have generated concern and fear among individuals and groups that have accepted the conclusions from those authors which Colby et al., indicate are based upon "unproven hypotheses" and as previously suggested by Colby et al., are also based upon case study designs that are only appropriate for generating hypothesis and which can never between wind turbine emissions and the symptoms those authors attributed to that exposure. We summarize this section in our report because we feel it provides valuable information for those without specific research methods knowledge. It will provide additional information that helps explain why the case studies by Pierpont, Harry and Krogh et al., can't be used to make conclusions of a causal link.]

The author start by indicating that often the first step in recognizing exposure may be harmful comes from observations of individuals including physicians who think a possible association exists (e.g., exposure to symptom or disease) and who then communicate their findings to others in the form of case reports or a case series. Colby et al., then describe the methodological problems associated with case studies to include: observations that are not controlled; and a lack of comparison between people who have been exposed and have the symptoms to those who have not been exposed and don't have the symptoms. The authors then indicated that controlled studies (e.g., case-control and cohort) are essential and are designed to determine if a causal association is likely. The authors also indicate that "only after multiple independent-controlled studies show consistent results is the association likely to be broadly accepted". The following descriptions were provided on page 4-12 of the report:

"Case-control studies compare people with the disease to people without the disease (ensuring as far as possible that the two groups are well-matched with respect to all other variables that might affect the chance of having the disease, such as age, sex, and other exposures known to cause the disease). If the disease group is found to be much more likely to have had the exposure in question, and if multiple types of error and bias can be excluded (Genovese, 2004), a causal link is likely. Multiple case-control studies were necessary before the link between smoking and lung cancer could be proved.

Cohort studies compare people with the exposure to well-matched control subjects who have not had that exposure. If the exposed group proves to be much more likely to have the disease, assuming error and bias can be excluded, a causal link is likely. After multiple cohort studies, it was clear that excessive noise exposure caused hearing loss (McCunney and Meyer, 2007)."

Conclusions

- Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effect in humans. The authors indicate that sound emissions and vibrations from wind turbines are not unique [*Note – i.e., there is no special characteristic that makes them more of a health risk*]. The body of evidence on noise and health is substantial and that when all the information is considered there is no evidence that noise emissions from wind turbines cause direct adverse 'physiological' health effects.

- Low frequency noise and infrasound from wind turbines do not present a risk to human health.

- A small minority of people may be annoyed at the presence of sound from wind turbines. The authors then indicate that they do not consider annoyance is not a pathological entity.

- A major cause of concern including what generates most complaints is the aerodynamic "swish swish" sound component produced by the turbine blades.

- Case Studies and Future Funding – Based upon the number and "uncontrolled nature" of the highly reported case studies, the authors concluded that the current evidence does not warrant funding for additional studies.

Chief Medical Officer of Health of Ontario (2010). The Potential Health Impact of Wind Turbines.

Overview

The document is a report that was published by the Chief Medical Officer of Health (CMOH) of Ontario with assistance from members of a working group comprised of member from the newly created Ontario Agency for Health Protection and Promotions, and others from the Ministry of Health and Long-term Care and the Council of Ontario Medical Officers of Health.

Purpose & Methods

The CMOH indicated that the report was a response to public concerns about wind turbines with a focus on th potential effects of noise emissions. Specific questions that were addressed included:

a) What scientific evidence is available on the potential health impacts of wind turbines?

b) What is the relationship between wind turbine noise and health?

c) What is the relationship between low frequency sound, infrasound and health?

d) How is exposure to wind turbine noise assessed?

e) Are Ontario wind turbine setbacks protective from potential wind turbine health and safety hazards?

f) What consultation process with the community is required before wind farms are constructed?

g) Are there data gaps or research needs?

These questions were addressed by: 1) conducting a literature search (1970 to 2010) on "wind turbines and health from scientific bibliographic databases, grey literature, and from a structured Internet search; and 2) a consultation process involving experts and members from the Council of Ontario Medical Officers of Health

The report summarizes information from a sources including: journal articles, books, grey literature, the World Health Organization, Community-Based Organizations and individuals with concerns, and conference papers. This included: a) overviews of the highly reported case studies; b) European cross sectional studies; c) noise and health research; d) infrasound, low frequency noise and vibration; e) information on other potential health effects (not noise related) from wind turbines; f) Ontario wind turbine regulations (e.g., set back distances);

Background Information

- In Ontario the minimum setback for a wind turbine is 550 metres from a receptor.
- Setback distances rise with the number of turbines and the sound level rating of the selected turbines. The report provides the following example: a wind project with five turbines that have sound power levels of 107dB would require a 950 metre setback from the nearest receptor.
- These guidelines are based on sound modelling and are intended to limit sound at the nearest residence to 40 dBA

Conclusions

The following conclusions were reported on page 10 of the CMOH Report:

- While some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects.
- The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct adverse health effects. However, some people might find it annoying. It has been suggested that annoyance may be a reaction to the characteristic "swishing" or fluctuating nature of wind turbine sound rather than to the intensity of sound.
- Low frequency sound and infrasound from current generation upwind model turbines are well below the pressure sound levels at which known health effects occur. Further, there is no scientific evidence to date that vibration from low frequency wind turbine noise causes adverse health effects.
- Community engagement at the outset of planning for wind turbines is important and may alleviate health concerns about wind farms.
- Concerns about fairness and equity may also influence attitudes towards wind farms and allegations about effects on health. These factors deserve greater attention in future developments." (p10)

Suggestions

It is important to assess and monitor noise level compliance at wind farms. These results would indicate whether or not epidemiological studies are needed.

SUMMARY OF WIND TURBINES AND HEALTH - GREY/SELF PUBLISHED LITERATURE

Overview

We separated the grey/self-published literature into the two categories:

i) Case studies and other papers that support the conclusion of negative health effects; and

ii) Other papers that do not support or suggest adverse health effects.

We made this separation because it was clear that groups that had reached conclusions about the health impact of exposure to the modern wind turbines typically used different sources of information that came from studies with different methods and the associated strengths and weaknesses. A very clear example of the differences can be illustrated by a comparison between an Ontario study reported by Krogh et al., (2010) and the Dutch study reported by Frits van den Berg et al., (2008).

Brief overviews of the study methods and results are provided below. In short, Krogh et al., report that 80.3% of their sample (n = 132) suffered from adverse health effects. Whereas, van den Berg et al., found no statistically significant association between wind turbine exposure and health outcomes (n = 725).

Krogh et al. (2010)

The Ontario study is titled: "A self-reporting survey: adverse health effects with industrial wind turbines and the need for vigilance". The report includes the following from the abstract:

> ***"Victims report disturbed living conditions and loss of quality of life and enjoyment of their homes and property, and financial loss due to the negative impact to the health of their families….. Comments from the victims are included in this report. They are both revealing and disturbing. No authority or compassionate member of our society can ignore the moving descriptions of the victims' experiences."***

Methods for this study included distributing "Health Survey Contact Flyers" to people who lived near wind farms where the fliers included statements such as: "victims suffering from adverse health effects from wind turbine complexes are hesitant to report due to the manner in which their reports have been discounted". People who responded to the fliers were then sent the survey instrument which included a symptoms check list. In addition, the researchers allowed more than one respondent per residence to self select. For example, the documents sent to the residences stated indicated: "If more than one adult in the home is affected please have each adult fill out a separate questionnaire". The authors report that 132 Ontario residents who responded to the fliers later completed the surveys

Results – The authors found that 106/132 (80.3%) of respondents reported adverse health effects.

The methods in this study clearly introduced significant sample bias at all stages. Other problems that make results or conclusions very questionable include: a) exposure was not measured, b) use of a symptoms check list; and c) multiple respondents per residence.

Frits van den Berg et al., (2008).

The report is a detailed statistical analysis about various factors and how they relate to wind turbine annoyance and health outcomes. The study looked at how people perceived the wind farm in their living environment (e.g., sight and sound). It consisted of a postal survey (n = 725, 37% response rate) of Dutch residents.

The sample came from 50,375 addresses were identified and subdivided into the three environment types (quiet countryside, countryside with main road, build-up area). Based upon modeling, the residences were placed in four exposure groups: 1) 25-30, 2) 30-35, 3) 35-40, and 4) 40-45 dB(A) with an equal number of individuals in each exposure group and at least 50 respondents each.

The purpose of the study was masked to the respondents. [*Note: thus attitudes about wind turbines would not likely affect who did and did not respond.]* The researchers conducted a survey in a random sample of 200 non-respondents and reported no statistically significant differences in annoyance between the responders [n=725] and the sample of non-responders.

Results – The authors reported that chronic disease, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease and migraine were ***not*** associated with sound levels or annoyance. They also found that those who received financial benefits from the WTs, and who were in the highest exposure category, (e.g., 45 dBA) were less annoyed than those in the lower exposure category who did not receive financial benefits.

What do we know from the grey/self published literature?

- We identified and reviewed thirty two documents in this category where our criteria for inclusion was broad because we were interested in what people were reporting about wind turbines and human health. However, as with the peer reviewed category there are a very few number of studies that have looked at the relationship between exposure to wind turbines and health effects.

- **No evidence was found that demonstrated a dose-response causal relationship between noise emitted from wind turbines and adverse health effects.**

- We know there are two distinct groups that have reached opposing conclusions about the relationship between wind turbine exposure and adverse health effects and that the information used to support those conclusions frequently come from different sources and different quality studies.

- The best evidence that there not a likely relationship between exposure to wind turbine noise emissions and adverse health outcomes comes from the large sample, controlled study. [This is also supported by the large sample study in the peer reviewed category.]

- **We know that the evidence in support of a relationship of a relationship between noise emitted from wind turbines and adverse health effects comes from several case series studies.** These types of studies are only appropriate for generating hypotheses and not for making assertions about a causal relationship between exposure and illness. **We also know that some of these studies had very significant methodological problems that make the results and conclusions difficult if not impossible to accept** (e.g., sample bias, symptoms check lists, use of proxy respondents, lack of defined research questions combined with a clear lack of objectivity in the primary investigators).

- We know that a small percentage of all people exposed to wind turbine noise annoyed (rather to very, 6% - 10%) and that a dose response does exist with more people highly annoyed at the higher exposure levels. However, we also know this annoyance response is affected by non-noise characteristics such as attitudes about wind turbines and visual impact. Supporting the relationship between non-noise (individual) factors and annoyance is the van den Berg et al., result that those receiving financial benefits were less annoyed despite being exposed to the highest SPL.

What do we need to know?

- The evidence base in both the peer reviewed and grey/self published literature is small. The few good quality studies did not find evidence that exposure to wind turbines causes ill health. Although these studies had large sample sizes and were of good quality, they still relied on self-reported health outcomes and modeled versus measured exposure levels. Given this there is a value in completing studies cohort and case control studies that in addition to self reported health outcomes and quality of life indicators also included biomarkers, administrative utilization data and other objectively measurable health outcomes.

- We need to know more about how to decrease 'Amplitude Modulation'. Amplitude modulation is considered to be the main source of noise annoyance associated with wind turbines. It is the 'swish swish' sound that is heard and is reported to be more pronounced at night and under colder conditions.

- Evidence from the Hayes McKenzie study (2006) suggests that some highly annoyed people incorrectly conclude the source of the annoyance (e.g., low frequency noise or sounds that caused them to wake up) to be wind turbines. We need to know more about what causes these perceptions and what approaches the developers, local communities and the individuals can implement to decrease the likelihood of annoyance from environmental noise and misdirected conclusions about the source.

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3) Government and Industry – Technical Information & Guidelines

This category was created to group together technical information about wind turbines. There are three distinct sources reported in this category: government documents and commissioned reports, industry documents and commissioned reports, and information from relevant peer-reviewed journals. For the peer-reviewed sub-category, journals articles identified in literature review that did not relate to health were reviewed. In addition, relevant journals were also individually searched.. For the other two sub-categories, any report or other document mentioned by sources identified in categories 1, 2 or 4 was obtained, as well as other reports by known authors. Further Google searches were conducted to ensure key reports were not missed. Our intention with the category was not to be exhaustive, because the technical nature of the information was beyond the scope of this study, but to provide an adequate amount of information of what is known about wind turbine sound emissions.

The results presented below are only those that impact upon the other categories in this report. A large volume of purely technical data on turbine sound generation was gathered and analyzed. It is not obviously relevant to the main discussion of this report.

The results will be presented in four categories: i) peer-reviewed journal articles, ii) government documents, iii) industry documents and iv) grey literature and other sources.

Peer-reviewed journal articles / scholarly publishers

Hau E. (2006) Wind turbines: fundamentals, technologies, application, economics.

Overview
Translated textbook (from German) on wind turbines from academic publisher Springer – Verlag. Only relevant sections were reviewed.

Background
Permissible Noise Levels in Europe (dB(A)) (day/night):

- Germany: Industrial (65/50) Mixed (60/50) Predominantly Residential (55/40) Only Residential (50/35) Rural (40/30)
- Netherlands: Mixed (50/40) Only Residential (45/35) Rural (/45)
- Denmark: Only Residential (/40)
- WTs emit the broad whooshing noise of the rotor (1000Hz range) and impulsive, low-frequency sound waves. The author indicates that modern WTs are equipped with an automatic shadow cut-out system that is programmed with the astronomically possible shadow-casting times and switches off the turbine with the aid of a light sensor as soon as the weather situation allows a shadow to be cast at a critical point.

Technical information

- Author states that noise emission of WTs has been noticeably reduced in the past 15 years. Author indicates that the background noise generated by wind (blowing around trees, grass and buildings) increases by about 2.5 dBA per 1 m/s increase in wind speed whereas noise emission from WTs increase only 1 dBA per one m/s wind increase.

- If the background noise level exceeds the calculated WT noise level by 6dBA, the WT noise will no longer contribute to any perceptible increase in the SPL at the location of emission.

- Sound Pressure Levels at the location of emission [receptor site] are determined/calculated by:
  - a) sound power level
  - b) factor of directivity
  - c) steradian factor
  - d) factor of distance
  - e) factor of atmospheric absorption
  - f) factor of ground and meteorological absorption
  - g) factor of vegetational absorption
  - h) factor of absorption by buildings
  - i) influence of the wind.

- If several sound sources (e.g., a WT farm), contribute to the SPL generated at one location of emission (receptor site), the noise levels generated by the WTs are calculated individually and the acoustic energies are added [to get the total SPL]

- Noise emissions increase by about the 5^{th} power of the flow velocity which is determined by the tangential velocity of the rotor blade tips. Thus – a reduction in blade tip speed by 25% results in a reduction in noise emissions by about 6 dBA. Shadow: Large WTs can cast a shadow of 1.5 to 2 km

Issues

- If a number of operating WTs simultaneously cast shadows onto an immission point, the effect is cumulative and occurs at higher frequency. These shadows can disturb people inside buildings.h

Hepburn H. (2006) Acoustic and geophysical measurement of intrasound from wind farm turbines.

Overview

Study measuring infrasound from a large Alberta wind farm with turbines both on and off.

Technical Information

The wind farm consists of 59 660 MW and 1 600 MW turbines. The terrain is rolling hills and flat prairie of southern Alberta. Three wind states were measured at low, medium and high, with the turbines both on and off at each wind state. Measurements were taken using geophones, microphones and a precision sound level meter using 1/3 octave band levels. Atmospheric data and visual observations were also made. Provide a detailed account of placement and calibration procedures.

Wind Speeds

Low ≤ 6 m/s **Medium 6-10 m/s** **High 10-25 m/s**

At low wind speeds the wind turbines will generally be stationary/idling and not generating power.
Above 25 m/s the wind turbines will shut down. [*Note: **6.4 m/s = 23.04 km/hr** which is the average wind speed on Wolf Island in Ontario where a large wind farm is located.*]

Results – Other

Hepburn's results are presented below. Note – these figures are extrapolated from the figures provided and will be a close approximation but will not be exact. Hepburn measured downwind sound pressure levels for low frequency noise between 6.3 Hz and 200 Hz with the wind turbines turned on and off.

Infrasound and Low Frequency Noise at 50 Metres from the Wind Turbines

Hz	Low Wind Speed		Med Wind Speed		High Wind Speed	
	WTs *ON*	WTs OFF	WTs *ON*	WTs OFF	WTs *ON*	WTs OFF
	dBL	dBL	*dBL*	dBL	*dBL*	dBL
6.3	***68***	**41**	***72***	**65**	**75**	**82**
8.0	***67***	**39**	***71***	**64**	**74**	**82**
10.0	***64***	**38**	***70***	**62**	**72**	**79**
12.5	***62***	**36**	***70***	**59**	**71**	**77**
16.0	***58***	**36.5**	***68***	**57**	**70**	**77**
20.0	***55***	**39**	***67***	**54**	**69**	**76**
25.0	***49***	**38**	***64***	**50**	**67**	**75**
31.5	***46.5***	**41**	***63***	**47**	**66**	**73**
40.0	***45***	**40**	***61***	**45**	**63**	**71**
50.0	***44.5***	**42**	***58***	**41**	**60**	**68**
63.0	***45***	**43.5**	***59***	**38**	**61**	**65**
80.0	***42***	**40**	***57***	**37**	**61**	**62**
100.0	***39***	**41**	***56***	**38**	**58**	**58**
125.0	***38***	**37**	***56.5***	**32**	**59**	**55**
160.0	***35***	**33**	***51***	**30**	**53**	**49**
200.0	***31***	**30.5**	***48***	**28**	**52**	**45**

Infrasound and Low Frequency Noise at 1000 Metres from the Wind Turbines

Hz	Low Wind Speed		Med Wind Speed		High Wind Speed	
	WTs *ON*	WTs OFF	WTs *ON*	WTs OFF	WTs *ON*	WTs OFF
	dBL	dBL	*dBL*	dBL	*dBL*	dBL
6.3	*56*	62	53	*	*79*	76
8.0	*55*	63	51	*	*78*	74
10.0	*53*	60	47	*	*76*	72
12.5	*49*	59	46	*	*73*	71
16.0	*48*	56	44	*	*71*	68
20.0	*47*	52	43	*	*68*	67
25.0	*46*	50	41	*	*67*	64
31.5	*45*	46	43	*	*64*	60
40.0	*43*	43	43	*	*60*	56
50.0	*44*	44	46	*	*57*	53
63.0	*42*	38	41	*	*56*	49
80.0	*41*	37	39	*	*52*	46
100.0	*38*	36	38	*	*49*	43
125.0	*33*	29	36	*	*45*	39
160.0	*29*	25	32	*	*41*	36
200.0	*28*	22	29	*	*39*	33

* Not provided

- **Figure 5** shows LLeqs for **ON and OFF conditions** for low wind speeds at **50 m** from the WTs: a) at 16 Hz and below the WTs contribute over 20dB above the ambient noise; b) Above 50 Hz the WTs do not contribute significant sound above ambient noise; and c) With WTs ON the SPL decreases almost linearly from 68 dB (6.3 Hz) to 30 dB (200 Hz).

- **Figure 6** shows **ON and OFF conditions** for **medium wind** at **50m** from the WTs. Above 50 Hz the WTs added about 20 dB to ambient noise wheres below 50Hz the WTs contributed between about 15 – 7dBL. Note: at medium wind speed – the ambient noise (WTs off) has increased considerably. With the WTs on the dBL decreased linearly from 72dbL (6.3Hz) to 48dBL (200 Hz).

- **Figure 7** shows **ON and OFF conditions** for **high wind** speeds at **50m** from the WTs. a) Ambient wind noise exceeds the sounds from the WTs by 8dB from 6.3-50Hz; and b) at over 100Hz the WTs add about 7dB to (above) the ambient noise; c) It should be noted that below 80 Hz the WTs serve to decrease the ambient wind noise. (Authors point out that as the wind increases from medium to high wind – the WT blade speed does not increase.)

- **Figure 8** shows **ON and OFF conditions** for **low wind** speeds at **1000m** from the WTs. i) Between 6.3-25Hz the ambient wind noise exceeds levels when the WTs are ON by about 8dB. ii) Between 50Hz-200Hz – the WTs appear to add about 5dB.

- **Figure 9** shows **ON and OFF conditions** for **high wind** speeds at **1000m** from the WTs**. i) The WTs contribute 2-6dB above ambient noise at all frequencies. Note the SPL decreases linearly from 79db (6.3 Hz) to 38db at 200 Hz).**

- **Figure 10 - At high wind speeds, the ambient wind noise is the dominant factor –** little decrease in noise while WTs on at 50m vs 1000m confirms that the dominant sound contributor is the wind**.**

- **Figure 11** shows **ON condition** for **medium wind** speed at **50m & 1000m** from the WTs**. Sound levels decrease with increasing distance** and as expected higher frequencies have larger decreases in sound levels with distance.

- **Figure 12** shows **ON condition** for **high wind** speeds at **50m & 1000m** from the WTs**.** Very little difference exists between distances because ambient wind noise is the main factor. Note: at frequencies above 80Hz noise decreases with distance.

- **Figure 13** shows **ON and OFF conditions** for **low wind** speeds at **50m ON & 1000m OFF** from the WTs**.** Below 31.5 Hz, less than 12 dB is contributed by the WTs. Above 31.5 Hz very little contribution from the WTs is seen.

- **Figure 14** shows **ON condition** for **low, med and high wind** speeds at **50m** from the WTs**. Note –** SPLs for all frequencies increase from low to medium wind speeds but there is little increase from med to high.

- **Figure 15** shows **OFF condition** for **low, med and high wind** speeds at **50m** from the WTs**. Note -** the ambient wind noise, below 50 Hz, increases from low wind speed to medium speed. Between med and high wind – ambient wind noise increases about 20 dB at all frequencies. **At high wind speeds, the ambient wind noise will exceed the sound output from the Wts. In addition, at high wind, the LLeqs are higher when the WTs are turned off.**

- **Figure 16** shows **ON condition** for **low and high wind** speeds at **1000m** from the WTs**.**

- **Figure 17** shows **<u>OFF condition</u>** for **<u>low and high wind</u>** speeds at **<u>1000m</u>** from the WTs**.** An increase of 10-12 dB in ambient wind noise is observed at most frequencies between low and high winds.

- Wind turbines do not generate more sound at higher wind speeds. The results also indicate that under some wind conditions WTs actually decrease ambient wind noise or at least this is what appears to be the case. The results indicate that attenuation due to distance (noise decreases) was a decrease of 3 dB for every doubling of distance. The formula used was: L(R2) = L(R1) – 10 Log10(R2/R1), R1 and R2 = distance from metres, L = Db

<u>Implications</u>

- The results conclusively demonstrate that the wake effect of the WTs significantly decreases ambient noise for <u>high wind speeds</u> in the down wind direction for frequency bands 3 Hz to 207 Hz.

- Infrasound emissions from the WTs is present in close proximity to the WTs, but it is not a significant concern.
- The infrasound frequencies detected were strongly attenuated (decreased) by distance from the WTs.

- All data sets confirm that atmospheric infrasound emissions from the WTs are not significantly above the ambient wind noise levels at a distance of 1,000 m.

- Ambient infrasound levels, when the WTs are NOT OPERATING, are significant for the medium and high wind conditions.
  a) High wind, infrasound LLeqs range from 76-82 dBL when WTs are OFF – exceeding the levels when the WTs are turned on.
  b) Medium winds: Ambient infrasound LLeqs range from 53-65 dBL for WTs OFF.
  c) Low Winds: Ambient infrasound LLeqs range from 53-62 dBL, exceeding the infrasound when the WTs are on.

- Ambient noise is not attenuated with distance and the ambient wind noise exceeded the attenuated output from the WTs.

- All data support the conclusion that some attenuation of wind noise occurs when the wind farm is operating in low and high winds. ***The time domain telemetry data for the frequency band of 3 Hz to 207 Hz support the same conclusion for all wind conditions, particularly at a distance from the WTs of 200m and greater.***

<u>Jakobsen J. (2005) Infrasound emission from wind turbines.</u>

<u>Overview</u>

A critical review of the literature on infrasound from wind turbines.

<u>Background</u>

In Denmark, the indoor recommended limit for infrasound is 85 dB(G). A-weighting is used above 10Hz. The night-time recommended limit is 25 dB(A). Wind turbine limit is 40 dB(A) dwelling group and 45 dB(A) single dwelling.

Technical information

- Argues that C-weighting is inadequate. This is in contrast to earlier articles (see b). Disputes other content in those articles.

- "It seems fair to summarize the findings for the infrasound level as a rough estimate, that the level from an upwind turbine of contemporary design at 100m distance would be about 70 dB (G) or lower, while the level from a downwind machine can be 10 – 30 dB higher" (150).

- Even very close to the above mentioned turbines, infrasound is well below the Danish recommendations (and two standard deviations below the threshold).
- Argues that "it is estimated rather unlikely" that turbines can cause the rattling of objects on walls indoors.

Conclusions

- **Infrasound from upwind turbines can neglected when evaluating the environment effects of wind turbines.**

- **Infrasound alone is hardly responsible for the complaints mentioned from people living up to two km from the large down wind turbines.**

- **In positions very close to upwind turbines, the indoor infrasound level is expected to be far below the Danish recommended limit for environmental infrasound , 85 dB(G).**

Suggestions

- The 'normal' (spectrum) of wind turbine noise is a good explanation of 'adverse public reaction' and it is extremely unlikely that infrasound (or even low frequency noise) is to blame.

Jaskelevicius, B and Uzpelkiene N. (2008) Research and assessment of wind turbine's noise in Vydmantai.

Overview

Measurements and other research about wind turbine sound production.

Background

Note that terrain plays a major role in wind turbine sound levels. Discuss the varying national dB standards (UK, Lithuania).

Technical Information

Measurements made using national (Lithuanian) and European standards. Microphone covered with protection screen, at height of 1.2-1.5m at air speeds between 6-9m/s and using a frequency characteristics filter (not a C filter). Turbine is 630 kW at 76m of common German company.

Results

The highest sound levels were registered at the air screw, downwind, and the lowest was to both sides of the tower, neither upwind nor downwind. The levels at 200m ranged from 40.4 to 55.8 dB. Levels noticeably higher than background ended in the 250-300m zone.

[*Note – all graphs presented showed SPLs at multiple distances (0, 25, 50, 100, 200 metres) from the WTs. The slopes from all graphs clearly suggest the SPL at 400M would be below 40 dB.]*

Kaygusuz, K. (2004) Wind energy: progress and potential.

Overview
Written in 2002, author provides a look at wind energy over the previous decade.

Background
Worldwide capacity doubled every three years in the 1990s. 70% was in Europe and 19.1% in North America, mostly the USA. They are also cost competitive with other energy sources, and the higher the average wind speed, the lower the costs.

Issues
Visual intrusion is the most reported public objection. Noise, and effects on radio and TV signals are also reported. Cites a study that found that the response to wind turbines is usually conditioned by attitudes to different types of energy production. The size, height, colour, material, wind farm configuration, landscape background and sitting to reduce line of sight are all important factors to consider.

Tickell, C. (2006) Wind farm assessment in Australia and model comparison
Overview
Technical discuss of the merits of various models used to predict wind turbine sound propagation.

Background
Australia, and other jurisdictions, require the use of sound models in wind turbine proposals. There are many common models: ENM (Australia and other jurisdictions) and modified versions, WiTuProp (EU), the New Zealand Standard, CadnaA and others. There is little work on verification of these models. Known accuracy of the models is necessary in order to address noise issues.

Technical Information
Used a basic scenario involving one (hypothetical) turbine to compare variation of models.

Results – Health Impact
Suggests that community complaints about wind turbine noise can be in part appeased through demonstration via model that wind turbines can achieve acceptable sound levels when sited correctly.

Results – Other
- At 1000m, the models vary by up to 9 dB and this increases with wind speed. This result is statistically significant and can potentially have a major impact on sound prediction in site proposals – different models will give different outcomes in predicted sound levels.

- "The models generally indicate that a distance of about 1.2 to 1.5km is required from a multi-turbine wind farm to achieve a sound level of less than the ambient sound level under most conditions."

Recommendations
There must be internationally-conducted model validation in order to narrow the credibility gap between developers/regulators and communities.

Shepherd K, Hubbard H. (1991) Physical characteristics and perception of low frequency noise from wind turbines.

Overview
Two old, overlapping articles that still contain good information about turbine acoustics.

Technical information

- In a typical house/structure, "noise reduction decreases as the frequency decreases, thus roughly following the mass law, until a minimum is reached around 10 Hz. Below that value the noise reduction increases because of stiffness effect." Later site another room where resonance was highest at 9 Hz, and attribute it to construction techniques.

- Rooms can exhibit large pressure gradients (standing waves) or rather uniform conditions (Helmholtz resonance), which can change based upon "room door positions"; "when rooms can be excited into resonance there will be large pressure gradients" and thus "people moving within the rooms and hallway may thus be exposed to large variations in sound pressure level for a constant low frequency external excitation" (although, the authors caution that turbines rarely produce a constant excitation).

- "Frequencies below about 20 Hz are more likely to be observed as a result of induced vibrations whereas the frequencies above 20 Hz will probably be observed aurally."

- Authors find that rattling of objects on a wall will increase annoyance, but does not change the threshold.

- Cite data that may explain why only some homes out of a large number near a wind farm (several hundred) perceived; while no direct correlation was found, "diffraction and refraction due to terrain and atmospheric effects (wind and temperature gradients) was believed to result in substantial focusing of the noise into certain limited areas."

- "People who are exposed to wind turbine noise inside buildings experience a much different acoustical environment than do those outside, and they may actually be more disturbed by the inside exposure."

- "A person may perceive low-frequency noise differently depending on whether he is inside or outside of a building."

Government sources

Ontario Ministry of the Environment – Ontario Regulation 359/09 & Noise Guidelines for Wind Farms

Setbacks
Column is calculated based on the number of wind turbines within a three kilometre radius from the noise receptor. A noise receptor is: "the centre of a building or structure that contains one or more dwellings", "a building used for an institutional purpose", the site of an approved construction of the above, a vacant lot at which a dwelling would reasonably be located and campsites or the like.

Item	Column 1	Column 2	Column 3
	Number of wind turbines calculated in accordance with subsection (2)	Sound power level of wind turbine (expressed in dBA)	Total distance from the centre of the base of the wind turbine to a noise receptor described in subsection 55 (2.1) (expressed in metres)
1.	1-5	102	550
		103 – 104	600
		105	850
		106 – 107	950
2.	6-10	102	650
		103 – 104	700
		105	1000
		106 – 107	1200
3.	11-25	102	750
		103 – 104	850
		105	1250
		106 – 107	1500

In addition, maximum sound levels, measured in dB(A) are also provided. Class 3 areas are rural, while Class 1 & 2 areas are urban. The measurements are taken at the point of reception.

Wind Speed (m/s) at 10 m height	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Wind Turbine Sound Level Limits Class 3 Area, dBA	40.0	40.0	40.0	43.0	45.0	49.0	51.0
Wind Turbine Sound Level Limits Class 1 & 2 Areas, dBA	45.0	45.0	45.0	45.0	45.0	49.0	51.0

Ramakrishnan R. (2007) Wind turbine facilities noise issues.

Overview
Report prepared for the Ontario Ministry of the Environment. A major portion is devoted to a critique of van den Berg's thesis (see b).

Background
Noise regulations (night time limits, dB(A)) around the world:
35 (adjusted higher with wind speed): Australia
35 to 36: Germany and Oregon
40: Alberta, British Columbia, Quebec, Denmark and the Netherlands
40 (adjusted higher with wind speed): UK, Ireland, Ontario and New Zealand
50 and higher: New York, Maine, Pennsylvania and Washington

Issues

- Critical about van den Berg's thesis in its use of substitute or extrapolated data, as well as various decisions made concerning formulas and techniques. Generally, the conclusions are not conclusively supported by the evidence.

- Van den Berg presents no evidence, other than anecdotal accounts, linking increased amplitude modulation with increased annoyance. He does not conduct a simultaneous annoyance/noise measurement study. Provides data from Ontario weather stations disputing van den Berg's ability to generalize from one weather station across all instances, although he does not argue that this doesn't mean van den Berg is correct (on this point).

- Again, he does not outright dispute van den Berg, only cautions his conclusions about night time wind speed increases.

- There is general agreement that standard assessment procedures (those based on standards) do not account for all possible sound influences.

- There is no evidence that modulation increases at night time, although it could be more audible at night time.

Industry sources

American Wind Energy Association – Siting Handbook

Overview
Impact analysis section from the AWEA siting handbook, which discusses numerous variables that ought to be considered in siting turbines.

Background

- “Visual and aesthetic impacts are among the most commonly expressed concerns about the development of wind energy projects.”

- Defines adverse visual impact as “an unwelcome visual intrusion that diminishes the visual quality of an existing landscape” and state that it is a “highly subjective” judgment, based on “the values, beliefs, and experiences of individual viewers.”
  a) Usually occurs due to “the introduction of visual contrast to the existing scene, based on differences in form, line, color, and/or texture.”

  b) Concerns often arise due to spacing, appearance or markings/lighting of/on turbines, “however, it is the simple size of the wind turbines that is the predominant source of visual contrast.”

- “Visual contrast with the existing landscape is often unavoidable because of the size and typical location of wind farms” but its impact should be mitigated as much as possible, while recognizing that “wind turbines cannot be adjusted to meet visual criteria alone” and that “visual issues are by necessity the last criteria by which turbines can be sited.”

  a) Mitigation suggestions: “employ turbine units (towers, nacelles, and rotors) that are uniform and balanced in shape, color, and size”; do not allow commercial markings; minimize lighting around turbines and synchronize all safety lighting; burry power collection cables; place all auxiliary buildings in less visible locations; plan carefully road construction; “maintain project facilities regularly during operation” (including auxiliary facilities).

  b) States that turbine sound occurs in pulses and is most noticeable at middle wind speeds (when the wind does less masking) and that there may also be mechanical tonal sounds.

- Without a reference state that “in some situations, those who are opposed to or not part of the wind project may be more annoyed by the same sound than those who are in favor of, or directly involved in the project.”

- “[S]ound impacts at most wind farm sites are anticipated to be minor.”

- Mitigation suggestions: “siting turbines beyond a minimum setback distance to all residential structures” (which may already be required); working carefully to minimize construction noise; limit the amount of vegetation cleared; adding screening; keep turbines maintained; notify residents in advance of construction noises; “pursuing development agreements with neighbors whose residence is located within a certain distance of a project turbine”; “implementing a complain resolution procedure.”

World Wind Energy Association – World Wind Energy Report 2010

Overview

This is the most recent report available at the time of writing from the World Wind Energy Association. These annual reports provide an overview of the global picture of wind energy production.

Background

- Global capacity at end of 2010: 196,630 MW or 430 TWh (~ energy requirements of Great Britain or 2.5% global consumption).
  New capacity (2010): 37,642 MW (18,928 MW of which were in China).
  Projected 2011 capacity: 240,000 MW
  Projected 2020 capacity: 1.5 million MW

- There are currently 5 countries (China, USA, Germany, Spain and India) with more than 10,000 MW installed capacity, up from 3 in 2007.

- There are currently 20 countries with more than 1000 MW installed capacity, up from 13 in 2007. There are currently 39 countries with more than 100 MW installed capacity, up from 30 in 2007.

- Canada is currently the 9th ranked country in terms of installed capacity, with 4,008 MW (4 GW) installed capacity. Canada added 690 MW in 2010 and will see a number of large installations come on line in 2011.

- WWEA blames "insufficient political support" for the global slowdown (outside of China). While statements of political support continue to grow, actual policy support does not. The USA in particular is singled out for "regulatory uncertainty."

HGC Engineering. (2006) Wind Turbines and Infrasound.

Overview

The authors indicate that the report was written for the Canadian Wind Energy Association to address issues relating to infrasound emissions from wind turbines and to clarify issues and misconceptions. Specific questions to address included: a) at what levels do infrasound pose an issue with respect to health or annoyance; b) do modern wind turbines produce infrasound and at what levels; and c) are there acoustic phenomena and characteristics associated with wind turbines that could be mistaken for infrasound, and do they present a hazard?

Background

- Infrasound is sound that is generally considered to be below the range of human hearing and is limited to frequencies below 20 Hz. Infrasound can be perceived under some circumstances such as with the non-auditory mechanisms of the vestibular balance system and the resonant excitation of body cavities by which humans can sense infrasound.

- Infrasound levels below 85-90 dBG are not sufficient to create human perception.

- Denmark – the environmental protection agency set 85 dBG as an infrasound guideline.

- The author cites studies prepared for NASA which indicate that no significant effects from infrasound occur until the levels exceed 125 dBL.

- **The authors indicate that measuring infrasound from wind turbines presents problems because the back ground wind itself contains infrasound.**

Results

- HGC completed a study of a wind farm near the Atlantic Ocean and reported that it was "inconclusive in separating the infrasonic sound due to wind turbines from the interference of wind and/or wave action in the Atlantic Ocean". The measured linear sound levels in the 5 – 35 Hz range were about 60 dB (from the 1.8 MW wind turbines). G-weighted measurements were: a) 79 dBG at 60 m, b) 81 dBG at 330 m, and c) 74 dBG at 700m.

- In another study in Poland of a farm with 15 wind turbines where sound measurements were taken at 100 m from the wind turbines, the maximum overall G-weighted level was 75 dBG.

- The authors report another study in Alberta that found that under high wind conditions the maximum infrasound level was 91 dBG measured at 50 metres compared to an ambient level of 83 dBG.

Conclusions

- Infrasonic levels created by wind turbines are often similar to the ambient levels prevalent in the natural environment due to wind, typically 85 dBG or lower.

- There is no evidence of adverse health effects caused by this infrasound.

- Infrasound near modern wind turbines is generally not perceptible to humans, either through auditory or non-auditory mechanisms.

- There is often an audible 'swoosh' created by wind turbines, which is essentially broadband noise whose amplitude is modulated at a low frequency, but this should not be mistakenly confused with infrasound.

- **"…, the discussion of whether or not infrasound poses a health risk at low levels is somewhat academic since, in the absence of wind turbines, comparable infrasonic levels are present in the natural environment."**

What do we know from government, industry and technical sources about wind turbines?

International Trends

The World Wind Energy Association reported global capacity (2010) to be 196,630 MW or roughly the consumption of Great Britain. Canada is the 9th ranked country in installed capacity at 4,008 MW, including the local Wolfe Island wind farm, the second largest in Canada.

Sound modeling

Sound modeling is used to predict wind turbine emissions based upon the following factors: sound pressure level generated at the hum, directivity, steradian factor, distance, atmospheric absorption, ground and meteorological absoption, vegetation absorption, buildings, and influence of the wind.

Concerns have been raised about the validity of sound models used by industry in proposals. For example, Tickell (2006) found that at 1,000m different model results varied by 9dB and suggested there must be internationally-conducted model validation in order to narrow the credibility gap between developers/regulators and communities.

International Noise Guidelines
A review indicated that international maximum noise guidelines for wind turbines at the receptor sites (e.g., residences) range from 35 dBA to 65 dBA depending upon settings and wind speeds. For most residential (and rural) settings the limits were 40-45 dBA with frequent allowable increases with increased wind speed. Examples are provide below:

Permissible Noise Levels in Europe (dBA) (day/night):

- Germany: Industrial (65/50) Mixed (60/50) Predominantly Residential (55/40) Only Residential (50/35) Rural (40/30)
- Netherlands: Mixed (50/40) Only Residential (45/35) Rural (/45)
- Denmark: Only Residential (/40)

Wind turbine noise levels at receptor site:

- Australia (35 dBA adjusted upwards per wind speed)
- Alberta, British Columbia, Quebec, Denmark, Netherlands (40 dBA)
- UK, Ireland, New Zealand (40 dBA adjusted higher for increased wind speed)
- New York, Maine, Pennsylvania, Washington (50 dbA and higher)
- Denmark – indoor recommended limit for infrasound is 85 dB(G)

Ontario Guidelines
Wind turbine sound guidelines are based on wind speeds and urban versus rural categories. Maximum sound levels range between 41 dBA to 51 dBA depending upon the wind speed and category.
Setback guidelines are based upon the number of wind turbines within a 3 km radius from the centre of the noise receptor (residence). The minimum setback is 555m for 1-5 turbines producing 102 dBA and increases incrementally to 1,500m with more powerful wind turbines or larger wind farms.

Wind Turbine Noise Emissions
At the hub, modern wind turbines emit between 102 and 107 dBA. The noticeable 'whooshing' sound comes from the blades is in the 1,000 Hz range and is not low frequency noise.

Hau (2006) reported that: i) background noise generated by wind (blowing around trees, grass and buildings) increases by about 2.5 dBA per 1 m/s increase in wind speed whereas noise emission from wind turbines increase by 1 dBA per 1 m/s wind increase; and ii) if the background noise level exceeds the calculated wind turbine noise level by 6dBA, the WT noise will no longer contribute to any perceptible increase.

There is some agreement on two items: the first is that it is very difficult to generalise results from one set of measurements to all areas, as there are so many factors affecting the sound produced by wind turbines in any given location. The other item is that wind turbines are not 'noisy' beyond a few hundred meters, in that they do not dramatically overpower background noise levels. They do not produce exceptionally high levels of infrasound, nor do they produce high levels of sound in our hearing range. They do however produce sound with a unique character (modulated), often described as whooshing. This whooshing sound is not, however, in the low frequency or infrasonic range.

Infrasound/Low Frequency Sound – Infrasound (<20 Hz) and Low Frequency Noise (< 250 Hz)
These naturally exist and increase with increasing wind speed. A general characteristics of low frequency sound is that it does not decrease in power over distance to the same extent that high frequency sound does and that it can be experienced indoors (and by room) differently than it is outdoors.

Wind turbines also emit infrasound and low frequency sounds; however, measuring contributions from wind turbines presents problems because the background wind always contains infrasound/low frequency noises.

G-weighted measurements from one study conducted at a wind farm near the Atlantic Ocean reported sound levels (5-35 Hz) between 74 – 81 dBG (measured at 60 – 700 m) and concluded the contributions from the waves and the wind turbines could not be differentiated.

In an Alberta study of a 60 turbine wind farm, Hepburn (2006) found that under different wind speeds, wind turbines can add to or take away low frequency nosise/infrasound. For example, under high wind conditions the levels were 91 dBG at 50 metres but the normal (ambient) conditions with the wind turbines turned off were 83 dBA under the same wind speed. This study also found under different conditions wind turbines can add or take away low frequency noise/infrasound.

- The Hepburn results indicated that the wind turbines added about 24 decibels (unweighted) of infrasound under low wind conditions and about 9.5 decibels under medium wind conditions. However, the wind turbines decrease infrasound by about 7 decibels under high wind conditions.

- **Infrasound -** Under all wind speed conditions infrasound ranged from **55-75 dBL** (at 50 M) with the Wind Turbine **ON** and ***37 – 82 dBL*** with the Wind Turbines ***OFF***.

- **Low frequency noise** (25-200 Hz)- Under all wind speed conditions low frequency noise ranged from **31-67 dBL** (at 50 M) with the Wind Turbine **ON** and 28 ***– 75 dBL*** with the Wind Turbines **OFF**.

- The main conclusions from these studies is that under medium and high wind conditions, infrasound and low frequency noises are naturally present and that the wind turbines contribute little and sometimes nothing to ambient levels.

Technical Info

Modern wind turbines are visually intrusive. The bigger ones can be 80 m or higher to the hub, with rotor diameters of 90 m or more. They spin at variable speeds, usually around 5 – 20 rpm and have sophisticated breaking mechanisms for high winds. They are technologically sophisticated and contain sensors that will detect light conditions and shut the turbines down during periods of increased likelihood of shadow flicker and ice throw.

While modeling is used to predict wind turbine sound emissions, there is no agreement on the correct model or even decibel weighting.

Implications/Suggestions

There is clear need for further studies to be conducted that measure ambient noise levels in a location prior to any wind turbine development occurring and then comparing that to levels measured post development.

There is also a clear need for further studies to be conducted that measure sound levels both inside and outside dwellings near wind turbines. Such studies could both contribute to possibly being able to factor in inside sound levels to future sitting planning, as well as to learn conclusively what materials work and which do not to moderate sound levels.

Nothing conclusively can be said about ‘correct’ setbacks based on the existing evidence, although nothing here would suggest that the current Ontario guidelines are not sufficient.

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4) Community –Based Organizations, Advocacy groups and News Media

This category was created to group together those entities writing about wind turbines that were not generating producing new reports, but were rather commenting on or retransmitting Category 1 and 2 information. This includes community and advocacy groups, more often than not found on the Internet, as well as all forms of news media, although again our focus was on the Internet (print-based media was consulted on a local basis). There is no original research here, beyond reporting of anecdotal accounts and a strong reliance on adverse-reporting Category 2 material/authors as the evidential base. Our intention here was not to be exhaustive in our collection of these articles, there are quite literally hundreds of thousands of them, but rather to give a representative sample of what someone searching the internet was likely to come across. Thus preference was given to those articles or organizations appearing high on Google searches, as well as to those news articles and other sources relied upon by already identified Category 4 sources. We wanted to provide a fair account of the myriad groups and websites and thus chose the most prominent (and/or locally important) sources, while also taking into account the extremely repetitive nature of the source material. The news articles were chosen from indexes compiled by several blogs and from the references of other materials. While a great many were consulted, the articles reported on below were chosen to provide an overview of the global nature of the debate, and that featured prominent critical voices or references to known figures from the Category 2 literature.

Results will be reported in two categories:

1) articles, opinion pieces, advertising or other commentary by community or advocacy groups, and
2) news media.

1 – Articles, Opinion Pieces, Advertising, Commentary by Community or Advocacy Groups

Out of Kirby Mountain. (May 8, 2009). *Wind Turbine Syndrome.*

Overview

Provides a summary of what is known about wind turbine syndrome so far, as well as further reference material.

Issues

- Defines wind turbine syndrome by paraphrasing Pierpont: "essentially low-frequency noise or vibration tricking the body's balance system into thinking it's moving" and distinguishes this from vibroacoustic disease. Cites Pierpont on the causes being low frequency noise, vibration, shadow flicker, and the risk groups being people with migraine disorder, balance and motion sensitivity.

- Provides, via Pierpont, a list of symptoms: sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, panic episodes.

- Claims there is "direct experimental evidence" of "normal" human sensitivity to noise and vibration lower than our perception threshold that Pierpont cites as the cause of wind turbine syndrome.

- Claims vibroacoustic disease has a different cause than WTS and that Pierpont's "research protocol" cannot demonstrate whether "wind turbine exposure" can cause VAD; "although there are similarities that may be worthy of further clinical investigation, especially regarding asthma and lower respiratory infections."

- References a CanWEA article that mentions references to the special issue of Canadian Acoustics referenced in Categories 1 and 3. Is critical of CanWEA's article, and references like this because of "the fact they are not medical articles" and because of another Category 4 reference (see Gulden W below).

- Cites the French Academy of Medicine's recommendations of 1.5 km setbacks (see Out of Kirby Mountain below). In addition, Harry, Nissenbaum, McMurtry, Alves-Pereira, Kamperman and the Noise Association are all cited (see Category 2).

Martin CL, Pierpont N. (October 18, 2008). *Read peer reviews.*

Overview

Reports Pierpont's views on the peer review process, as well as what other scientists, doctors and her own peer-reviewers are saying about her book and about wind turbines and health more generally. [Note: posted prior to publication of book, so the original page is now only available via archive retrieval. The content was carried over into the book.]

Issues

- Provides a rough overview of the peer-review process, as well as stating that Wind Turbine Syndrome (her book) is peer-reviewed. Provides no account of how her reviewers were chosen, although does comment that reviewers can either be recommended by the author or chosen by the publisher, which in this case is her husband.

- All four reviewers of her book she cites found the book worthy of publication and the issue important. All also praise her research methods.

- Also cites Dr. McMurtry (see below), Dr. Christopher Hanning, Prof. Lord Robert May and Dr. Owen Black (see KATU-TV).

Gulden, W. (April 24, 2009). An Assessment of CANWEA's Research on Health Issues with Wind Turbines

Overview

Provides a critique of a series of documents referenced by CanWEA in support of their claims that there are no negative health impacts of wind turbines.

Background

- Characterizes the wind turbine and health issue as being composed of two groups: "doctors" who would like "an epidemiological study to scientifically establish what the heath affects of wind turbine noise might be" and "the wind energy community," which he labels CanWEA, who say that research already says there is no health affect.

- Characterizes the CanWEA side as being about making money and characterizes the research they cite as having little to do with health impacts of wind turbines.

Issues

- The most common criticisms are that authors are not health care professionals and that they ignore the work of Pierpont, Harry, Frey & Haddon, the French Academy of Medicine and the vibroacoustic disease team.

- Is also quick to point out that the research often stipulates that guidelines must be adhered to and that there are some poor (or completely irrelevant) documents cited by CanWEA.

- The only document cited by CanWEA not cited in this report is Markandya & Wilkinson on the health impact of renewable energy because, on review, it does in fact not cover the health impact of wind turbines as noted by Gulden.

Out of Kirby Mountain. (March 2006). *French Academy of Medicine warns of wind turbine noise.*

Overview
Provides a translation of a notice of a report by the French National Academy of Medicine about the health impact of wind turbines. A copy of the original report (in French) is also provided.

Issues

- Wind turbines will have to comply with the regulations of industrial installations.
- "People living near the towers...sometimes complain of functional disturbances similar to those observed in syndromes of chronic sound trauma." Note that no study, unlike those done near airports, has validated said complaints.
- Note that because of the low frequency sound emitted by wind turbines, "they constitute a permanent risk for the people exposed to them."
- "While waiting for precise studies of the risks...the Academy recommend halting wind turbine construction closer than 1.5 km from residences."

[*Note: the complete study is found in Category 2 above. The actual recommendation is for those setbacks for turbines of 2.5 MW or higher. The Wolfe Island turbines are each 2.3 MW.*]

McMurtry, R. (February 3, 2009). Commentary on Chatham-Kent Public Health Unit Literature Review and (December 15, 2008). Industrial Wind Turbines – safe or sound?

Overview
Summarizes the adverse Category 2 reports and criticizes government, industry and academic responses.

Issues

- Criticizes the Chatham-Kent report for not mentioning Pierpont, Harry or the VAD research, and for being overly reliant on industry sources. Is critical of the treatment of the Frey & Haddon report. Is critical of the use of the Leventhall paper.
- Criticizes not citing the French Academy recommendation of a well-designed study or their set back recommendation (correctly cited for 2.5 MW or higher).
- "Another simpler option is a survey of people living near existing wind turbine installations."
- "A minimum of uncertainty exists. When that is the case it is an obligation of public health authorities to address the issue."
- Is critical of there being no national regulations on wind turbines and for the Ontario guidelines not taking into account low frequency noise, which is cited by "experts and the World Health Organization" as being important to measure for. Those experts are Styles, et al., and Kamperman and James.
- Is clear that there has been no "systematic epidemiological field study" of the issue and that "there is an absence of evidence. Conversely no evidence of an absence of adverse health effects exists either."

<u>County Sustainability Group. (ND). Ontario's Green Energy Act and Comment on the nature of the NIMBYist position.</u>

<u>Overview</u>
Commentary written against the NIMBY position in the Prince Edward County wind turbine debate. It works through the common arguments of the opponents to wind turbines and then works to debunk their claims.

<u>Background</u>

- Credit the critics of wind farms with (perhaps) being the reason behind the Ontario government itself establishing regulations and setbacks for wind turbines in Ontario. Note that this is probably better than letting each country go it alone.

- Provide an account of what they see as the four extreme positions of the wind energy debate: two NIMBY positions and two pro-wind positions. Each relates to the Gaia hypothesis in some way. All of this involves the broader picture of the current state of the global environment.

- Pose this as an issue between short term interests (NIMBY) and long term survival strategies – harnessing wind energy in a wind and population rich region. Claim that the NIMBYists use 'trickery' to get their way.

- Point out that wind turbines (in Prince Edward Country and elsewhere) would be/ are part of an alternative energy network. This is made in strong 'do our part' language.

- Address a number of non-health related issues raised by NIMBY groups and provide counter-arguments or qualifications on them.

- Cite the Chatham-Kent report, news article interviewing members of the Canadian Association of Physicians for the Environment, the study from University of Gothenburg, reporting on studies out of the UK that indicated few complaints about wind turbines.

<u>Category 2</u>

<u>Neighbors at odds over noise from wind turbines. USA Today. November 4, 2008.</u>

- AWEA: almost 15,000 turbines in US; no national regulations; setbacks are locally determined

- Meyer Family (Brownsville, Wis.): headaches, insomnia, "fluttering in … chest," nausea, "hears crackling" – attribute to noise; "not long after" start; situated ~475m from house; quotes neighbors who have no problems with noise. Larry Wunch (same farm): 335m; lost sleep, irritated.

- Cites Pierpont, Harry and Alves-Pereira. Also Cites a 2008 EU study which says sounds may annoy, but will not affect health, except for sleep disruptions.

- References a Texas court case (eventually appealed to Eleventh Court of Appeals, Texas) in which a jury found against the complaining residents, in favour of company (2006 – Appeal decision in 2008). Note that the conflicting expert testimony on decibel regulations was rejected by the court on a technicality. Rick James (acoustical engineer; Okemos, Mich.): suggests ~ 2 km setbacks (1.25 miles).

- National Wind Watch (‘information clearinghouse’): recommends ~1.6 km setbacks (1 miles).

- Pierpont: “proper setbacks are the best cure”.

- Symptoms reported: hearing problems, sleep disturbances, insomnia, chest flutters, headaches, nausea

Something in the wind as mystery illnesses rise. Asahi. February 6, 2009.

- There will be 1,409 turbines by the end of 2007. There are no national regulations.

- Tsuyoshi Okawa (and family; Tahara, Japan): farm starting 350 meters from house; ill “soon after” turbines started; “lose feeling in parts of their bodies,” dizzy and insomnia; leave property – symptoms disappear, return – symptoms begin again; house assessed by “a group of acoustics experts” – found that there were low frequency sound vibrations but that they were not adversely affecting health.

- More than 70 people across Japan have reported ill health living near turbines – “wind turbine diseases.”

- Izumi Ushiyama (engineering professor in Ashikaga): adverse health more common in densely populated Japan; “turbines … dominate the landscape, obstructing views and making local residents feel boxed in”; companies should engage with local residents early in planning process; government should develop comprehensive response.

- Symptoms: dizziness, insomnia, loss of feeling in parts of body

Wind turbines causing health problems, some Ont. residents say. CBC. April 14, 2009.

- Barbara Ashbee and Denis Lormand (Shelburne, Ontario): 450 meters; were not initially opposed; noise began immediately; sleep and work disturbances, “even lose desire to do the normal, everyday things”; ringing in ears; low vibrations (not constant); now moving.

- Carmen Krogh: retired Alberta pharmacist; conducted WindConcernsOntario survey; “once fell ill while vacationing near a wind turbine complex in 2005. Initially the turbines weren’t moving, but once the wind picked up the blades started turning. Within 10 minutes she began to experience vibrations through her body, an intense headache, queasiness, dizziness and heart rhythm irregularities”

- About the survey: “she is currently distributing questionnaires in areas with wind turbines, asking residents to describe whether they have experienced any effects from turbines, and if so, what those might be. ‘We need some kind of vigilance program so people can report their adverse effects.’”

- Note the above is about the McMurtry survey.

- Michael A. Nissenbaum: sleep disturbances, headaches, dizziness, weight changes, possible increases in blood pressure, increased prescription medication use; 15 people lived near wind farm in Mars Hill, Maine

- Nina Pierpont cited

- Geoff Leventhall: noise consultant says that LFN is below our hearing limit; believes they are not having any effect on us; no different from other noises (nothing special)

- Sean Whittaker, VP Policy, CanWEA: no peer-reviewed literature.

- Symptoms: dizziness, tinnitus/ringing in ears, increased blood pressure, sleep disturbances, work disturbances, loss of motivation, body vibrations/pulsations, heart beat irregularities, headaches, nausea, weight changes

Reports of wind farm health problems growing. CTV News. April 22, 2009.

- Survey conducted by Carmen Krogh (‘retired Alberta pharmacist’) with Dr. Robert McMurtry (‘retired orthopedic surgeon’ ‘assistant deputy minister of the Population and Public Health branch of Health Canada’).

- Krogh and ‘a group of volunteers’ distributed the questionnaires ‘in areas near wind farms’ asking whether or not they have experience adverse health effects.

- 53/76 respondents to the ‘informal survey’ had at least one health complaint: headaches, heart palpitations, hearing problems, stress, anxiety, depression; one admitted to hospital with “acute hypertensive episode” and another had “atrial fibrillation”.

- Survey: most complaints within a kilometer, further away less likely to experience health problems.

- Not sure of causes. “Some suspect that the constant, low frequency noise and vibration from the rotating blades may be what cause the problems”.

- McMurtry claims there is an absence of evidence.

- Sean Whittaker: no evidence of any impact, cites study that says approval higher the closer you get.

- Barbara Ashbee & Denis Lormand (Shelburne): in ‘shadow of’ 11 turbines; initially liked idea of turbines; immediately sleep was disturbed; both noise level and vibration; cognitive functioning impaired and tinnitus.

- Symptoms: anxiety, stress, irritation, hearing problems, tinnitus/ringing in the ears, acute hypertensive episodes, sleep disturbances, cognitive impairment, heart beat irregularities, heart palpitations, headaches, depression

Noise protesters howling about windfarms. Toronto Star. May 11, 2009.

- Ontario insists there is no health effects of noise or electromagnetic fields associated with wind turbines.
- Sandy MacLeod (Huron-Kinross): 800m; sleep, headaches, heart palpitations; noise (uses ear plugs, headphones).
- “Others” (Wind Concerns Ontario): nausea, ringing ears, high blood pressure, heightened anxiety, depression.
- McMurtry: cites ‘his’ survey (53/76 had health complaints), average setback 780m. The article refers to his survey as unscientific.
- Refer to a famous case reported in a French paper that discusses a family who complained of health effect of cell phone towers near house – they were never turned on.
- Cites: Dutch survey with 92% health satisfaction.
- Dr. James Rubin (Institute of Psychiatry, King’s College, London): nocebo (reverse placebo researcher); says there appears to be similarities between symptoms attributed to wind turbines and phone towers.
- Essex County survey (March 2009): of 301 residents, 87% support windfarm development plans.
- Ontario: current Ministry recommended setback is 400m; Smitherman (minister) thinks 500m is reasonable. McMurtry: 1.5 – 2 km setback.
- Symptoms: anxiety, tinnitus/ringing in ears, increased blood pressure, sleep disturbances, heart palpitations, headaches, nausea, depression

Wind farms: Is there a hidden health hazard? KATU-TV Portland. November 14/21, 2008.

- Sherry and Mike Eaton (Morrow County, Ore.): seek the peace of their country residence; dislike the look of the turbines; extreme fear for Mike’s health now that turbines are being constructed (motor disorder (vertigo), artillery in Vietnam) because certain sounds trigger symptoms; concern arises from Pierpont’s book; within 800 meters of home.
- Dr. Black: thinks the cases documented warrant investigation given the potential hazards; does not attribute cause to wind turbines (“what the cause is, I have no idea”); says that research in the area is difficult, because there are few real experts; wind turbine syndrome would need a “comprehensive and very expensive study” to be proven.
- Pierpont is cited as a 1 ¼ mile setback.
- Symptoms: panic episodes, dizziness, vertigo, sleep disturbances, body vibrations/pulsations, headaches, nausea

Oregon wind farms whip up noise, health concerns. The Oregonian. March 26, 2009.

- Oregon: 1,000 MWe, ~300,000 homes; 2,000 MWe are in the works; would give state 2,000 turbines; each country must enforce its own noise complaints.
- Dan Williams (Morrow County, Ore.): 'not healthy for us', sounds like a freight train; disbelieves wind energy claims of noise levels; can see from home (within a half-mile); thinks setbacks were done improperly.
- Pierpont: 'not rare, but it doesn't affect everybody'; 'wind turbine syndrome will likely become an industrial plague'.
- Mike Eaton: (see immediately above news) has measured 67 dB on hand-held meter "beside his home"; claims 'I can hear windmills at my house from Arlington, 12 miles away'; experiencing nausea; noise and vibrations are the cause.
- Invenergy: doesn't think there is substance to resident complaints, but has hired a company to do sound testing anyways; suspects "sour grapes" (Mike Logsdon) due to payments for property use.
- Pierpont is cited as a 2 mile setback.
- Symptoms: nausea

Feel the noise: Yvonne Sheehan believes a turbine near her Rockchapel, Co. Cork, home affects her health while local farmers have joined the wind rush. The Daily Mail. December 8, 2007.

- Ireland: 700 MWe or ~450,000 homes; 6-7% total energy; figure to "double" by 2012; government target is 33% by 2020.
- Noise: "some assessments" measure 35 dB @ 400m, 45 dB @ 20m and 55 dB @ turbine.
- Yvonne Sheehan (Rockchapel): cites noise pollution of low frequency noise over three years; lives 1.5km from nearest of 11 turbines; headaches, dizziness, earaches, tiredness, vertigo, has been put on anti-depressants; husband and neighbours not as affected (one John Buckley, who is payed 60,000 pounds a year to run them on property); thinks she may have acquired VAD "a virtually unheard-of condition caused by constant exposure to sound and vibrations from wind turbines"; turbines did interfere with TV and radio signals (company provided a Satellite box).
- Reporter: visited Sheehan's house – "it is possible to hear a very faint hum from the living room and only when we are absolutely silent" and they don't know if that is from weather, stream or turbine; with the windows open, they can hear it – "it is a natural sound, not an unpleasant one, like gusts of wind by the sea on a stormy day".
- Symptoms: dizziness, vertigo, earaches, tiredness

Winds of change. The Whig Standard. May 20, 2009.

- Wolfe Island: 86 turbines to be started by end of June, 2009; almost 600,000 MWe; developer Canadian Hydro Developers (Calgary, Mike Jablonicky project manager).

- Turbines: 125m tall; top speed of 16 rpm.

- Reporter: sound audible next to turbines, inaudible above wind noise across a field

- Mike Jablonicky: claims they are inaudible; claims they produce no vibrations (measures by placing hand on one of them).

- Neal Michelutti (Research Associate, Queen's University, noted as being a Wolfe Island resident): conducting survey of health effects; pre-activation survey had 150 responses; first survey to establish a baseline (to their knowledge); says that any reported illness could be "imagined, or psychosomatic, particularly among opponents".

- Article cites "health surveys" from Europe and the U.S. that "have registered a number of medical disorders they blame on the machines – sleeplessness, depression, anxiety and even tinitis".

- Tom Dixon: can see several turbines on his father-in-law's land; doesn't think there is a health risk; thinks they look better turning than still.

- Symptoms: anxiety, tinnitus/ringing in ears, insomnia, depression

Family to measure wind farm 'misery'. The Dominion Post (New Zealand). July 7, 2008.

- Wendy Brock (Ashhurst): noise and low-frequency sound; have complained since 2004; sleep disturbances; wooden-floored home 2.5 km from nearest turbine (55 in total); "throbbing beat in the ears, chest or spine".

- Company: sent recorder and microphone to family; family claim will not record low-frequency sound; application promised minor noise only; independent report commissioned all noise "was within national standards".

- Robyn Phipps: noise disturbed individuals more than 10km from the turbines; "national noise standards did not measure infrasound or take into account atmospheric effects, cumulative noise or the nature of wind turbine noise".

- Symptoms: body vibrations/pulsations

Turbine project humming. The Dominion Post (New Zealand). April 29, 2009.

- West Wind (near Wellington): 62 turbines (14 operational), 143 MWe, ~ 70,000 homes, or 1.5% of national need.

- Deb Compton (Makara): turbines produce humming noise, audible above weather; can see four from her home; expected noise going in under some conditions, but now thinks noise is far above that; member of community liaison group and filler of 2 of 3 noise complaints against company.

- Environment Court of New Zealand: imposed conditions in W031/2007 decision that noise from turbines measured at homes should not exceed 40 dB.

Summary and Conclusions– CBOs, Advocacy Groups and News Media

Summary

Below is a list of symptoms reported by news sources, CBOs and advocacy groups as being attributed to wind turbine exposure. Some or all of these symptoms are reported in the large number of websites and documents available on the internet and in many news articles. Some of these symptoms are include in the broad descriptions of wind turbine syndrome and/or vibroacoustic disease, and may have been reported that way.

Anxiety	Stress	Irritation
Panic episodes	Dizziness	Vertigo
Nausea	Hearing problems	Tinnitus/Ringing in ears
Earaches	Headaches	Acute hypertensive episode'
Increased blood pressure	Sleep disturbances	Insomnia
Tiredness	Work disturbances	Loss of motivation
Body vibrations/pulsations	Chest flutters	Heart beat irregularities
Heart palpitations	Loss of feeling in body parts	Weight changes
Depression	Cognitive Impairment	

Conclusions

- **Reason for Concern**
  a) We know that for many people the internet is often the first and frequently the main source of health information. Given this and based upon the above information, one can clearly understand why the average person consulting the Internet or reading the newspaper could become very worried. There are a number of high profile blogs across the world dedicated to propagating information about the negative health impacts of wind turbines.

  b) The most notable features of the non-news documents from this category are the extreme skepticism towards the government (and industry) and the belief that only medical doctors or other health professionals (reinforced by some of the Category 2 literature) are qualified to do research on the health impact of wind turbines. There is a total discounting of seemingly relevant information, such as quantitative qualifications of wind turbine sound output (see Category 3).

  c) The most notable feature of the news documents is the effect of pursuing a 'balanced' approach (both critics and proponents being interviewed), which allows for a number of unqualified statements regarding wind turbines being 'an industrial plague' (quoting Pierpont). An uncritical reader will be presented with a number of horror stories that have been carefully crafted into sound bites.

- **The Internet and the Lack of Critical Appraisal**
  a) The internet has been described as **"information without knowledge"** and the amount of information (web pages) is vast. For example, we previously indicated that a simple internet search using the terms wind turbines and health will return close to 2 million results and a search using the term 'wind turbine syndrome' will provide close to 60,000 results.

  b) **The problem with the web documents and frequent news articles is their extensive use of the results and conclusions from the few but widely reported case studies in the absence of any critical appraisal of the methods used and the validity of conclusions reached based upon the methods.** (Note: there is a reason why scientific journals use peer review to evaluate methods and conclusions and why the results of a case study would not be published as demonstrating proof of a causal relationship.)

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5) Research – Noise and Health in other settings

In the September 2005 Health Canada document ‘Community Noise Annoyance’, Health Canada indicates that that there is concern about excessive community noise because people can find it highly annoying and that over a period of time, high annoyance can affect quality of life. The document indicates that the most common effect of community noise is annoyance and that the World Health Organization considers noise annoyance to be an adverse health effect. Health Canada also indicates that noise starts to make people highly annoyed when the sound level outside the home is around 55 dBA and compares this to sound at the side of a major highway 80 – 90 dBA.

In the context of wind turbines, most of the focus regarding possible adverse health effects has been directed at the noise emissions. Those who have concluded that wind turbines cause ill health argue one or both of the following: a) exposure to the noise emitted directly causes adverse health effects (e.g., symptoms, illness or disease); and b) noise from the wind turbines causes annoyance which then causes sleep problems and stress and then leads to adverse health effects. Our purpose in adding this section was to provide information from peer reviewed noise and health research that will help contextualize the issues and themes (e.g., evidence and non-evidence based conclusions) that emerged in our reviews of different wind turbine documents. Time and human resources constraints would not allow for an exhaustive review of the current noise and health evidence base and this was not our intent. Our main goal was to provide an overview of some of the known health effects of noise exposure and also to identify the risk thresholds (noise levels in decibels) for different adverse health effects.

Residential Noise Exposure From Wind Turbines

One of the main tenets of causality described by Hill (1965) is the ‘Biological Gradient’ or the ‘Dose-Response’ which in this case would argue that if noise causes ill health that more exposure to noise (i.e., more powerful noise at higher levels measured in decibels) would result in more illness. For example, we know that the death rate from lung cancer rises linearly with the amount of daily smoking. Following this relationship, if noise from wind turbines or other sources causes ill health, one would expect those exposed to more noise (i.e., higher dB levels) should experience more ill health compared to those exposed to lower levels and the unexposed.

In addition, it would help to contextualize the wind turbine concerns by comparing international wind farm exposure guidelines to the evidence in other non-wind farm settings. We recognize that noise emissions from different wind farms can have different characteristics (combinations of low and high frequencies) compared to other settings and that this limits generalization. However, it still helps provide information that will help compare known risks in other settings to likely risk from wind farms.

Keith et al. (2008), presented the following international guidelines for exposure to wind turbine noise:

Australia	35-43 dBA	(Depends upon normal background level)
Denmark	40 dBA	(8 m/s)
UK	45 - 54 dBA	(Night time at 8 m/s – 12 m/s wind speeds)
Ontario	40-53 dBA	(6 m/s – 11 m/s wind speeds)
Alberta	40 dBA	(6-9 m/s)
British Columbia	40 dBA	(residence or residentially zoned)

In addition, the large sample study conducted by van den Berg et al., (2008) stratified their exposure categories according to the following groups: a) 30 dBA, b) 30-35 dBA, c) 35-40 dBA, d) 40-45 dBA, and e) > 45 dBA. Pedersen and Waye (2007) also used very similar groupings.

The guidelines illustrated above combined with the exposure categories used in the two large sample research studies should help provide a reasonable example of A-weighted exposure levels at residences close to wind farms. This does not mean that the upper range for exposure never exceeds 40-54 dBA. However, it does help when comparing exposure levels from other sources.

Passchier-Vermeer W & Passchier W. (2000) Noise Exposure and Public Health.

Overview

The authors conducted a narrative review of the literature on noise and health.

Background Information

1. The human ear is not equally sensitive to sounds of different frequencies. Thus, a spectral sensitivity factor is used that rates SPL (sound levels) at different frequencies in a way comparable to that of the human hearing organ. This is called A -weighting expressed in decibels [dB(A)]

2. **Common Environmental SPLs (dBA)**: a) falling leaves = 10-20 dBA, b) vacuum cleaner = 55-65 dBA, c) near busy road/highway=70-80 dBA, d) rock concert=100-110 dBA,

3. Most urban populations in the industrialized world are exposed to Ldn of >50dBA. It is estimated that 2-8% of the population in Europe is exposed to >60dBA.

4. **Annoyance:** The same noise can be both a positive experience and negative depending on context. Example: a) a person in a disco will perceive the load music as pleasurable whereas the neighbours may be annoyed by it. b) A city dweller may find it easy to sleep hearing traffic nearby but find the crickets in the country disturb his sleep.

Results/Health Impact

The authors cited the International Committee on Noise and Health (Netherlands) that assessed the health effects of environmental and occupational noise exposure and rated the evidence as sufficient or (limited, inadequate, or lacking) for observation thresholds for those adverse health effects. An observation threshold was defined as the lowest noise value at which on average the effect was observed in well-designed epidemiologic studies.
The Committee Report indicated that there was sufficient evidence that the following health effects occurred at the corresponding exposure levels:

a)	hearing impairment	70-85 dBA
b)	hypertension	70-85 dBA
c)	ischemic heart disease	70 dB A
d)	annoyance (office)	55 dBA (outdoors = 42dBA)
e)	performance	70 dBA
f)	changes in sleep pattern	<60 dBA
g)	awakening	55 dBA.
h)	sleep stages	35 dBA
i)	subjective sleep quality	40 dBA
j)	heart rate	40 dBA
k)	mood next day	<60dBA

The Committee Report indicated that the evidence was insufficient (i.e., limited, inadequate or lacking) regarding a causal path between noise and the following health effects:

a. psychiatric disorders
b. biochemical effects
c. immune effects
d. birth weight
e. congenital effects,

Annoyance

a) The main psychosocial effect of exposure to industrial noise is annoyance and can include: resentment, displeasure, discomfort, dissatisfaction or offense when it interferes with ones thoughts, feelings or activities. The authors indicate that people become annoyed differently for different noise sources.

b) The degree of annoyance is affected by intensity (dB) and by (non-acoustical modifying factors): anxiety, fear of the noise source, feelings that the noise could be avoided.

c) 35-40% of office workers become annoyed with SPLs reach 55-60 dBA.

d) N**oise is a stressor and reactions to stressors can be psychologic (fear, depression, sorrow), behavioral (isolation, aggression), or somatic (CV, GI, respiratory illnesses)**

Cognitive Impairment - School children exposed to high levels of traffic noise show impairment in performing cognitive tasks. (The observational threshold derived from the data was 70dBA.)

Hypertension in different environments

a) The authors report that an analysis of 12 studies indicates that the risk of noise induced hypertension in occupational noise exposed workers (i.e., blue collar) is 85 dBA ($L_{Aeq.8h}$). The authors also suggested that because people working in offices are more likely to become annoyed by lower noise levels that the risk of noise induced hypertension was lower for office workers. Thus (without providing supporting data) the authors hypothesize that the risk for office workers would be 55 dBA (or 30 dBA lower).

b) Increased systolic and diastolic blood pressures have been observed in children exposed to high levels of road traffic noise (>60 dBA)

Conclusions and Suggestions

1) Assessing the health effects of noise exposure is more complicated than simply looking at harm (with the exception of hearing damage). This is because the people's response is strongly associated with the context of the exposure.

2) Research into the chronic effects of long-term noise is complicated because it is difficult to control for many factors. The authors site an example where people self select by moving away from noisy jobs/places thus leaving a sub-population that is less sensitive than the general population. The author described this hypothetical population as 'noise proof'.

3) There is a need for a tested model on sleep disturbance, environmental noise exposure, and secondary effects, in which causal and modifying factors and their mutual relations are assessed.

4) The Health Council Committee agreed that adjustment factors should be applied to account for differences in tonal and impulse characteristics of noise.

Berglund B, Lindvall T. (1995) Community Noise.

Overview

This document was prepared for the World Health Organization. It critically reviews the adverse effects of community noise, including interference with communication, noise-induced hearing loss, annoyance responses, and effects on sleep, the cardiovascular and psychophysiological systems, performance, productivity, and social behaviour. The scope of this document is to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise. [*Note – this document is over 160 pages. Our intention is to provide information relevant to the debate about exposure from wind turbines.*]

Background Information

1) Almost 25 % of the European population is exposed, in one way or another, to transportation noise over 65 dBA (an average energy equivalent to continuous A-weighted sound pressure level over 24 hours)

2) In a study of four European countries (France, Germany, Great Britain and the Netherlands) road traffic noise is annoying to 20-25 % of the population and railway noise to 2-4 %.

3) Community noise may have a number of direct adverse effects other than hearing damage. These include adverse effects on communication, performance, and behavior; nonauditory physiological effects; noise-induced disturbance of sleep; and community annoyance. The effects depend not only on the sound pressure levels but also on the "type" or "quality" of the noise, on the number of noise events, and on the "image" of the noise.

4) Equivalent continuous sound pressure level (SPL) is gaining widespread acceptance as a scale for the measurement of long-term noise exposure.

5) **Typical sound pressure levels** range from about 20 dB LAeq in a very quiet rural area to between 50 and 70 dB LAeq in towns during the day time, to 90 dB LAeq or more in noisy factories and discotheques to well over 120 dB LAmax near to a jet aircraft at take-off. Relaxed conversation occurs at a voice level of approximately 54-56 dBA and normal and raised voices at levels of approximately 60 and 66 dBA

6) In the EU countries about 40 % of the population are exposed to road traffic noise with an LAeq,T exceeding 55 dB daytime and 20 % are exposed to levels exceeding 65 dB.

Technical Information

Sound is defined as acoustic energy. (Humans hear 20-20,000 Hz) Infrasound is sound in frequencies below 16-20 Hz.

Low frequency noise is common as background noise in urban environments and as an emission from many artificial sources: road vehicles, aircraft, industrial machinery, artillery and mining explosions, and air movement machinery including wind turbines, compressors, and indoor ventilation and air conditioning units.

Adding sounds (dBs) is not 100% cumulative – Adding two sound sources of 80dB will result in a new SPL of 83dB (it is not 160 i.e., 80 +80)

A-weighting

a) The A weighting curve is used to weight sound pressure levels as a function of frequency, approximately in accordance with the frequency response characteristics of the human auditory system for pure tones. That is, energy at low and high frequencies is de-emphasized in relation to energy in the mid-frequency range.

b) If sounds with different spectral envelopes are compared (e.g., various community noises), the **dBA-value obtained may be an inaccurate indicator of human subjective response**.

c) Laboratory and field evidence indicates that A-weighting predicts loudness and annoyance of community noise rather poorly. A-weighted sound pressure level underestimates the impact of the low-frequency components of noise. It is strongly dependent on the exposure pattern with time.

d) A-weighted sound pressure levels do not consider the effects of mutual masking among the components in a complex sound nor the asymmetry of masking patterns produced in the auditory system.

Equivalent Continuous Sound Pressure Level -To measure an average sound pressure level the meter averaging time is extended to equal the period of interest, T, which may be an interval in seconds, minutes, or hours. This gives a dB-value in Leq which stands for equivalent continuous sound pressure level; {dB LAeq,T] Thus, Leq is the level of that steady sound which, over the same interval of time as the fluctuating sound of interest, has the same mean square sound pressure, usually applied as an A-frequency weighting. The interval of time must be stated.

Distribution Analysis - A widely used method of recording the variations in sound pressure level is that of level distribution analysis: a graph of the % of the total time for which any given sound pressure level is exceeded; for example, L10, L50, and L90, the levels exceeded for 10, 50, or 90 % of the time, are frequently used as average measures typical for the “maximum”, “median”, and “background” levels, respectively.

Noise main characteristics include: sound pressure level, sound frequency, type of sound, and variation in time. People agree that when moderately intense single component sound is increased by 10 dB, it sounds twice as loud.

Auditory masking is defined as the decrease in audibility of one sound due to the presence of another sound.

Frequency Analysis - Frequency analysis provides a physical description of frequency content. The main principle of frequency analysis is that any selected frequency range is divided into a number of consecutive and discrete analysis bandwidths, such that the amount of energy present in each analysis bandwidth can be determined.

Results – Health Impact

Noise and Self-Reported Health

a) Pulles, Biesiot and Stewart (1990) reported differences in subjective health complaints between noise exposed and nonexposed groups to be dependent upon subjects’ perceived control over noise, and to be independent of sound pressure level.

b) Individual responses to noise may be more highly correlated with symptoms of ill health than with the noise itself.

c) Controllability over noise as a stressor, necessity and importance of the source of noise and its predictability are currently postulated as factors which may modify the physiological effect of high noise exposures.

d) Uncontrollable stressors are typically appraised as more threatening and are frequently associated with negative effects on health leading to the hypothesis that adverse adrenergic responses occur only after appraisal of noise as a stressor (Kristensen, 1989).

e) In real life community noise interferes with a number of activities, for example, recreation, sleep, communication, and concentration. The risk of adverse effects on health must be considered in the light that noise as a stressor may operate through physiological responses modified in complex ways by individual psychological processes.

f) Subjects describing themselves as sensitive to noise have reacted to noise with larger increases in vasoconstriction than their ”normal” counterparts . A person's reports about symptoms of ill-health seem to be related to the quality of sleep. Sensitivity to noise is related to reported sleep problems as well as impaired health.

Tinnitus - Tinnitus (ringing in the ear is a common with hearing impairment that is sometimes described as the illusory (illusion) sensation of sound not brought about by simultaneously applied acoustical signals. Some forms of tinnitus are due to the sound produced by the blood flows through structures in the ear. **Commonly, tinnitus is referred to as sounds that are emitted by the inner ear itself and are heard by the subject, physiological tinnitus.** A sensitive microphone may pick up the sounds heard by the subjects in some cases.

Pain & Discomfort – Tissue damage can result at 130-140dB. Discomfort begins at 100-110 dB, acute pain at 130dB.

Sleep Disturbance

a) Many people experience sleep disturbance due to noise. Sleep disturbance is considered to be a major environmental noise effect. However, 10-20 % of sleep disturbance is due to other reasons than noise.

b) The probability that sleep will be disturbed by a particular noise depends on a number of factors including the interference criterion used (e.g., awakening or solely EEG changes), the stage of sleep, the time of night, the character of the noise exposure, and adaptation to the noise. **Individual differences in sensitivity are pronounced. Measurable effects start from about 30 dB LAeq.**

c) The **sensitive groups** are believed to include mainly <u>elderly persons, shift workers, persons who are especially vulnerable due to physical or mental disorders</u>, and other individuals who have sleeping difficulties.

d) **Primary sleep disturbance effects** include: a) difficulty to fall asleep, b) alterations of sleep pattern or depth, c) awakening, d) increased blood pressure, e) increased heart rate, f) increased finger pulse amplitude, g) vasoconstriction, h) change in respiration and cardiac arrhythmia, and i) body movements.

e) **Secondary sleep disturbance effects** include: a) reduced perceived sleep quality, b) increased fatigue, c) decreased mood or wellbeing, and d) decreased performance. Long-term effects on psychosocial wellbeing have also been related to noise exposure during the night. Sleep changes are measured for SPLs that exceed 40dB LAmax for road/train/aircraft noise.

Noise Levels/Characteristics

a) The correlation between outdoor noise levels and sleep disturbance may be low. It is not clear in what proportion noise contributes to regularly occurring sleep disturbances or awakenings in the general population.

b) A longer time to fall asleep was found in sensitive as well as nonsensitive adults at sound pressure levels of 50 and 60 dB LAmax road traffic noise.

c) The number of noise events per time unit rather than the absolute noise level seems to be important for the time

d) needed to fall asleep since the effects were similar at 45, 50, and 60 dBA of road traffic noise.

e) Awakening reactions for young to middle aged start at 50-55dB LAmax indoors. At 65dB LAmax – 10% of the noise events produce awakening in 1/3 of the exposed.

Blood Pressure, Cardiovascular Changes and Myocardial Infarction

Blood Pressure

a) **The overall evidence for the effects of noise on cardiovascular functioning is suggestive of weak to moderate effects of community noise on blood pressure**. The authors indicate that much of the studies were methodologically weak (based upon small selective samples with insufficient control for confounders. The cross sectional nature of most designs did not take into account temporal relationships between exposure and health outcome.

b) **Studies of exposure to 60-65 dBA shows mixed results.** The authors referred to studies by Ising (1983) which conflicting results. In one study, policemen exposed to traffic noise (60 dB LAeq, several h) showed a slight increase in mean systolic and diastolic blood pressure but some individuals showed a decrease. In another study of hospital patients experimentally exposed to traffic noise (65 dB LAeq for 12 h) some showed blood pressure decreases and some showed increases in comparison with days of no exposure). ***In regression analysis, poor general condition and pain were associated with decreased blood pressure whereas a hypertensive disposition was associated with increased blood pressure***.

c) **Exposure ≥ 85 dB -** Significantly increased blood pressure levels have been reported from many studies of individuals chronically exposed to levels of continuous noise exceeding 85 dB in which other risk factors for hypertension are not controlled or only partially controlled.

d) Recent studies of workers exposed to similar noise levels in which major risk factors for hypertension (age, alcohol and tobacco use, body mass index, family history of hypertension) have been taken into account tend to show weak associations between noise exposure and elevated blood pressure, but sample sizes have been small.

Ischemic Heart Disease

a) Preliminary results of large prospective investigations in the UK have not given convincing evidence of a dose-response association between sound pressure levels of road traffic noise and nine identified biological risk factors for ischemic heart disease (Babisch, Gallacher, Elwood, & Ising, 1988; Elwood, Ising, & Babisch, 1993; Babisch, Elwood, & Ising, 1993).

b) Hospital and population-based case-control studies in Berlin (comprising 243 and 4035 men, respectively, aged 35-70 years, predicted levels of **road traffic noise ranging from 60 to 80 dB LAeq**) demonstrated relative risks for the incidence of myocardial infarction of 1.2 and 1.3 among men in the highest noise exposure categories (71-80 dB LAeq).

c) In page 99 the authors suggest that although the available data are inconclusive, it appears that traffic noise is, at most, only weakly associated with increased blood pressure or other cardiovascular changes.

Immune System - The results and conclusions from four of the papers were considered to be reliable. However, these results do not provide a consistent basis for a conclusion concerning the potential effect of noise stress on health by modulation of immune function.

Effects on Sense of Balance - On page 102 the authors indicate that a high level of noise may influence balance equilibrium because of the stimulation of the vestibular sense organ. Complaints of nystagmus (rapid involuntary side-to-side eye movements), vertigo (dizziness), and balance problems have been reported after noise exposure in the laboratory, as well as in field situations. The **levels needed to cause such effects** in personnel working on jet engines were quite high, typically, ***130 dB or more***. <u>Less intense sound pressure levels ranging from 95 to 120 dB also disturb the sense of balance, if there is unequal stimulation of the two ears</u>.

Mental Health

a) Noise is not believed to be a direct cause of mental illness but might accelerate and intensify the development of latent mental disorders. The relationships among noise annoyance, noise sensitivity and mental morbidity is complex and not yet well differentiated

b) The evidence relating noise to mental illness is scanty and much of it is based only on clinical impression. Several studies relating community noise to mental health may have confounded noise exposure and demographic variables.

c) Tarnopolsky et al. (1978) report a marked association between annoyance by aircraft noise and psychiatric symptoms. Noise sensitivity may be an indicator of subclinical psychological morbidity. If noise causes annoyance and frustration, it seems plausible that prolonged exposure could cause or aggravate mental illness (S. Cohen & N. Weinstein, 1982; S. Cohen et al., 1986; Evans & S. Cohen, 1987).

d) Example 1 - The relationship between noise exposure, the presence of mental disorders, and annoyance was studied in a field investigation on 200 persons, half of whom lived near London Heathrow Airport. No association was found between noise exposure and mental morbidity, but **symptoms of mental disorders were more common among those who reported that they were very annoyed by the noise** (Tarnopolsky, Barker, Wiggins, & McLean, 1978).

e) Example 2 - Evidence from these studies further suggest that <u>noise sensitivity may be a self-perceived indicator of vulnerability to stressors</u> in general and **may also be indirectly measuring a subclinical level of psychological morbidity.** (Tarnopolsky et al., 1980a; Stansfeld, C.R. Clark, Jenkins, & Tarnopolsky, 1985; Stansfeld, 1988, 1992).

f) Example 3 - Preliminary results from a prospective traffic noise study in the UK showed a strong association between noise sensitivity and psychiatric symptoms, but no association between noise level at baseline and later development of psychiatric disorder (Stansfeld, Gallacher, Babisch, & Elwood, 1993).

Performance, Cognition and Reading

a) Noise can interfere with complex task performance. **The uncontrollability of noise rather than the intensity of noise appears to be the most critical variable.**

b) Subjects highly sensitive (self-reported) to noise performed significantly poorer in deep mental processing (i.a. difficult mental arithmetic) as compared to subjects less sensitive to noise.

c) Cross-sectional studies and two longitudinal studies showing negative associations between chronic exposure to high noise sources (e.g., >55-66 dBLAeq from aircraft or road traffic) and deficits in reading acquisition among children.

Annoyance

Annoyance could be defined as: "feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them" (Lindvall & Radford, 1973).
In terms of the numbers affected, annoyance is probably much more widespread than other overt effects caused by a noise environment.

Percent Highly Annoyed – (**% HA**) is a measure often used to indicate magnitude of the problem

Sound pressure levels – Noise levels (SPLs) typically explain only 10 to 30% of the variability in annoyance responses. Intersubject variability is high.

Annoyance, Individual Characteristics & Other Factors

a) Much of the variation between individuals can be attributed to sociopsychological factors.
b) Annoyance depends mainly upon noise intensity and spectral characteristics, and variations of these with time.
c) Annoyance reactions are sensitive to many nonacoustic factors of a social, psychological, or economic nature and there are considerable differences in individual reactions to the same noise.
d) Annoyance is affected by the equivalent sound level, the highest sound level of a noise event, the number of such events, and the time of the day.
e) A large proportion of low frequency components in the noise may increase annoyance considerably.
f) The annoyance during night time influences the total daily annoyance level.
g) In a review of the literature, Job (1988a) concludes that only a small percentage (< 20%) of the variation in individual reaction is accounted for by noise exposure. Variables, such as attitude to the noise source and sensitivity to noise, account for more variation in reaction than does noise exposure.
h) The stress reduction model postulates that annoyance response to noise is mediated by three primary factors: (i) the inherent unpleasant characteristics of the noise; (ii) the meaning associated with the noise source; and, (iii) the interference with ongoing activities (Lindvall & Radford, 1973; Borsky, 1980).
i) Community noise is perceived as more annoying during night time than during daytime. The number of events influences the extent of annoyance and the sleep disturbance; for annoyance there is seemingly a threshold above which an increase in the number of events does not increase the extent of annoyance.

In a study of aircraft noise (TRACOR, 1971), the most important of the factors were fear of crashes, general noise susceptibility, ability to adapt to noise, opinions about the importance of the aircraft operations, and belief that the noise could be better controlled.

Dose Responses - At the community level there is a steady increase in annoyance with SPL. Available data indicate that **daytime sound pressure levels of less than 50 dB LAeq cause little or no serious annoyance in the community**.

Hearing Loss - There is a definite risk of hearing damage associated with prolonged exposure to SPLs between 85 - 90 dBA, or more. The risk threshold is at about 75 dBA (8-h continuous equivalent).

Infrasound

a) Infrasound is sound in frequencies below 16-20 Hz. The the range from the first soft perception to pain is only 30-40 dB. Perception of sound from 100 Hz down to about 2 Hz is a mixture of auditory and tactile sensations. The main sensitive organ for sound at frequencies below 20 Hz is within the ear.

b) **There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects.** Infrasounds slightly above detection threshold may cause perceptual effects but these are of the same character as for "normal" sounds.

Low Frequency Noise

a) The effects of <u>low-frequency noise</u> are of particular concern because of its pervasiveness due to numerous sources, efficient propagation and reduced efficacy of many structures (dwellings, walls, and hearing protection) in attenuating low frequency noise compared with other noise.

b) Intense low frequency noise may produce clear symptoms including respiratory impairment and aural pain. Evidence suggests that a number of adverse effects of noise in general may be greater for low frequency noise than for the same noise energy in higher frequencies: loudness judgments and annoyance reactions are greater for low frequency noise than other noises for equal sound pressure level regardless of which weighting scheme is employed

<u>Conclusions and Suggestions</u>

Assessing Noise and Health

From a theoretical point of view, an assessment of the causal relationship between noise exposure and nonspecific health effects presents difficulties. It is difficult to exercise sufficient control over all relevant risk factors in epidemiological studies, particularly as several of the risk factors such as social class, personal habits, and personality characteristics are difficult to define.

The potential noise-induced effects on physical health are not well established with respect to community exposures. The available data do not permit one to draw definite conclusions.

Cross sectional studies do not provide information on temporal relationships between exposure and onset of disease and can not be used to conclude causality.

Sleep Disturbances

a) **Recommended guideline values for bedrooms inside are 30 dB LAeq for steady-state continuous noise and 45 dB LAmax. At nighttime <u>outside</u> noise levels should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open.**

b) The period which seems to be the most sensitive, as far as disturbance is concerned, is the first one-third to two-thirds of the night.

c) **For a good sleep**, it is believed that sound pressure levels of approximately 45 dB LAmax should not appear more than 10-15 times per night. Noise-abatement measures should aim at reducing the number of intense noise events. Guidelines for community noise to avoid sleep disturbance should be expressed not only in terms of equivalent sound pressure level but as maximum levels, and number of noise events during night, as well.

d) In order to avoid negative effects on REM-sleep, the equivalent continuous (average) sound pressure level during the sleeping period ***<u>should not exceed 30-35 dB LAeq for continuous noise indoors [pp92]</u>***.

e) **For dwellings, recommended guideline values <u>inside bedrooms</u> are 30 dB LAeq for steady-state continuous noise and for a noise event 45 dB LAmax**.

f) Special attention should be given to noise sources in an environment with a low background level, to environments where a combination of noise and vibrations are produced and to sources with low frequency components where disturbances may occur even though the sound pressure level is below 45 dB LAmax.

g) Measures to reduce sleep disturbances during the first part of the night are most effective.

h) Sound pressure levels during the evening and night should be *<u>5 to 10 dB lower than during the day.</u>*

i) At night time outdoors, sound pressure levels should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open (page 171). This value has been obtained by assuming that the reduction from outside to inside with the window open is 15 dB; note that the actual reduction may be less in some cases, maybe only 5-7 dB, which then would mean that the sound pressure level outdoors needs to be kept at or below 35-37 dB LAeq.

j) Fast deep sleep may best be related to the perceived sleep quality.

Annoyance

a) Annoyance: a) depends upon physical characteristics (SPL, spectral characteristics, and variations of these properties of noise with time); b) annoyance reactions are sensitive to many non-acoustic factors of a social, psychological, or economic nature and there are considerable differences in individual reactions to the same noise; and c) is affected by the equivalent SPL, the highest SPL of a noise event, the number of such events, and the time of the day.

b) Available data indicate that daytime sound pressure levels of less than 50 dB LAeq cause little or no serious annoyance in the community.

c) To protect the majority of people from being seriously annoyed during the daytime, the sound pressure level from steady, continuous noise on balconies, terraces, and in outdoor living areas should not exceed 55 dB LAeq. To protect the majority of people from being moderately annoyed during the daytime, the sound pressure level should not exceed 50 dB LAeq.

d) For outdoor playgrounds the sound pressure level from external sources should not exceed 55 dB LAeq.

e) Better noise measurements ought to be obtainable through accumulated psychoacoustic knowledge. Psychoacoustic measurement is methodologically close to physical measurement, but with humans as the measurement apparatus. In this way it is possible to account for the different biological processes which can be disturbed by exposure to noise, for example, fatigue and stress.

f) It is important to establish indices based on physical measurements which correspond to the perceptual qualities of different noise situations. However, these qualities are functions also of a set of personal and psychological factors such as expectation, habituation, attitude, and social activity. Consequently, <u>for health assessments</u> we will probably need a number of noise indices based on different physical parameters, each one designed for a specific purpose: for example, an index for sleep disturbance should probably be based on maximum sound levels and number of events,

g) One of the central problems in assessing the perception of community noise sources is that different persons may be required to make judgment of different sources, widely separated in time and space. This makes it dubious to compare judgments across conditions because it is clear that individual differences exist in people's perception of sound

h) There is no general model that relates physical measures of sound to auditory experiences (e.g., loudness) and, in turn, to annoyance (or noisiness) of community noises.

Measuring Noise

a) C-weighting should be used for measurements where extreme high or low frequencies are involved, in addition to measurements using the A-weighting.

b) Noise measures or indices based only on energy summation are not enough for the characterization of most noise environments. This is particularly true when concerned with health assessment and predictions.

c) The difference between dBlin (or dBC) and dBA will give a crude information about the contribution of low frequency sounds. If the difference is more than 20 dB, it is recommended to perform a frequency analysis of the noise.

d) It has been proposed tentatively (Lambert & Vallet, 1994) that when the difference between dBC and dBA is 10 dB or more a penalty of 5 dBA should be added for a Leq of less than 60 dBA, and a penalty of 3 dBA for a Leq of 60 dBA or more.

PP179 - Thus, it is harmful to have too much sound but also harmful to have too little sound in our environment.

<u>Ising H, Kruppa B. (2004) Health Effects caused by Noise: Evidence in the Literature from the Past 25 Years.</u>

<u>Overview</u>
Author's presented results and suggested that the paradigm that focused primarily on sound-level (dB only) was not sufficient to evaluate potential danger to health.

<u>Results</u>
Authors presented dose response data for air, traffic, and rail that demonstrated that people become annoyed by different sound types at different levels. The data was taken from a meta-analysis (Miedema & Vos, 1998) and the rates are for the threshold at which 20% report being significantly disturbed / very disturbed: a) aircraft 51dBA / 61 dBA; b) road 57dBA/65dBA; and c) rail 63dBA/78dBA.

Cardiovascular Risk

a) Studies show a trend towards increased CV risk (disease/mortality): a) if daytime SPLs are >65 dB(A); b) for traffic noise >70 dBA, and with b) long-term work noise exposure.

b) Maschke et al., 2003 – found increase hypertension in people exposed to >50 dBA (night time) but not for same SPL daytime.

c) The threshold for possible noise induced risk of myocardial infarction (daytime exposure) is 65 dBA.

d) Some studies have found that people who self-report as noise sensitive have higher BP increases from road noise (60 dBA) compare those the non-sensitive.

Annoyance

a) Only 30 % of Noise disturbances can be predicted based upon noise level, exposure time and frequency – Non acoustical variables (individual/situational) exert a considerable influence.

b) The Netherlands "Noise and Health" report indicates that the disturbance threshold for environmental noise is 42dBA (outside).

Biological Indicators of Stress

a) Acute and chronic stress hormones increases during sleep have been measured at relatively low sound levels. The authors cited several studies that measured increased (adrenaline, noradrenaline and cortisol) levels in people living near airports (or simulated airport noise studies) In one study, women exposed to >57 dBA (outside) had higher catecholamine levels compared to women in exposed to <52 dBA.

b) The authors cited another study where people on noisy streets (53-69 dBA) were asked to leave their windows open at night which cause increases of 9-18 dBA (indoors). It was found that the test subjects free cortisol levels were significantly higher than control subjects in <45 dB(A) areas and the cortisol levels were higher in the 'noisy test group' whether the windows were open or closed.

c) Evans et al, 2001 – Found children exposed to > 60 dB(A) day time, had higher urine cortisol metabolites compared to children living in 'quieter areas' <50 dBA (day time)

d) Research indicates that even during sleep, noise can be processed as danger signals and consequently result in the release of stress hormones

Conclusions and Suggestions

1) The paradigm that focused primarily on sound-level (dB only) was not sufficient to evaluate potential danger to health.

2) Environmental noise effects can't be extrapolated from short-term laboratory findings. (e.g., field vs. lab experiments showed very different results in studies evaluating BP and traffic noise.)

3) Future studies, those aimed at establishing environmental noise limits, need to include appropriate inderdisciplinary teams: physic-technical, socio-psychological, medical and epidemiological disciplines.

4) Sleep disturbances – the authors suggest that just evaluating 'arousal reaction' is not enough because this does not account for interference with sleep stages and other physiological processes. (The authors suggest that noise can affect people without actually waking them up.)

5) The long-term consequences of noise induced increase of stress hormones need to be investigated in epidemiological studies.

Babisch W. (2000) Traffic Noise and Cardiovascular Disease

Overview and Methods
Authors described the paper as a ***Quantitative Review*** which appears to be a modified Systematic Review (papers were grouped/classified by type of study and evaluated for quality. N= over 30 studies. Study aims were to review the evidence on the relationships between traffic noise and cardiovascular disease (mean BP, hypertension, Ischemic Heart Disease).

Methods
Author evaluated the results from over 30 studies. Types of studies included: surveys, ecological studies, proportional morbidity studies, cross-sectional studies, general population follow-up studies, case-control studies, and cohort studies (prospective and retrospective).

Exposure Criteria **-** Operational definitions for high exposure compared to low exposure appeared to start on average at ≥ 65 dBA for the high exposure group (the range indicated was 50dBA to over 70 dBA).

Results

1) With the exception of a few studies, the results of the environmental noise studies are not statistically significant (CIs usually included 1.

2) Blood Pressure – the available literature provides NO consistent findings in the relationship between traffic noise level and mean systolic or diastolic blood pressure in adults. But – in children noise-related higher BP readings have been measured repeatedly.

3) Ischemic Heart Disease - there is some epidemiological evidence in the literature of an increased risk in subjects who live in noisy areas with outdoor noise levels more than 65-70dBA

Conclusions and Suggestions

1) Across all studies there was no consistent pattern of the relationship between traffic noise level and prevalence of hypertension.

2) There are a limited number of epidemiological studies on the relationship between traffic noise and cardiovascular diseases. With the exception of a few studies, the results of the environmental noise studies are not statistically significant. This is caused by both lack of power and possible misclassification of individual exposure

3) There is a need for more studies in this field. These studies should consider mediating factors like room orientation, window opening habits and residence time, in order to reduce the exposure misclassification and to account for longer induction periods.

Evans G et al. (2001). Community noise exposure and stress in children.

Overview

The paper reports a cross-sectional study of 4rth grade children that examined multimethodological indices of stress among children living under 50 dB or above 60 dB (A-weighted, day-night average sound levels).

Background Information

1) Traditional concern about noise has focused on auditory damage.
2) Chronic noise is associated with stress, interferences with relaxation, concentration problems, psychosomatic symptoms of anxiety and nervousness, and deficits in motivation and helplessness.
3) A typical urban neighborhood residential area in the United States ranges from 55-70 dBA L (Kryter, 1994)
5) In the European Union 20% of the pop lives in areas with daytime Leq>65dBA (Gottlob,1995).
6) Exposure to high intensity noise can cause motivational deficits and similar research evaluating chronic aircraft noise – has demonstrated similar results in children

Methods

The study compared effects (non-auditory) of chronic exposure to sound on children. Subjects (N = 115) were pre-screened for normal hearing.

Exposure – Two exposure categories were used: a) Low – under 50 dBA; and b) High – above 60 dBA where the main sources of noise were road or rail traffic.

Outcome measures

f. Stress Symptoms – Self perceived stress was measured using a standardized German instrument for the assessment of stress in children (e.g., felt tired, didn’t have a good appetite). Psychophysiological stress was measured by testing urine samples for epidnephrine and norepinephrine.
g. Motivation – Motivation was evaluated using an adaptation of the Glass and Singer (12972) ‘Stress-aftereffects Test’ which was designed to measure motivational deficits.

Results

Children in the High Noise (>60dB) areas:

a) Had elevated resting Systolic BP.
b) Had elevated 8h overnight urinary cortisol.
c) Had elevated heart rate reactivity to discrete stressor in the lab test.
d) Rated themselves higher in perceived stress symptoms. R
e) Rated their neighborhoods as significantly more noisy.
f) Had elevated total free cortisol.
g) Affected (decreased) motiviation among the girls but no affect on the boys.

Conclusions

The combination of elevated cardiovascular and neuroendocrine measures supports the stress model of chronic noise exposure.

Although the exposure levels were below "levels indicative of pathology", the results suggest the children living in the higher noise areas (>60dBA) are subject to stress.

Lercher P, Evans G, et al. (2002) Ambient neighbourhood noise and children's mental health.

Overview & Methods

The authors conducted a large sample cross sectional study (N=1280 and extreme sample n=123) that evaluated the effects of community noise on mental health outcomes.

The sample (N = 1,280) included school children in grades 3-4 (mean age was 9.44 years) from 26 local schools with a 79.9% participation rate. As second sub-sample (n = 123) was stratified by **high exposure (>60 dBA)** and low exposure (<50 dBA).

Exposure - noise levels were modeled at each children's residence. Noise measurements were taken at 31 locations to assess and adjust the model. Noise levels ranged from 31 dBA – 72 dBA.

Psychological health was measured using a 22 item scale formed from two subscales of the KINDL,21 a valid and reliable index of children's quality of life that included four items on a sleep disturbance scale. (Surveys were self reported. Children were asked questions about how often they experiences symptoms "indicative of anxiety and depression appropriate for a non-clinical population". In addition teachers were also surveyed about children's performance

Results

Ambient levels of noise in the community are associated with decreased mental health in elementary school children. The authors indicated that the association, a linear dose-response function in a large population study, holds with multiple statistical controls.

Results of the sub-sample study indicated that children with "pre-existing biological risk" (e.g., low birth weight and preterm delivery) may be at greater risk of noise related mental health outcomes.

Fields J. (1993). Effect of personal and situational variables on noise annoyance.

Overview

Fields conducted a **meta-analysis of 136 surveys** on environmental noise. The researchers reported the findings about the effects of personal and situational variables on annoyance were quantified by calculating the proportion of the findings on each noise topic that showed: 1) no important effect, 2) an important effect which supported the hypothesis, or 3) an important effect which was in the opposite direction of the hypothesis.

Results

1) Demographic Variables - Fields found that none of the demographic variables affected annoyance (per his 'important effect' criteria): age, length of residence, sex, socio-economic status, income, education, homeownership, type of dwelling and benefit from noise source.

2) Attitudes – Fields reported there was firm evidence that noise annoyance was associated with: a) fear of aircraft crashing or danger from nearby surface transportation; b) the belief that the aircraft noise could be prevented or reduced; and c) self reported sensitivity to noise (in general). Fields also indicated that ¾ of the surveys supported the hypothesis that annoyance is decreased when there is the perception that the noise source is economically (or for other reasons) important to the local area.

3) Noise Levels - Fields found that annoyance and noise levels are positively related and indicated that reductions in noise levels below 55 dB would reduce community annoyance.

4) Ambient Noise - Fields also found that the evidence does not support the hypothesis that residents in low ambient noise areas are more annoyed by a specific noise source. [*Note – this finding is contrary to common thought in both wind farm and residential areas.*] Field's suggested the reason for this finding was that for a sound to be annoying it has to be 'intrusive' and thus be heard above the usual background noise.

Conclusions

1) Annoyance is not affected by the demographic variables, hours in the residence, mode of interviewing and the ambient noise conditions.

2) Noise annoyance occurs at levels below 55 dB and is positively related to three attitudes: fear, preventability and sensitivity.

Pedersen C, Moller H, Waye K. (2008). A Detailed Study of Low-Frequency Noise Complaints.

Overview

The authors conducted an investigation into the nature of LFN complaints of 21 individuals.

Background Information

Many cases of noise annoyance are associated with low frequency noise (often describes as rumbling) where sources include: compressors, ventilation systems and slow running/idling engines.

The authors describe a specific group of cases "where persons claim to be annoyed by rumbling noise, but where they are not helped in a way that they find satisfactory. This often leads to repeated complaints, anger at authorities, feelings of helplessness, and reports in the daily press." Pedersen et al., indicate that common characteristics of these cases are that: a) there is no obvious noise source, b) frequently only one or a few people are annoyed, and c) many cases are in quiet areas where when the noise is measured the results are low values. The authors then suggest the result is a lack of belief that noise is the source of the annoyance and suggest that one explanation could be that the annoyed persons suffer from an internal sound referred to as tinnitus.

Tinnitus – the authors define tinnitus as: "***the sensation of sounds in the ears, head, or around the head in the absence of an external sound source***" or "the perception of a sound in the absence of any external sound applied to the ear". The authors report that tinnitus may arise from abnormal activity at different points in the auditory system and that the mechanisms are not well understood.

<u>Methods</u>

Sample

a) 21 subjects were randomly selected from pool of 203 previously determined low frequency noise complaints. Subjects included 8 men, 13 women with average age of 53.5 years; 13 had contacted authorities; all claim to 'hear' LFN; 5 reported alone being able to 'hear' the noise.
b) All subjects were tested and most found to have normal hearing. Those with hearing issues included: one with directional preponderance, two with minor one side hearing loss, four with noise induced hearing loss, and one with presbyacusis.

Exposure Measurements - Recordings were made in room where noise was most annoying and where the subjects confirmed presence of noise prior to and during recording. Subjects were also asked to identify any other present annoying sounds. Recordings were taken with 20 microphones for five recording periods of 3 minutes.

<u>Results</u>

1) The authors found no evidence that the study subjects had an 'extraordinary hearing threshold' (i.e., were not sensitive to LFN).

2) In 7/20 subjects it was concluded that noise in the home was the source of their annoyance.

3) In 6/20 subjects it was concluded that their annoyance was caused by internal low frequency tinnitus.

4) In 7/20 subjects no conclusions noise versus tinnitus were made.

[*Note – In other documents that discuss the effect of noise on health, the authors frequently refer to 'tinnitus' as an unwanted outcome of the external noise exposure and not an outcome of internal biological factors that are not caused by an external noise source.*]

<u>Conclusions</u>

1) Infrasound (<20 Hz) was not responsible for any of the complaint and was not audible in any of the cases.

2) In the confirmed cases of physical sound, the annoying components were in the range of 20-180Hz.

3) In both cases where the <u>annoying sound was either physical or internally generated</u>, the level was just above the hearing threshold. The authors concluded that this then confirms that annoyance occurs much more rapidly for noises in the low frequencies.

<u>Berglund et al., (1996) Sources and effects of low-frequency noise</u>

<u>Overview</u>

Berglund et al., provide an overview of low-frequency noise exposures and their physical, physiological, and psychological effects on humans.

Background Information
The demarcation of 20Hz as the lower boundary of human hearing is arbitrary. "Human hearing capacity extends well below the 20-Hz range if one considers a signal that is sufficiently loud" (p2986). **A**uthors define LFN as below 250 Hz, although recognize this is purely arbitrary.

Authors argue that regardless of how we *detect* a sound, it must still be considered. We should consider sound detected through skeletal bones, the ear, harmonics, tactile senses, or resonance in body organs.

Natural sources of LFN include wind, thunder, ocean waves, volcanoes and earthquakes, but people react more to artificial sources, "probably because of their attitude to the source.

On wind turbines, the authors look at data from a 1990 study and conclude that the amount of LFN produced by turbines is a "concern" for those living near the turbines, but note that the levels are "theoretically" below our hearing threshold after a "few hundred meters".

Night time is a particular concern for low frequency noise, because masking noise from other sources is reduced and low frequency noise is not well masked. In addition, since walls tend to filter out only higher frequencies under some conditions low frequencies will dominate the spectrum of perceived noise.

The A filter underestimates the importance of frequencies below approximately 100 Hz. The authors indicate that within the range of 52-70 dB(A) it has been shown to underestimate by as much as 9dB and that A-weighting "severely underestimates annoyance as well as (perceived) loudness when the noise contains low-frequency components".

The authors suggest there are problems with field studies of LFN, including the inability to identify the noise source and the necessity of working with broadband emissions with a significant low-frequency component (as opposed to pure low-frequency laboratory-produced noise); thus, this makes it difficult to attribute anything to low-frequency noise.

Health Impact
The detection threshold for 20Hz is ~84dB and for 10Hz is ~105dB (from Figure 2 on p2986); whereas, the pain threshold for 50Hz is ~135dB and for 5Hz is ~155dB (steady increase in between).

Human defenses against excessive noise are less resilient against low frequency noise

The authors indicate that impulsive noise generates greater levels of subjective reactions such as annoyance and dissatisfaction than does nonimpulsive noise of the same energy level (e.g., quarry blasting, sonic booms, explosions and artillery.)

Intense energy (140dB – 172) in the very low-frequency ranges may affect the vestibular system.

Respiratory effects (e.g., suspended or reduced respiration, gagging, and coughing) has been demonstrated in animals exposed to high levels (150-154 dB).

Annoyance

a) The authors cited many references when indicating that the degree of annoyance generated by a specific noise is difficult to predict (for individuals) and that the same noise for different people can result in totally different responses that are affected by: cultural factors, activity at the time, attitude to the noise source, noise sensitivity, controllability of the stressor, and other individual differences.
b) Sound with more low frequency noise components (than higher frequencies) is more likely result in complaints at the same exposure levels.

Cardiovascular and other health effects
The authors indicate a large body of evidence for health effects of exposure to noise. [*Note – The duration and exposure levels from the different studies were not provided. This means that one cannot generalize the results to exposure to wind turbines. However, the authors did indicate some of the studies were about long term exposure and/or of people highly exposed to road traffic noise or aircraft noise.*]

Studies have found that noise exposure is associated with: changes in blood pressure, vasoconstriction or vasodilation, changes in heart rate, increased heart disease risk, increased prevalence of cardiovascular disease, changes in cortosol and catecholamine levels, task performance, sleep disturbance, cardiovascular changes while sleeping,

<u>Mental Health</u> – The authors indicate that it is difficult to establish the effects of noise on mental health because of significant confounding problems associated with differences between exposed and unexposed populations. The authors then referred to studies that have suggested: a) a complex relationship between noise and mental health effects such as depression and noise sensitivity; b) effects of noise on psychosocial well-being; c) and an effect on psychiatric hospital readmissions and aircraft noise.

<u>Conclusions and Policy Suggestions</u>

1. Further research is needed to address:
   a) The effect of different noise frequencies on humans.
   b) Longitudinal studies of the effects of long-term exposure to low frequency noise.
   c) Examination of individuals who are most effected by noise and what characteristics they share.
   d) The effect of low frequency noise on different risk groups.

2. Berglund et al., suggest that the effects of low frequency noise on humans are difficult to establish because of methodological problems. However, they conclude that: "The balance of probability would appear to favour the conclusion that low-frequency noise has a variety of adverse effects on humans, both physiological and psychological."

3. The authors also suggest that in community settings more emphasis should be on determining the frequency spectrum (of the noise) versus a focus on the sound pressure level alone.

<u>Castelo Branco (1999) The Clinical Stages of Vibroacoustic Disease</u>
Castelo Branco describes vibroacoustic disease (VAD) as an occupational disease that occurs in workers with long-term exposure (≥ 10 years) to large pressure amplitude (≥ 90 dB) and low frequency noise under 500 Hz. Castelo Branco conducted a study of 140 that he indicated had VAD [*Note – it is unclear but it appears that it was the VAD team that made the diagnoses of VAD in this study group.*]

Castelo Branco reports that VAD progresses over time in three stages: Mild (2 years), Moderate (5-9 years), and Severe (11-15 years) with a broad array of symptoms that include: mood swings, GI dysfunctions, oropharynx infections, bronchitis, chest pains, back pains, fatigue, skin infections, conjunctivitis, allergies, psychiatric disturbances, depression, hemorrhages, varicose veins, hemorrhoids, ulcers, colitis, decreased visual acuity, headaches, osteorticular pain, muscular pain, and neurological disturbances.

<u>Davies et al., (2005) Occupational Exposure to Noise and Mortality From Acute Myocardial Infarction.</u>
Davies et al., evaluated long-term exposure in a cohort of 27,464 blue-collar lumber mill workers exposed to ≥ 85 dBA where the mean (full-shift) exposure was 92 dBA and the average duration of employment was 10 years. The researcher found an elevated risk for acute myocardial infarction in the cohort (RR 1.5, 95% CI 1.1-2.2) compared to the general population and reported an increased risk among a subgroup that didn't use ear protection.

SUMMARY AND CONCLUSIONS – NOISE AND HEALTH IN OTHER SETTINGS

Overview

Our purpose in adding this section was to provide information from peer reviewed noise and health research that will help contextualize the issues and themes (e.g., evidence and non-evidence based conclusions) that emerged in our reviews of different wind turbine documents. For example, one of the main tenets of causality described by Hill (1965) is the 'Biological Gradient' or the 'Dose-Response' which in this case would argue that, if noise causes ill health, one would expect that more noise (i.e., more powerful noise at higher levels measured in decibels) would result in more illness. In addition, we also thought it would help to contextualize the wind turbine concerns by comparing international wind farm exposure guidelines to the evidence in other non-wind farm settings.

The most common effect of community noise is annoyance and the World Health Organization considers noise annoyance to be an adverse health effect. Health Canada also indicates that noise starts to make people highly annoyed when the sound level outside the home is around 55 dBA (compared to highway noise 80 – 90 dBA).

However, debate exists regarding whether noise annoyance is or is not an adverse health effect that can always be attributed to the source or whether it is a subjective response to unwanted stimuli. Adding to the debate is that dictionaries describe annoyance as a state of mind or a mood and that the evidence indicates that only a small percent of a noise annoyance response can be directly attributed to the actual noise itself.

The research also clearly indicates that many other individual factors contribute such as: attitudes about the source, culture, fear, perceived preventability, value placed on the source, psychological sensitivity to unwanted sounds and other environmental stimuli, economic benefits tied to the source, perceptions of inequity and mental health. This creates a situation where one could reasonably conclude that a state of chronic annoyance is an adverse health outcome but also where one cannot conclude that most significant or main cause of the annoyance is the wind turbine sound emissions. [*Consider the example of constant background Rap music versus Country music versus Classical music. Medicine and a sleep aid for some but poison for others.*]

In the context of wind turbines, most of the focus regarding possible adverse health effects has been directed at the noise emissions. Those who have concluded that wind turbines cause ill health argue one or both of the following: a) exposure to the noise emitted directly causes adverse health effects (e.g., symptoms, illness or disease); and b) noise from the wind turbines causes annoyance which then causes sleep problems and stress and then leads to adverse health effects.

<u>What do we know from the peer-reviewed noise and health literature?</u>

Health Effects

Narrative reviews of the literature and the WHO document indicate that noise affects health. Passchier-Vermeer W & Passchier W. (2000) found sufficient evidence that the following health effects occur at the corresponding levels:

hearing impairment	70-85 dBA	hypertension	70-85 dBA
ischemic heart disease	70 dB A	performance	70 dBA
annoyance	55 dBA	changes in sleep pattern	<60 dBA
awakening	55 dBA.	mood next day	<60dBA
subjective sleep quality	40 dBA	heart rate	40 dBA
sleep stages	35 dBA		

- The Passchier-Vermeer results (2000) presented above seem to be supported by the additional evidence indicating that: a) exposure to high levels of noise (65-85 dBA or more) is associated with health effects such as: hearing impairment, hypertension, ischemic heart disease, cardiovascular risk, and balance (at higher levels 95 – 130 dB). (Note - results from studies are mixed and the associations are not always strong.; and b) exposure to lower levels are known to affect changes in sleep patterns (<60 dBA), awakening (55 dBA), subjective sleep quality (40dBA), heart rate (40 dBA), mood next day (<60 dBA), annoyance (55 dBA outdoors), continuous sleep (30 dBA), and stress hormones - adrenaline & cortisol (>57 dBA).

- The overall evidence suggests a weak to moderate effect on blood pressure where studies in exposure levels of 60-65 dBA show mixed results.

- **Infrasound -** There is no reliable evidence that infrasound (< 20 Hz) below the hearing threshold (> 84 – 105 dB) causes adverse physiological or psychological effects.

- Sound with low frequency components are more likely to result in complaints and annoyance at lower sound levels (SPLs) compared to sounds with fewer low frequency characteristics.

- Tinnitus (sensation of sound or ringing in the ears) can be produced by the person (e.g., abnormal activity at different points in the auditory system) or by external noises.

Noise Levels

- Typical sound pressure levels range from about 20 dB LAeq in a very quiet rural area to between 50 and 70 dB LAeq in towns during the day time, to 90 dB LAeq or more in noisy factories and discotheques to well over 120 dB LAmax near to a jet aircraft at take-off. Relaxed conversation occurs at a voice level of approximately 54-56 dBA and normal and raised voices at levels of approximately 60 and 66 dBA.

- People in urban environments are very frequently exposed to 50dBA noise levels.

Noise Annoyance

- Data indicate that daytime sound pressure levels of less than 50 dB LAeq cause little or no serious annoyance in the community. Given this, the WHO recommends that the continuous (average) sound pressure levels outdoors should not exceed 55 dB LAeq to protect the majority of people from being 'seriously annoyed' and should not exceed 50 dB LAeq to protect the majority of people from being 'moderately annoyed' during the daytime.

- The degree of annoyance generated by a specific noise is difficult to predict for individuals. The same noise for different people can result in totally different responses that are affected by: cultural factors, activity at the time, attitude and value attached to the noise source, noise sensitivity, controllability of the stressor, and other individual differences.

- Annoyance is a very individual response appears to first start with knowing about and/or hearing the sound and then which goes through an intermediate pathway (affected by perceptions, attitudes, culture, and physiological and psychological characteristics) before resulting in an annoyance response. [*Note – we provide the example of constant but different back ground music (rap versus country versus classical) where the response can range from pleaseant/sleep aid for some to intolerable/painful for others.*]

- Sound can be detected through skeletal bones, the ear, harmonics, tactile senses, or resonance in body organs.

Sleep Disturbance

- Recommended guideline values for bedrooms inside are 30 dB LAeq for steady-state continuous noise and 45 dB LAmax. At night time outside noise levels should not exceed 45 dB LAeq, so that people may sleep with bedroom windows open.

- Individual differences are very pronounced and measureable effects start at about 30 dBLAeq.

- The probability that sleep will be disturbed by a particular noise depends on a number of factors including the interference criterion used (e.g., awakening or solely EEG changes), the stage of sleep, the time of night, the character of the noise exposure, and adaptation to the noise. However, 10-20 % of sleep disturbance is due to other reasons than noise.

- Sensitive groups include: elderly persons, shift workers, persons who are especially vulnerable due to physical or mental disorders, and other individuals who have sleeping difficulties.

- Primary and secondary sleep disturbance effects include: a) difficulty to fall asleep, b) alterations of sleep pattern or depth, c) awakening, d) increased blood pressure, e) increased heart rate, f) increased finger pulse amplitude, g) vasoconstriction, h) change in respiration and cardiac arrhythmia, i) body movements, j) reduced perceived sleep quality, k) increased fatigue, l) decreased mood or wellbeing, and m) decreased performance.

Assessing Noise and Health

An assessment of the causal relationship between noise exposure and nonspecific health effects presents difficulties. For example, it is difficult to exercise control over all relevant risk factors in epidemiological studies such as: social class, personal habits, and personality characteristics are difficult to define. In addition, cross sectional studies can't be used to conclude causality because they do not provide information on temporal relationships between exposure and onset of disease.

There is evidence to suggest that assessing the relationship between noise and health can be problematic particularly when using self-reported health outcomes. For example, Berglund and Lindvall provided the following examples from the literature:

e) **Self reported that differences in subjective health complaints between noise exposed and nonexposed groups were dependent upon subjects' perceived control over noise, and were independent of sound pressure level.**
f) **Individual responses to noise may be more highly correlated with symptoms of ill health than with the noise itself.**
g) Noise is not believed to be a direct cause of mental illness but might accelerate and intensify the development of latent mental disorders and/or that noise sensitivity may be an indicator of subclinical psychological morbidity.
h) Noise sensitivity may be a self-perceived indicator of vulnerability to stressors in general and may also be indirectly measuring a subclinical level of psychological morbidity.

What do we need to know?

Further research is needed to address:

a) The effect of different noise frequencies on humans.
b) Longitudinal studies of the effects of long-term exposure to low frequency noise.
c) Examination of individuals who are most effected by noise and what characteristics they share.
d) The effect of low frequency noise on different risk groups.

With Respect to Wind Turbines

International and Canadian noise guidelines for emissions from wind farms generally set the allowable limit to be between 40 and 54 dBA for exposure at the residence with increases allowed for increasing wind speeds (because the ambient levels would exceed the guidelines). Studies measuring wind turbine infrasound and low frequency noise emissions indicate that levels for infrasound (<20 Hz) fall below the threshold indicated by the WHO known to cause adverse physiological or psychological effects.

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IMPLICATIONS

Our findings are the result of a review of the international body of English language literature that included peer reviewed indexed research, grey/self-published literature and community-based organization and news media documents. The main implications of our findings are:

- There is a need for multiple well-designed epidemiological studies. The studies should not rely on self-reported health outcomes, should include some pre-post studies, and should include noise exposure measurements (not models) at receptor sites (in and outdoors) and at control locations with similar ambient wind conditions.

- We need to know more about the relationship between individual and community characteristics and the likelihood of becoming highly annoyed by visual and noise exposures to wind turbines under different conditions. This includes a better understanding of how to improve the local political decision-making process and perceptions of community-wide equity. The literature suggests that opposition (and noise annoyance) is likely to be less pronounced when residents are given more power in the planning process and if the financial benefits are given to everyone, not just landowners who have turbines on their property.

- To narrow credibility gaps between developers/regulators and communities, there would be a value in improving or standardizing sound propagation models where the data and results are available and presented in an interpretable format to communities. Reports should illustrate the expected ranges under different assumptions and conditions.

- The evidence we found supports the conclusions of the French study (French Agency for Environmental and Occupational Health Safety & French Environment and Energy Management Agency) that was conducted following recommendations from the French Academy of Medicine that a precautionary 1,500 metre set-back distance be implemented until a study was completed. **The conclusion of the subsequent French Study was that the precautionary distance of 1,500 metres** (from the existing 650m) **was not warranted.** *[This is notable because the 1,500 'temporary' recommendation is often used in the web-based literature to suggest strong evidence of formal medicine's acknowledgement of a causal relationship.]* However, there is a need for evidence based set-back limits where the evidence should come from the additional research and improved sound propagation.

- There is need of a formal complaint resolution mechanism that can provide real and effective remedies for residences with complaints. This mechanism should involve sound pressure level measurements at the residences (inside and outside) under different wind conditions. Reports should be made available to the complainants and the general public that compare the measured SPLs to noise guidelines limits. If the maximum and equivalent average noise levels exceed the guideline, a pre-determined resolution/adjudication process should be implemented. (E.g., which could result in actions such as shut-down during some conditions or compensation.)

- There is a need for a better response from Public Health at local, provincial and federal levels. This should include increased coordination/collaboration, a better web presence to ensure credible sources appear more frequently during internet searches, and more careful messaging. Public Health should also provide information to improve public education about critically evaluating information sources, methods and conclusions.

MAIN CONCLUSIONS

A review of the available wind turbine and health literature does not provide evidence of a direct causal relationship between wind turbine noise emissions and ill health and does not suggest the likelihood of a causal relationship between ill health and wind turbine noise emissions that meet Ontario noise guidelines.

This conclusion is based upon the following:

- Two large sample European studies (N = 754 – 725 subjects) found no association between self-reported health outcomes and sound levels. Van den Berg also reported no association between self-reported health and annoyance. These studies used a masked survey design where the randomly selected respondents did not know the purpose of the study.

- Ontario wind turbine guidelines specify a maximum sound pressure level of 40 – 51 dBA at residences depending upon residential category and wind speeds.

- Evidence from the peer reviewed noise and health literature base supports the lack of health effect findings from the two European studies. Internationally, countries have set allowable limits for wind turbine noise exposure outside residences to be within a range of about 35-54 dBA depending upon different conditions. If these limits are met, noise exposure from wind turbines (includes infrasound and low frequency noise) falls well below levels known to have adverse health effects.

Annoyance

Annoyance is both defined in dictionaries as a feeling or state and by others as a negative health outcome. The research indicates a relationship between chronic stress and future morbidity and people who are annoyed also report higher stress levels. However, attributing wind turbine annoyance to the actual wind turbine noise and also to future negative health outcomes is a complex issue.

The noise and health evidence indicates that only a small percentage of annoyance can be attributed to the noise source itself and that other factors exert a considerable influence (e.g., attitudes, can see the source, culture, ability to control the noise, mental health, financial benefits, and perceived importance of the source). This suggests there is an intermediate pathway that includes knowing of the existence of the wind turbines and seeing and/or hearing them which then goes through the individual characteristics before the response is annoyance. Research also has found that those who report being highly annoyed also score higher on self-reported sensitivity test which indicates increased sensitivity to noise, odour, air pollution, and litter. Given this complex situation, we cannot attribute the annoyance (and future effects of annoyance) to the wind turbine noise alone.

Putting wind turbine annoyance into perspective – The large sample European studies (e.g., 754 – 1,095 subjects) found that a small percentage (E.g., 4.1 % - 7.7%) of total residents living close to industrial wind farms report being annoyed by wind turbine noise. Research indicates that a dose response clearly exists such that the percent annoyed increases rapidly as the sound level increases. For example Pedersen & Waye (2007) found that 15% of those exposed to ≥40 dBA were annoyed. However, putting this into perspective, only 20 of 754 in their study lived in areas with SPLs > 40 dBA.

In addition, in a 2008 study of 725 randomly selected subjects who did not know the purpose of the surveys, van den Berg et al., (2008) found that those in the highest noise exposure category (> 45 dBA) which meant they were receiving financial benefits from the turbines were less annoyed than respondents in lower SPL categories.

MAIN CONTRIBUTIONS

The main contributions from this research derive from a modified scoping review of the international body of English language literature that included peer reviewed indexed research, grey/self-published literature and community-based organization and news media documents. Our objective was to to discover and synthesize knowledge and identify what is known and where primary research is needed. Contributions include:

- The development and analysis of five categories for evaluating what is known about potential health effects of noise emissions from wind turbines: 1) Wind Turbines and Health - Peer Reviewed Research; 2) Wind Turbines and Health - Self-Published/Grey Literature Research;3) Government and Industry – Technical Information, Guidelines and Standards; 4) Community Based Organizations, Advocacy Groups and News Media; 5) Noise and Health in Other Settings - Peer Reviewed Research.

- An evaluation of vibroacoustic disease (VAD) and the suggested link to low frequency noise emissions from wind turbines.

- A recognition that there is a need for an improved response from government and Public Health regarding: local equity and the public consultation process, public education, access to information on the internet, and health concerns

- Identification of an international body of indexed and unindexed literature relevant to wind turbine noise emissions and concerns about human health (1985-2009).

- Documentation of suggestions made by the international body of papers.

APPENDIX 1: Document Analysis Template

Ref Man #:	**Authors/Date:**	**Title:**	
Context/mini abstract:	**Category**	**Source**	**Check One**
	1) Research – WTs and Health	Published Literature (peer-reviewed)	_______
	2) Research - WTs and Health	Grey Literature (not peer reviewed)	_______
	3) WTs (Tech, other & Health)	Government and Industry	_______
	4) WTs and Health	Non-government organizations & other	_______
	5) Research Noise &Health - other settings	Published Literature (peer reviewed)	_______

Background Information	
Technical Information	
Issues or concerns presented/ or discussed (e.g., noise/emissions, annoyance, stress health variables, visual impact, govt guidelines & other)	
Results – Health Impact	
Results – Other non-Health	
Policy Implications/Suggestions	

Notes: (Other relevant information (e.g., Research Methods) that is relevant to validity of results/conclusions)

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