Lincoln-Lancaster County Health Department
Recommendations for Noise Levels from
Commercial Wind Energy Conversion Systems

June 2015

The Lincoln-Lancaster County Health Department (LLCHD) recommends the following language for an updated text amendment to the County Resolution addressing noise levels from Commercial Wind Energy Conversion Systems:

No CWECS or combination of CWECS machine(s) shall be located as to cause an exceedance of the following as measured at the closest exterior wall of any participating or non-participating dwelling:

- **From the hours of 7 am to 10 pm:**
    - **Forty (40) dBA maximum 10 minute Leq or;**
    - **Three (3) dBA maximum 10 minute Leq above background level as determined by a pre-construction noise study. The background level shall be an Leq measured over a representative 15 hour period.**
- **From the hours of 10 pm to 7 am:**
    - **Thirty-seven (37) dBA maximum 10 minute Leq or;**
    - **Three (3) dBA maximum 10 minute Leq above background level as determined by a pre-construction noise study. The background level shall be an Leq measured over a representative 9 hour period.**

LLCHD has modified the recommended allowable levels previously suggested for the Lancaster County Resolution text amendment in January 2015. The main changes to our recommendation are:

- changing the L10 noise metric to the more common Leq,
- changing the daytime limit of 45 dBA L10 to 40 dBA Leq,
- changing the nighttime limit of 40 dBA L10 to 37 dBA Leq,
- reducing the measuring period from 1 hour to 10 minutes,
- reducing the level of noise allowed above existing background noise from 5 dBA to 3 dBA, and
- establishing the same noise levels for both participating and non-participating households, assuring equal public health protection for all persons.

These recommendations are based on the most recent research and review reports cited on the next pages. Of particular importance to the updated recommendations were findings in studies published in late 2014 and early 2015. These studies expanded and improved the knowledge on the potential health risk posed by wind turbine noise, the percentage of people exposed to wind turbine noise that will be annoyed or extremely annoyed, and found that self-reported annoyance was statistically significantly associated with sleep disturbance, and human physiological responses of stress levels (as measured by cortisol) and increased blood pressure (directly measured in exposed individuals).

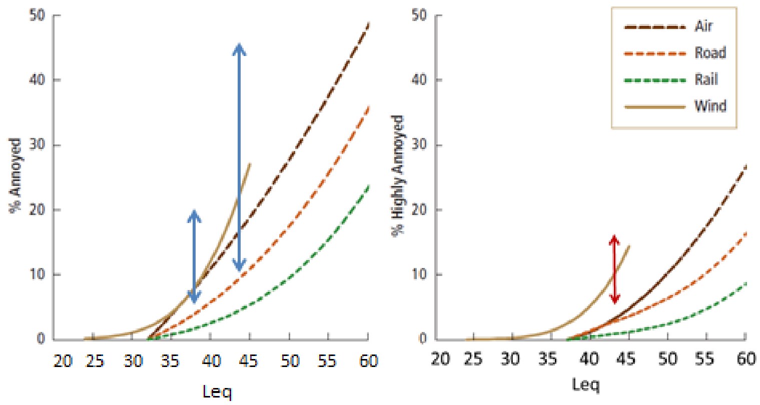
Other factors that influenced LLCHD's recommendation included:

1) Wind turbine noise is more annoying to people than other comparable noise, such as noise from traffic or airports. The primary reason appears to be that wind turbine noise has unique characteristics (significant and frequent amplitude modulation). No matter what the source of noise, if it includes amplitude modulation persons exposed to it will respond as if it were a higher level of noise and indicate that it is more annoying than a noise of the same sound pressure level which does not have amplitude modulation.

2) The 2015 Canadian Academies Expert Panel included this statement in their report: "The Panel stresses that, given the nature of the sound produced by wind turbines and the limited quality of available evidence (small sample sizes, small number of studies available, lack of comprehensive exposure measurement), the health impacts of wind turbine noise cannot be comprehensively assessed at this time."

   This means that there is still considerable uncertainty in potential health impacts with the research that has been conducted to date. In addition, the data on chronic disease health outcomes is significantly limited by the short period of time (last 7 to 10 years) that wind energy systems have grown substantially in number, size, and power output . Chronic disease health outcomes may take 20 to 30 years to develop.

3) Data on annoyance from multiple studies, including the 2015 Health Canada study, indicated that the percentage of people that will be "very" or "extremely" annoyed increases considerably when they are exposed to noise levels above 40 dBA. In late 2014, Schmidt and Klokker indicated that 35 dBA appears to be a "tolerable level". The somewhat older Massachusetts expert panel review (2012) recommended Denmark's nighttime noise limit for residential areas of 37 dBA when wind speeds were 6 m/sec (about 13 mph) and 39 dBA when wind speeds are 8 m/sec (about 18 mph) as a "Promising Practice".



LLCHD estimates of Annoyance with Leq in dB(A)
based on Canadian Academies study Figure 6.1
using a 5dB conversion factor for Lden to Leq
- Range estimates ↕ from Pedersen (2011)
- Range estimate ↕ from Health Canada (2015) of very or extremely annoyed

4) There appears to be evidence that a small percentage of the population is more senstive to wind turbine noise than the population as a whole.

Staff reviewed many studies, papers, news reports, websites, etc. on wind turbines and potential health impacts. Staff considered the following to be the most valuable and scientifically sound.

1) ***Wind Turbine Health Impact Study: Report of Independent Expert Panel***; January 2012; Prepared for: Massachusetts Department of Environmental Protection & Massachusetts Department of Public Health

2) ***Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review.*** This article was written by Jesper Hvass Schmidt and Mads Klokker. (Reference: Schmidt JH, Klokker M (2014) Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. PLoS ONE 9(12): e114183.)

3) ***World Health Organization, Nighttime Noise in Europe***, 2009. ISBN 978 92 890 41737

4) ***Understanding the Evidence: Wind Turbine Noise; The Expert Panel on Wind Turbine Noise and Human Health*** by the Council of Canadian Academies (2015), http://www.scienceadvice.ca/en/assessments/completed/wind-turbine-noise.aspx

5) **Health Canada Wind Turbine Noise and Health Study (2015)**, http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php
This was a very well designed epidemiological study of people residing in 1,238 dwelling units exposed to wind turbine noise.

LLCHD also recommends the following with regard to noise modeling, monitoring and complaints.

1) Pre-construction Noise Modeling. A pre-construction noise study on property with a dwelling within one mile of a tower support base shall be required. The protocol and methodology for such studies shall be submitted to the Lincoln-Lancaster County Health Department for review and approval. The results of such studies shall be submitted to the Lincoln-Lancaster County Health Department for review.

2) Pre-Construction Noise Level Monitoring. Prior to the commencement of construction of any CWECS machine, pre-construction noise monitoring may be conducted to determine ambient sound levels in accordance with procedures acceptable to the Lincoln-Lancaster County Health Department.

3) Post-construction Noise Monitoring. At the discretion of the County Board, post-construction noise level measurements may be required to be performed in accordance with procedures acceptable to the Lincoln-Lancaster County Health Department.

4) CWECS Noise Complaints. All noise complaints regarding the operation of any CWECS shall be referred to the County Board. The County Board shall determine if noise monitoring shall be required to determine whether a violation has occurred.

Wind Turbine Health Impact Study: Report of Independent Expert Panel; January 2012; Prepared for: Massachusetts Department of Environmental Protection & Massachusetts Department of Public Health

The Massachusetts Department of Environmental Protection (MassDEP) in collaboration with the Massachusetts Department of Public Health (MDPH) convened a panel of independent experts to identify any documented or potential health impacts of risks that may be associated with exposure to wind turbines, and, specifically, to facilitate discussion of wind turbines and public health based on scientific findings.

Expert Independent Panel Members:

Jeffrey M. Ellenbogen, MD; MMSc; Assistant Professor of Neurology, Harvard Medical School; Division Chief, Sleep Medicine, Massachusetts General Hospital

Sheryl Grace, PhD; MS Aerospace & Mechanical Engineering; Associate Professor of Mechanical Engineering, Boston University

Wendy J Heiger-Bernays, PhD; Associate Professor of Environmental Health, Department of Environmental Health; Boston University School of Public Health; Chair, Lexington Board of Health

James F. Manwell, PhD Mechanical Engineering; MS Electrical & Computer Engineering; BA Biophysics; Professor and Director of the Wind Energy Center, Department of Mechanical & Industrial Engineering University of Massachusetts, Amherst

Dora Anne Mills, MD, MPH, FAAP; State Health Officer, Maine 1996–2011; Vice President for Clinical Affairs, University of New England

Kimberly A. Sullivan, PhD; Research Assistant Professor of Environmental Health, Department of Environmental Health; Boston University School of Public Health

Marc G. Weisskopf, ScD Epidemiology; PhD Neuroscience; Associate Professor of Environmental Health and Epidemiology; Department of Environmental Health & Epidemiology, Harvard School of Public Health; Facilitative Support provided by Susan L. Santos, PhD, FOCUS GROUP Risk Communication and Environmental Management Consultants

Extensive literature searches and reviews were conducted to identify studies that specifically evaluate human population responses to turbines, as well as population and individual responses to the three primary characteristics or attributes of wind turbine operation: noise, vibration, and flicker. Beyond traditional forms of scientific publications, the Panel also took great care to review other non-peer reviewed materials regarding the potential for health effects including information related to "Wind Turbine Syndrome" and provided a rigorous analysis as to whether there is scientific basis for it. Since the most commonly reported complaint by people living near turbines is sleep disruption, the Panel provided a robust review of the relationship between noise, vibration, and annoyance as well as sleep disturbance from noises and the potential impacts of the resulting sleep deprivation.

In assessing the state of the evidence for health effects of wind turbines, the Panel followed accepted scientific principles and relied on several different types of studies. The non-peer reviewed material was considered part of the weight of evidence. In all cases, data quality was considered; at times, some studies were rejected because of lack of rigor or the interpretations were inconsistent with the scientific evidence. The report cited about 100 specific references and provided a Bibliography containing about 115 reports, papers, regulations, etc. that were considered by the panel.

The Panel came to the following conclusions on health impacts of noise and vibration:

1. Most epidemiologic literature on human response to wind turbines relates to self-reported "annoyance," and this response appears to be a function of some combination of the sound itself, the sight of the turbine, and attitude towards the wind turbine project.

a. There is limited epidemiologic evidence suggesting an association between exposure to wind turbines and annoyance.

b. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.

2. There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption. In other words, it is possible that noise from some wind turbines can cause sleep disruption.

3. A very loud wind turbine could cause disrupted sleep, particularly in vulnerable populations, at a certain distance, while a very quiet wind turbine would not likely disrupt even the lightest of sleepers at that same distance. But there is not enough evidence to provide particular sound-pressure thresholds at which wind turbines cause sleep disruption. Further study would provide these levels.

4. Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.

5. There is insufficient evidence that the noise from wind turbines is *directly (i.e., independent from an effect on annoyance or sleep)* causing health problems or disease.

6. Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically. Available evidence shows that the infrasound levels near wind turbines cannot impact the vestibular system.

7. There is no evidence for a set of health effects, from exposure to wind turbines that could be characterized as a "Wind Turbine Syndrome."

8. The strongest epidemiological study suggests that there is not an association between noise from wind turbines and measures of psychological distress or mental health problems. There were two smaller, weaker, studies: one did note an association, one did not. Therefore, we conclude the weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems**.**

9. None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.

Health Impacts of Shadow Flicker

1. Scientific evidence suggests that shadow flicker does not pose a risk for eliciting seizures as a result of photic stimulation.

2. There is limited scientific evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

Ice Throw

Production of Ice Throw

Ice can fall or be thrown from a wind turbine during or after an event when ice forms or accumulates on the blades.

1. The distance that a piece of ice may travel from the turbine is a function of the wind speed, the operating conditions, and the shape of the ice.
2. In most cases, ice falls within a distance from the turbine equal to the tower height, and in any case, very seldom does the distance exceed twice the total height of the turbine (tower height plus blade length).

Health Impacts of Ice Throw

1. There is sufficient evidence that falling ice is physically harmful and measures should be taken to ensure that the public is not likely to encounter such ice.

Other Considerations

In addition to the specific findings stated above for noise and vibration, shadow flicker and ice throw, the Panel concludes the following:

1. Effective public participation in and direct benefits from wind energy projects (such as receiving electricity from the neighboring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall.

The Panel developed "Best Practices" Recommendations Regarding Human Health Effects of Wind Turbines

Noise

Evidence regarding wind turbine noise and human health is limited. There is limited evidence of an association between wind turbine noise and both annoyance and sleep disruption, depending on the sound pressure level at the location of concern. However, there are no research-based sound pressure levels that correspond to human responses to noise. A number of countries that have more experience with wind energy and are protective of public health have developed guidelines to minimize the possible adverse effects of noise. These guidelines consider time of day, land use, and ambient wind speed. The table below summarizes the guidelines of Germany (in the categories of industrial, commercial and villages) and Denmark (in the categories of sparsely populated and residential). The sound levels shown in the table are for nighttime and are assumed to be taken immediately outside of the residence or building of concern. In addition, the World Health Organization recommends a maximum nighttime sound pressure level of 40 dB(A) in residential areas. Recommended setbacks corresponding to these values may be calculated by software such as WindPro or similar software. Such calculations are normally to be done as part of feasibility studies. The Panel considered the guidelines shown below to be Promising Practices (Category 3) but to embody some aspects of Field Tested Best Practices (Category 2) as well.

Promising Practices for Nighttime Sound Pressure Levels by Land Use Type

Land Use	**Sound Pressure Level dB(A) Nighttime Limits**
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8 m/s wind*	44
Sparsely populated areas, 6 m/s wind*	42
Residential areas, 8 m/s wind*	39
Residential areas, 6 m/s wind*	37

**measured at 10 m above ground, outside of residence or location of concern*

The time period over which these noise limits are measured or calculated also makes a difference. For instance, the often-cited World Health Organization recommended nighttime noise cap of 40 dB(A) is averaged over one year (and does not refer specifically to wind turbine noise). Denmark's noise limits in the table above are calculated over a 10-minute period. These limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance.

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy *(in Massachusetts)* regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.

Shadow Flicker

Based on the scientific evidence and field experience related to shadow flicker, Germany has adopted guidelines that specify the following:

1. Shadow flicker should be calculated based on the astronomical maximum values (i.e., not considering the effect of cloud cover, etc.).
2. Commercial software such as WindPro or similar software may be used for these calculations. Such calculations should be done as part of feasibility studies for new wind turbines.
3. Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern (e.g., residences).
4. Shadow flicker can be kept to acceptable levels either by setback or by control of the wind turbine. In the latter case, the wind turbine manufacturer must be able to demonstrate that such control is possible.

Ice Throw

Ice falling from a wind turbine could pose a danger to human health. It is also clear that the danger is limited to those times when icing occurs and is limited to relatively close proximity to the wind turbine. Accordingly, the following should be considered Category 1 Best Practices.

1. In areas where icing events are possible, warnings should be posted so that no one passes underneath a wind turbine during an icing event and until the ice has been shed.
2. Activities in the vicinity of a wind turbine should be restricted during and immediately after icing events in consideration of the following two limits (in meters).

For a turbine that may not have ice control measures, it may be assumed that ice could fall within the following limit:

$x \left(R\ H \right)_{throw} = 1.5\ 2 + {}_{max,}$

Where: R = rotor radius (m), H = hub height (m)

For ice falling from a stationary turbine, the following limit should be used:

$\left(\right)/15\ {}_{max,}\ x\ U\ R\ H_{fall} = +$

Where: U = maximum likely wind speed (m/s)

The choice of maximum likely wind speed should be the expected one-year return maximum, found in accordance to the International Electrotechnical Commission's design standard for wind turbines, IEC 61400-1. Danger from falling ice may also be limited by ice control measures. If ice control measures are to be considered, the wind turbine manufacturer must be able to demonstrate that such control is possible.

Public Participation/Annoyance

There is some evidence of an association between participation, economic or otherwise, in a wind turbine project and the annoyance (or lack thereof) that affected individuals may express. Accordingly, measures taken to directly involve residents who live in close proximity to a wind turbine project may also serve to reduce the level of annoyance. Such measures may be considered to be a Promising Practice (Category 3).

The following is the Abstract for the December of 2014 PLOS One published an article titled Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. This article was written by Jesper Hvass Schmidt1,2,3*, Mads Klokker4,5 1. Institute of Clinical Research, University of Southern Denmark, Odense, Denmark, 2. Department of Audiology, Odense University Hospital, Odense, Denmark, 3. Department of ENT Head and Neck Surgery, Odense University Hospital, Odense, Denmark, 4. Department of ENT Head and Neck Surgery & Audiology, Copenhagen University Hospital, Copenhagen, Denmark, 5. Faculty of Health and Medical Sciences, Copenhagen University, Copenhagen, Denmark (Refernce: Schmidt JH, Klokker M (2014) Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. PLoS ONE 9(12): e114183.

Background: Wind turbine noise exposure and suspected health-related effects thereof have attracted substantial attention. Various symptoms such as sleep related problems, headache, tinnitus and vertigo have been described by subjects suspected of having been exposed to wind turbine noise.

Objective: This review was conducted systematically with the purpose of identifying any reported associations between wind turbine noise exposure and suspected health-related effects.

Data Sources: A search of the scientific literature concerning the health-related effects of wind turbine noise was conducted on PubMed, Web of Science, Google Scholar and various other Internet sources. Study Eligibility Criteria: All studies investigating suspected health-related outcomes associated with wind turbine noise exposure were included.

Results: Wind turbines emit noise, including low-frequency noise, which decreases incrementally with increases in distance from the wind turbines. Likewise, evidence of a dose-response relationship between wind turbine noise linked to noise annoyance, sleep disturbance and possibly even psychological distress was present in the literature. Currently, there is no further existing statistically-significant evidence indicating any association between wind turbine noise exposure and tinnitus, hearing loss, vertigo or headache.

Limitations: Selection bias and information bias of differing magnitudes were found to be present in all current studies investigating wind turbine noise exposure and adverse health effects. Only articles published in English, German or Scandinavian languages were reviewed.

Conclusions: Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship. There appears, though, to be a tolerable level of around LAeq of 35 dB. Of the many other claimed health effects of wind turbine noise exposure reported in the literature, however, no conclusive evidence could be found. Future studies should focus on investigations aimed at objectively demonstrating whether or not measureable health-related outcomes can be proven to fluctuate depending on exposure to wind turbines.

In 2009, the World Health Organization – Europe published a report titled: Night Noise Guidelines for Europe. The following is an abstract from that report:

The WHO Regional Office for Europe set up a working group of experts to provide scientific advice to the Member States for the development of future legislation and policy action in the area of assessment and control of night noise exposure. The working group reviewed available scientific evidence on the health effects of night noise, and derived health-based guideline values. In December 2006, the working group and stakeholders from industry, government and nongovernmental organizations reviewed and reached general agreement on the guideline values and key texts for the final document of the *Night noise guidelines for Europe.*

Considering the scientific evidence on the thresholds of night noise exposure indicated by Lnight,outside as defined in the Environmental Noise Directive (2002/49/EC), an Lnight,outside of 40 dB should be the target of the night noise guideline (NNG) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly. Lnight,outside value of 55 dB is recommended as an interim target for the countries where the NNG cannot be achieved in the short term for various reasons, and where policy-makers choose to adopt a stepwise approach. These guidelines are applicable to the Member States of the European Region, and may be considered as an extension to, as well as an update of, the previous WHO *Guidelines for community noise* (1999).

Below is a chart from the Executive Summary. This study was NOT specific to wind turbine noise, but did consider noise from all sources, such as traffic, industry, and airplanes.

Table 3
Effects of different levels of night noise on the population's health

Average night noise level over a year $L_{night,outside}$	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30 dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

Council of Canadian Academies, 2015. *Understanding the Evidence: Wind Turbine Noise*. Ottawa (ON): The Expert Panel on Wind Turbine Noise and Human Health, Council of Canadian Academies.

Executive Summary

Demand for renewable energy, including wind power, is expected to continue to grow both in Canada and globally for the foreseeable future. The wind energy sector in Canada has grown at an ever-increasing pace since the 1990s, and Canada is now the fifth-largest market in the world for the installation of new wind turbines. As the sector grows, the wind turbines being installed are getting more powerful. The first megawatt-scale turbines were installed in Canada in 2004, with 3 megawatt models arriving in 2008; larger models up to 7.5 megawatt are currently being tested internationally. To produce this power, turbines have also increased in size. As wind turbines become a more common feature of the Canadian landscape, this new source of environmental sound has raised concerns about potential health effects on nearby residents.

Determining whether wind power causes adverse health effects in people is therefore important so that all Canadians can equitably share in the benefits of this technology.

THE CHARGE TO THE PANEL

In response to growing public concern about the potential health effects of wind turbine noise, the Government of Canada, through the Minister of Health (the Sponsor), asked the Council of Canadian Academies (the Council) to conduct an assessment of the question:

Is there evidence to support a causal association between exposure to wind turbine noise and the development of adverse health effects?

The Charge also includes the following sub-questions:

Are there knowledge gaps in the scientific and technological areas that need to be addressed in order to fully assess possible health impacts from wind turbine noise?

Is the potential risk to human health sufficiently plausible to justify further research into the association between wind turbine noise exposure and the development of adverse health effects?

How does Canada compare internationally with respect to prevalence and nature of reported adverse health effects among populations living in the vicinity of commercial wind turbine establishments?

Are there engineering technologies and/or other best practices in other jurisdictions that might be contemplated in Canada as measures that may minimize adverse community response towards wind turbine noise?

The Panel defined *health* in a way that is consistent with the World Health Organization's concept of health: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). The Panel interpreted *noise* to include both objective measures of acoustic signals in the environment (*sound*), as well as subjective perceptions of sound sensations that are unwanted by the listener (*noise*). As there are a variety of wind turbines available worldwide, with differing sound characteristics, the Panel focused specifically on the type that constitutes almost all of the installed turbines in Canada: modern, three-bladed, tower-mounted, utility-scale (500 kilowatt capacity or more), upwind, horizontal-axis wind turbines that were land-based.

THE PANEL'S APPROACH

To respond to the Charge, the Panel used an evidence-based approach to identify and review relevant research. First, the Panel identified more than 30 symptoms and health outcomes that have been attributed to exposure to wind turbine noise, based on a broad survey of peer-reviewed and grey literature, web pages, and legal decisions.

Empirical evidence related to any associations between these health outcomes and exposure to wind turbine noise was then collected from several sources, including peer-reviewed journal articles, conference papers, and grey literature. More than 300 publications were found through a comprehensive search, and these were narrowed down to 38 relevant studies related to the health effects of wind turbine noise. The body of evidence concerning each health outcome was appraised and assessed according to Bradford Hill's guidelines for causation, and summarized using standard terms adopted from the International Agency for Research on Cancer (IARC). The major steps of the Panel's approach are illustrated in Figure 1.

KEY FINDINGS

Based on its expertise and review of empirical research, the Panel made findings in the following areas:

- Acoustic characteristics of wind turbine noise;
- Evidence of causal relationships between exposure to wind turbine noise and adverse health effects;
- Knowledge gaps and further research; and
- Promising practices to reduce adverse community response.

Other aspects of the Charge, such as the prevalence of adverse health outcomes in Canada, could not be answered because of a lack of data.

ACOUSTIC CHARACTERISTICS OF WIND TURBINE NOISE

1. Sound from wind turbines is complex and variable

Like sound from any source, wind turbine noise can be described by frequency components (which determine pitch), sound pressure levels (which determine *loudness*), and the way both of these change over time. Sound from wind turbines is highly complex and variable, but has some characteristics that are similar to other sources of community noise, such as road and airport traffic noise:

- Sound from wind turbines is *broadband*, composed of sound over a broad range of frequencies.
- The overall sound pressure levels outdoors vary greatly depending on distance, wind speed, and transmission from the source to the receiver.
- However, higher frequencies tend to be reduced indoors and with increasing distance, leading to an emphasis on lower frequencies.

It is amplitude modulated, with sound levels changing over time.

Wind turbines also emit sound with the following characteristics, which are less common than other sources of community noise:

Sounds from wind turbines may extend down to the infrasonic range and, in some cases, may include peaks or tonal components at low frequencies.

Sound emissions from a wind turbine increase with greater wind speed at the height of the blades, up to the turbine's *rated wind speed* (speed at which it generates maximum power), above which sound does not increase.

Sound from wind turbines can exhibit periodic *amplitude modulation*, often described as a "swishing" or "thumping" sound. The causes and consequences of this periodic amplitude modulation are areas of ongoing research, as wind turbine designers and manufacturers seek ways to reduce or mitigate it.

Most sound from wind turbines is produced by interactions between the surface of the blade and the air flowing over it (aerodynamic processes), which is strongest near — but not at — the blade tips. Mechanical noise from the physical movements of the gearbox, generator, and other components produces low-frequency tones in some cases.

2. Standard methods of measuring sound may not capture the low-frequency sound and amplitude modulation characteristic of wind turbine noise

Measurement of sound for health surveillance and research uses standard methods. The most commonly used methods include A-weighting, which emphasizes the frequencies according to human hearing sensitivity, and de-emphasizes low and very high frequencies. Although A-weighted measurement is an essential method, it may fail to capture the low-frequency components of wind turbine sound. In addition, measurement is often averaged over time (L_{eq}), which does not convey changes in sound pressure levels occurring in short periods (for example, within a second). Time-averaged measurement may thus fail to capture amplitude modulation.

A-weighted measurements are an important first step in determining people's exposure to audible sound in most cases, but more detailed measurements may be necessary in order for researchers to fully investigate the potential health impact of specific sources of wind turbine noise. The metrics of sound exposure most relevant to potential health outcomes are not completely understood, however, and remain an important area for further research.

WIND TURBINE NOISE AND ADVERSE HEALTH EFFECTS

The relevant empirical evidence was reviewed and weighted in order to determine the strength of evidence for a causal link between wind turbine noise and each potential adverse health effect.

3. The evidence is sufficient to establish a causal relationship between exposure to wind turbine noise and *annoyance*

The evidence consistently shows a positive relationship between outdoor wind turbine noise levels and the proportion of people who report high levels of annoyance. However, many factors can modify the strength of this relationship, such as a person's attitudes toward wind turbines and any economic benefits the person derives from them. As well, visual and noise effects of wind turbines are difficult to isolate from each other. The current state of the evidence does not allow for a definite conclusion about whether annoyance is caused by exposure to wind turbine noise alone, or whether factors such as visual impacts and personal attitudes modify the noise-annoyance relation — and to what extent, since the studies completed to date do not measure these factors independently of each other. It is also unclear which sound characteristics contribute to long-term chronic annoyance, although low-frequency components and periodic amplitude modulation have been investigated as likely candidates.

4. There is limited evidence to establish a causal relationship between exposure to wind turbine noise and *sleep disturbance*

The available evidence suggests that a direct causal relationship or an indirect (via annoyance) relationship between exposure to wind turbine noise and sleep disturbance might exist. While sleep disruption has been investigated in several studies, the resulting evidence base is smaller than that which examines the relationship between wind turbine noise and annoyance.

5. The evidence suggests a lack of causality between exposure to wind turbine noise and *hearing loss*

There is convincing evidence that exposure to wind turbine noise at typical levels associated with regulated noise limits and setbacks (distance from structures) does not cause loss of hearing, even over a lifetime of exposure.

6. The Panel found inadequate evidence of a direct causal relationship between exposure to wind turbine noise and *stress*, although stress has been linked to other sources of community noise

Available evidence suggests that a direct or indirect mechanism between exposure to wind turbine noise and stress might exist, similar to the finding for sleep disturbance, but the evidence lacks methodological and statistical strength. *Stress* has been identified as a risk factor for a number of other diseases, such as cardiovascular diseases, in the context of long-term exposure to community noise from other sources, such as road, rail, and air traffic. The current evidence related to exposure to wind turbine noise and stress is inconsistent, however.

7. For *all other health effects* considered (fatigue, tinnitus, vertigo, nausea, dizziness, cardiovascular diseases, diabetes, etc.), the evidence was inadequate to come to any conclusion about the presence or absence of a causal relationship with exposure to wind turbine noise

Hypertension and other cardiovascular diseases, diabetes, tinnitus, cognitive or task performance, psychological health, and health-related quality of life have all been the subject of empirical, population-based, wind-turbine noise studies. The evidence, however, was inconsistent or the studies had methodological limitations preventing the determination of a causal relationship between these effects and exposure to wind turbine noise. None of the other health effects considered have been the subject of a population-level study or experiments in the context of wind turbine noise. Therefore, the evidence for a causal association is largely lacking for these other effects. Conclusions about causal relationships are therefore lacking for most of the health effects postulated in a wide variety of sources reviewed by the Panel, mainly as a result of lack of evidence or problems with the quality of evidence. However, research on environmental noise has shown that annoyance can be a contributing factor or precursor to adverse health effects such as sleep disturbance, stress and cardiovascular diseases. The Panel thus developed a conceptual framework of pathways through which sound from wind turbines could plausibly result in health outcomes. Figure 2 shows this framework and summarizes the Panel's findings on the potential causal pathways between exposure to wind turbine noise and the development of adverse health effects, or the exacerbation of existing health conditions.

KNOWLEDGE GAPS AND FURTHER RESEARCH

8. Knowledge gaps prevent a full assessment of public health effects of wind turbine noise

The Panel identified specific knowledge gaps for each health condition studied, where specific types of evidence would help clarify the strength of associations, minimize bias, or eliminate possible confounding factors with respect to exposure to wind turbine noise. For example, it is unclear whether the possible pathway that could lead to sleep disturbance or stress is the direct result of exposure to wind turbine noise or of annoyance as a mediating factor.

Most existing epidemiological studies of wind turbine noise lack sufficient power to detect small changes in the risk of adverse health effects, or were designed in a way that could not rule out bias in responses or adequately control confounding factors. The Panel also identified an absence of longitudinal studies. The Panel stresses that there is a paucity of research on sensitive populations, such as children and infants and people affected by clinical conditions that may lead to an increased sensitivity to sound.

The use of adequate methods and procedures for measuring and modelling sound exposure from wind turbines, particularly indoors, would improve the quality of future studies on adverse health effects (see Key Finding 2).

9. Research on long-term exposure to wind turbine noise would provide a better understanding of the causal associations between wind turbine noise exposure and certain adverse health effects

Chronic annoyance and sleep disturbance have been linked to stress responses in studies of long-term exposure to other sources of noise, such as air and road traffic. Furthermore, these health effects are themselves risk factors for other diseases, such as cardiovascular diseases, which have previously been associated with long-term exposure to other sources of community noise. Given the burden of cardiovascular diseases on society and Canada's health care system, further research on the long-term effects of exposure to wind turbine noise, in particular on stress and sleep disturbance, would provide more data to assess the health effects of wind turbine noise. Finally, the Panel stresses that the available evidence does not allow conclusions with regard to the prevalence of annoyance or other health effects within the population exposed to sound from wind turbines in Canada. Further research and surveillance would provide a better understanding of this prevalence, both in those exposed to wind turbine noise and in the general population.

PROMISING PRACTICES AND TECHNOLOGIES TO REDUCE ADVERSE COMMUNITY RESPONSE TO WIND TURBINE NOISE

10. Technological development is unlikely to resolve, in the short term, the current issues related to perceived adverse health effects of wind turbine noise

Wind turbine designs, modifications, and technology that could reduce sound emissions are currently being explored by wind turbine manufacturers. Ongoing technological development has contributed to lower sound emissions for turbines of a given size over the previous generation of turbines, with further improvements expected. Other factors such as power output favour larger turbines, however, which can offset overall reductions in sound emissions per kilowatt of electricity produced.

11. Impact assessments and community engagement provide communities with greater knowledge and control over wind energy projects and therefore help limit annoyance

Equity and fairness have been crucial for the acceptance of wind turbines in many communities, with perceived loss of social justice and disempowerment being significant barriers to acceptance in some cases. One important regulatory approach is to conduct a noise impact assessment of any proposed project; several Canadian provinces and other countries require such an assessment. In some of the international practices reviewed by the Panel, wind energy developers engaged in consultation and communication with local authorities and residents beginning at an early stage of project development, through all stages of implementation, and even after installation. Community engagement helps to inform and educate local residents, as well as involve them in a wind energy project with the goal of fostering social acceptance.

Wind turbines are a progressively familiar sight in Canada and contribute an increasing share of the electricity consumed in Canada. Concerns over the health effects of wind turbine noise have been expressed in many ways but rarely with detailed, reproducible, and rigorous data sufficient to support a conclusion on either causation or magnitude of any potential health effect. The Panel’s final report is an attempt to objectively and rigorously review empirical research on the causal link between wind turbine noise and adverse health effects, as well as potential solutions to noise-related issues contemplated elsewhere, all of which may help in addressing concerns about wind turbine noise in Canada. The report is intended not only as a tool to inform decision-making and academic research on the subject, but also to inform the continuing dialogue across Canada and internationally, and across many sectors, about wind turbine noise and adverse human health effects.

Health Canada Wind Turbine Noise and Health Study: Summary of Results
http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php#share

Background and Rationale

The Government of Canada is committed to protecting the health and well-being of Canadians. Jurisdiction for the regulation of noise is shared across many levels of government in Canada. Health Canada's mandate with respect to wind power includes providing science-based advice, upon request, to federal departments, provinces, territories and other stakeholders on the potential impacts of wind turbine noise (WTN) on community health and well-being. Provinces and territories, through the legislation they have enacted, make decisions in relation to areas including installation, placement, sound levels and mitigation measures for wind turbines.

Globally, wind energy is relied upon as an alternative source of renewable energy. In Canada wind energy capacity has grown from approximately 137 Megawatts (MW) in 2000 to just over 8.5 Gigawatts (GW) in 2014 (CANWEA, 2014). At the same time, there has been concern from some Canadians living within the vicinity of wind turbine installations that their health and well-being are negatively affected from exposure to WTN.

The scientific evidence base in relation to WTN exposure and health is limited, which includes uncertainty as to whether or not low frequency noise (LFN) and infrasound from wind turbines contributes to the observed community response and potential health impacts. Studies that are available differ in many important areas including methodological design, the evaluated health effects, and strength of the conclusions offered.

In July 2012, Health Canada announced its intention to undertake a large scale epidemiology study in collaboration with Statistics Canada (*Statistics Canada Official Title: Community Noise and Health Study*). The study was launched to support a broader evidence base on which to provide federal advice and in acknowledgement of the community health concerns expressed in relation to wind turbines.

Research Objectives and Methodology

The objectives of the study were to:

- Investigate the prevalence of health effects or health indicators among a sample of Canadians exposed to WTN using both self-reported and objectively measured health outcomes;

- Apply statistical modeling in order to derive exposure response relationships between WTN levels and self-reported and objectively measured health outcomes; and,
- Investigate the contribution of LFN and infrasound from wind turbines as a potential contributing factor towards adverse community reaction.

The study was undertaken in two Canadian provinces, Ontario (ON) and Prince Edward Island (PEI), where there were a sufficient number of homes within the vicinity of wind turbine installations. The study consisted of three primary components: an in-person questionnaire, administered by Statistics Canada to randomly selected participants living at varying distances from wind turbine installations; collection of objectively measured outcomes that assess hair cortisol, blood pressure and sleep quality; and, more than 4000 hours of WTN measurements conducted by Health Canada to support the calculation of WTN levels at residences captured in the study scope. To support the assessment and reporting of data, and permit comparisons to other studies, residences were grouped into different categories of calculated outdoor A-weighted WTN levels as follows: less than 25 dB; 25-<30dB; 30-<35dB; 35-<40dB; and greater than or equal to 40 dB[Footnote1].

Detailed information on Health Canada's *Wind Turbine Noise and Health Study*methodology, including the 60-day public consultation and peer review process is available on the Health Canada website. The detailed methodology for the study is also available in the peer reviewed literature (*Michaud et al., Noise News International, 21(4): 14-23, 2013*).

Preliminary Research Findings[Footnote2]

Health Canada has completed its preliminary analysis of the data obtained. Research findings are presented below in accordance with the study component in which they were obtained i.e. in-person, self-report questionnaire findings, objectively measured responses, and noise measurements and calculations. As with other studies of this nature, a number of limitations and considerations apply to the study findings including:

- results may not be generalized to areas beyond the sample as the wind turbine locations in this study were not randomly selected from all possible sites operating in Canada;
- results do not permit any conclusions about causality; and,
- results should be considered in the context of all published peer-reviewed literature on the subject.

A. *Study Population and Participation*

The study locations were drawn from areas in ON and PEI where there were a sufficient number of homes within the vicinity of wind turbine installations. Twelve (12) and six wind turbine developments were sampled in ON and PEI, representing 315 and 84 wind turbines respectively. All potential homes within approximately 600 m of a wind turbine were selected, as well as a random selection of homes between 600 m and 10 km. From these, one person between the ages of 18 and 79 years from each household was randomly selected to participate.

The final sample size consisted of 2004 potential households. Of the 2004 locations sampled, 1570 were found to be valid dwellings[Footnote3] of which a total of 1238 households with similar demographics[Footnote4] participated, resulting in an overall participation rate of 78.9%. Participation rate was similar regardless of one's proximity to wind turbines and equally high in both provinces. The high response rates in this study help to reduce, but not eliminate, non-response bias[Footnote5].

B. *Self-Reported Questionnaire Results*

Results are presented in relation to WTN levels. For findings related to WTN annoyance, results are also provided in relation to distance to allow for comparisons with other studies. WTN is a more sensitive measure of exposure level and allows for consideration of topography, wind turbine characteristics and the number of wind turbines at any given distance. To illustrate, two similar homes may exist in similar environments located at the same distance from the nearest turbine operating in areas with 1 small and 75 large wind turbines respectively. These homes would be treated the same if the analysis was conducted using only distance to the nearest wind turbine, however they would be completely different in terms of their WTN exposure levels.

The following were not found to be associated with WTN exposure:

- self-reported sleep (e.g., general disturbance, use of sleep medication, diagnosed sleep disorders);
- self-reported illnesses (e.g., dizziness, tinnitus, prevalence of frequent migraines and headaches) and chronic health conditions (e.g., heart disease, high blood pressure and diabetes); and
- self-reported perceived stress and quality of life.

While some individuals reported some of the health conditions above, the prevalence was not found to change in relation to WTN levels.

1. Self-reported Sleep

Long-term sleep disturbance can have adverse impacts on health and disturbed sleep is one of the more commonly reported complaints documented in the community noise literature. Self-reported sleep disturbance has been shown in some, but not all, studies to be related to exposure to wind turbines.

The Pittsburgh Sleep Quality Index (PSQI) is a frequently used questionnaire for providing a validated measure of reported sleep pathology where scores can range from 0-21 and a global score of greater than 5 is considered to reflect poor sleep quality. The PSQI was administered as part of the overall questionnaire, which was supplemented with questions about the use of sleep medication, prevalence of sleep disorders diagnosed by a healthcare professional and how sleep disturbed people were in general over the last year.

Results of self-reported measures of sleep, that relate to aspects including, but not limited to general disturbance, use of sleep medication, diagnosed sleep disorders and scores on the PSQI, did not support an association between sleep quality and WTN levels.

2. Self-reported Illnesses and Chronic Diseases

Self-reports of having been diagnosed with a number of health conditions were not found to be associated with exposure to WTN levels. These conditions included, but were not limited to chronic pain, high blood pressure, diabetes, heart disease, dizziness, migraines, ringing, buzzing or whistling sounds in the ear (i.e., tinnitus).

3. Self-reported Stress

Exposure to stressors and how people cope with these stressors has long been considered by health professionals to represent a potential risk factor to health, particularly to cardiovascular health and mental well-being. The Perceived Stress Scale is a validated questionnaire that provides an assessment of the degree to which situations in one's life are appraised as stressful.

Self-reported stress, as measured by scores on the Perceived Stress Scale, was not found to be related to exposure to WTN levels.

4. Quality of Life

Impact on quality of life was assessed through the abbreviated version of the World Health Organization's Quality of Life scale; a validated questionnaire that has been used extensively in social studies to assess quality of life across the following four domains: Physical; Environmental; Social and Psychological.

Exposure to WTN was not found to be associated with any significant changes in reported quality of life for any of the four domains, nor with overall quality of life and satisfaction with health.

The following was found to be statistically associated with increasing levels of WTN:

- annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts).

5 Annoyance

5.1 Community Annoyance as a Measure of Well-being

The questionnaire, administered by Statistics Canada, included themes that were intended to capture both the participants' perceptions of wind turbines and reported prevalence of effects related to health and well-being. In this regard, one of the most widely studied responses to environmental noise is community annoyance. There has been more than 50 years of social and socio-acoustical research related to the impact that noise has on community annoyance. Studies have consistently shown that an increase in noise level was associated with an increase in the percentage of the community indicating that they are "highly annoyed" on social surveys. The literature shows that in comparison to the scientific literature on noise annoyance to transportation noise sources such as rail or road traffic, community annoyance with WTN begins at a lower sound level and increases more rapidly with increasing WTN.

Annoyance is defined as a long-term response (approximately 12 months) of being "very or extremely annoyed" as determined by means of surveys. Reference to the last year or so is intended to distinguish a long term response from one's annoyance on any given day. The relationship between noise and community annoyance is stronger than any other self-reported measure, including complaints and reported sleep disturbance.

5.2 Community Annoyance Findings

Statistically significant exposure-response relationships were found between increasing WTN levels and the prevalence of reporting high annoyance. These associations were found with annoyance due to noise, vibrations, blinking lights, shadow and visual impacts from wind turbines. In all cases, annoyance increased with increasing exposure to WTN levels.

The following additional findings in relation to WTN annoyance were obtained:

- At the highest WTN levels (≥ 40 dBA in both provinces), the following percentages of respondents were highly annoyed by wind turbine noise: ON-16.5%; PEI-6.3%. While overall a similar pattern of response was observed, the prevalence of WTN annoyance was 3.29 times higher in ON versus PEI (95% confidence interval, 1.47 - 8.68).
- A statistically significant increase in annoyance was found when WTN levels exceeded 35 dBA.
- Reported WTN annoyance was statistically higher in the summer, outdoors and during evening and night time.
- Community annoyance was observed to drop at distances between 1-2km in ON, compared to PEI where almost all of the participants who were highly annoyed by WTN lived within 550m of a wind turbine. Investigating the reasons for provincial differences is outside the scope of the current study.
- WTN annoyance significantly dropped in areas where calculated nighttime background noise exceeded WTN by 10dB or more.
- Annoyance was significantly lower among the 110 participants who received personal benefit, which could include rent, payments or other indirect benefits of having wind turbines in the area e.g., community improvements. However, there were other factors that were found to be more strongly associated with annoyance, such as the visual appearance, concern for physical safety due to the presence of wind turbines and reporting to be sensitive to noise in general.

5.3 Annoyance and Health

- WTN annoyance was found to be statistically related to several self-reported health effects including, but not limited to, blood pressure, migraines, tinnitus, dizziness, scores on the PSQI, and perceived stress.
- WTN annoyance was found to be statistically related to measured hair cortisol, systolic and diastolic blood pressure.
- The above associations for self-reported and measured health endpoints were not dependent on the particular levels of noise, or particular distances from the turbines, and were also observed in many cases for road traffic noise annoyance.
- Although Health Canada has no way of knowing whether these conditions may have either pre-dated, and/or are possibly exacerbated

by, exposure to wind turbines, the findings support a potential link between long term high annoyance and health.
- Findings suggest that health and well-being effects may be partially related to activities that influence community annoyance, over and above exposure to wind turbines.

C. *Objectively Measured Results*

Objectively measured health outcomes were found to be consistent and statistically related to corresponding self-reported results. WTN was not observed to be related to hair cortisol concentrations, blood pressure, resting heart rate or measured sleep (e.g., sleep latency, awakenings, sleep efficiency) following the application of multiple regression models[Footnote6].

1. Measures Associated with Stress

Hair cortisol, blood pressure and resting heart rate measures were applied in addition to the Perceived Stress Scale to provide a more complete assessment of the possibility that exposure to WTN may be associated with physiological changes that are known to be related to stress.

Cortisol is a well-establish biomarker of stress, which is traditionally measured from blood and/or saliva. However, measures from blood and saliva reflect short term fluctuations in cortisol and are influenced by many variables including time of day, food consumption, body position, brief stress, etc., that are very difficult to control for in an epidemiology study. To a large extent, such concerns are eliminated through measurement of cortisol in hair samples as cortisol incorporates into hair as it grows. With a predictable average growth rate of 1 cm per month, measurement of cortisol in hair makes it possible to retrospectively examine months of stressor exposure. Therefore cortisol is particularly useful in evaluating the potential impact that long term exposure to WTN has on one of the primary biomarkers linked to stress.

The results from multiple linear regression analysis reveal consistency between hair cortisol concentrations and scores on the Perceived Stress Scale (i.e., higher scores on this scale were associated with higher concentrations of hair cortisol) with neither measure found to be significantly affected by exposure to WTN. Similarly, while self-reported high blood pressure (hypertension) was associated with higher measured blood pressure, no statistically significant association was observed between measured blood pressure, or resting heart rate, and WTN exposure.

2. Sleep Quality

Sleep was measured using the Actiwatch2™, which is a compact wrist-worn activity monitor that resembles a watch. This device has advanced sensing capabilities to accurately and objectively measure activity and sleep information over a period of several days. This device is considered to be a reliable and valid method of assessing sleep in non-clinical situations. The following measured sleep impacts were considered: sleep latency (how long it took to fall asleep); wake time after sleep onset (the total duration of awakenings); total sleep time; the rate of awakening bouts (calculates how many awakenings occur as a function of time spent in bed); and sleep efficiency (total sleep time divided by time in bed).

Sleep efficiency is especially important because it provides a good indication of overall sleep quality. Sleep efficiency was found to very high at 85% and statistically influenced by gender, body mass index (BMI), education and caffeine consumption.

The rates of awakening bouts, total sleep time or sleep latency were further found in some cases to be related to: age, marital status, closing bedroom windows, BMI, physical pain, having a stand-alone air conditioner in the bedroom, self-reports of restless leg syndrome and being highly annoyed by the blinking lights on wind turbines.

While it can be seen that many variables had a significant impact on measured sleep, calculated outdoor WTN levels near the participants' home was not found to be associated with sleep efficiency, the rate of awakenings, duration of awakenings, total sleep time, or how long it took to fall asleep.

D. *Wind Turbine Noise Measures Results*

Note - To support a greater understanding of the concepts included in this section, Health Canada has developed a short Primer on Noise.

Scientists that study the community response to noise typically measure different sounds levels with a unit called the A-weighted decibel (dBA). The A-weighting reflects how people respond to the loudness of common sounds; that is, it places less importance on the frequencies to which the ear is less sensitive. For most community noise sources this is an acceptable practice. However, when a source contains a significant amount of low frequencies, an A-weighted filter may not fully reflect the intrusiveness or the effect that the sound may have (e.g. annoyance). In these cases, the use of a C-weighted filter (dBC) may be more appropriate because it is similar to the A-weighting except that it includes more of the contribution from the lower frequencies than the A-weighted filter.

1. A- Weighted

More than 4000 hours of WTN measurements conducted by Health Canada supported the calculations of A-weighted WTN levels at all 1238 homes captured in the study sample.

- Calculated outdoor A-weighted WTN levels for the homes participating in the study reached 46 dBA for wind speeds of 8m/s. This approach is the most appropriate to quantify the potential adverse effects of WTN. The calculated WTN levels are likely to be representative of yearly averages with an uncertainty of about +/- 5dB and therefore can be compared to World Health Organization (WHO) guidelines. The WHO identifies an annual outdoor night time average of 40 dBA as the level below which no health effects associated with sleep disturbance are expected to occur even among the most vulnerable people (WHO (2009) *Night Noise Guidelines for Europe*).

2. Low Frequency Noise

Wind turbines emit LFN, which can enter the home with little or no reduction in energy potentially resulting in rattles in light weight structures and annoyance. Although the limits of LFN are not fixed, it generally includes frequencies from between 20Hz and 200Hz. C-weighted sound levels can be a better indicator of LFN in comparison to A-weighted levels, and were calculated in order to assess the potential LFN impacts.

- Calculated outdoor dBC levels for homes ranged from 24 dBC and reached 63 dBC.
- Three (3)% of the homes were found to exceed 60 dBC[Footnote7].
- No additional benefit was observed in assessing LFN because C- and A-weighted levels were so highly correlated (r=0.94) that they essentially provided the same information. It was therefore not surprising that the relationship between annoyance and WTN levels was predicted with equal strength using dBC or dBA and that there was no association found between dBC levels and any of the self-reported illnesses or chronic health conditions assessed (e.g., migraines, tinnitus, high blood pressure, etc.)
- Sound pressure levels were found to be below the recommended thresholds for reducing perceptible rattle and the annoyance that rattle may cause.

As LFN is generally considered to be an indoor noise problem, it was of interest to better understand how much outdoor LFN makes its way into the home.

- At a selection of representative homes, Health Canada measurements showed an average of 14dB of outdoor WTN is blocked from entering a home at low frequencies (16 Hz - 100 Hz) with closed windows compared to an average reduction of 10dB with windows partially open.

3. Infrasound

Long-term measurements over a period of 1 year were also conducted in relation to infrasound levels.

- Infrasound from wind turbines could sometimes be measured at distances up to 10km from the wind turbines, but was in many cases below background infrasound levels.
- The levels were found to decrease with increasing distance from the wind turbine at a rate of 3dB per doubling of distance beyond 1km, downwind from a wind turbine.
- The levels of infrasound measured near the base of the turbine were around the threshold of audibility that has been reported for about 1% of people that have the most sensitive hearing.

Due to the large volume of acoustical data, including that related to infrasound, analysis will continue over subsequent months with additional results being released at the earliest opportunity throughout 2015.

Data Availability and Application

Detailed descriptions of the above results will be submitted for peer review with open access in scientific journals and should only be considered final following publication. All publications by Health Canada related to the study will be identified on the Health Canada website.

Raw data originating from the study is available to Canadians, other jurisdictions and interested parties through a number of sources: Statistics Canada Federal Research Data Centres, the Health Canada website (noise data), open access to publications in scientific journals and conference presentations. Plain language abstracts outlining the research and identifying the scientific journals where papers can be found will further be published to the Departmental website.

Health Canada's Wind Turbine Noise and Health Study included both self-reported and physically measured health effects as together they provide a more complete overall assessment of the potential impact that exposure to wind turbines may have on health and well-being.

Study results will support decision makers by strengthening the peer-reviewed scientific evidence base that supports decisions, advice and policies regarding wind turbine development proposals, installations and operations. The data obtained will also contribute to the global knowledge of the relationship between WTN and health.