



Wind Turbines and Health

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Summary

- **Noise and Low Frequency Sound.** The sound level associated with wind turbines at common residential setbacks is not sufficient to damage hearing but may lead to annoyance and sleep disturbance.
- **Electromagnetic Fields (EMF).** Wind turbines are not significant sources of EMF exposure.
- **Shadow Flicker.** Shadows caused by wind turbine rotors can be annoying but are not likely to cause epileptic seizures at normal operational speeds of 18 to 45 rpm.
- **Ice Throw and Structural Failure.** Risk of injury can be minimized with setbacks of 200 to 500 m, warning signs and/or gated access, and by implementing shutdown procedures during conditions that cause ice to form.

Introduction

Wind turbines are large towers with rotating blades that use wind to generate electricity (Figure 1). A wind farm is a collection of wind turbines. As of December 2012, wind farms produced 6500 MW, approximately 3.0% of Canada's annual electricity

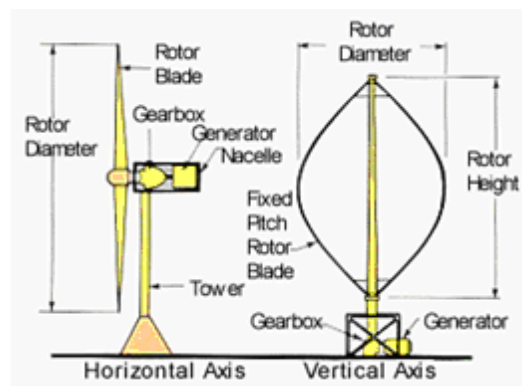


Figure 1. Typical Wind Turbine Configuration¹

consumption, with most provinces planning to significantly increase wind energy production over the next 5 to 10 years. Canada's wind farms are mostly distributed in rural areas throughout the country.²

This document updates the first review published in 2010 and synthesizes available research published since 2009 to January 2013, on the characteristics of wind turbines that may have the potential to affect the health of nearby residents (Table 1).

Wind turbines and health

Case studies have identified a range of complaints that may be associated with wind turbines including noise, dizziness, sleep disruption, and headaches.³ Health Canada has recently commissioned a study to explore the relationship between wind turbine noise and health effects in response to questions from residents living near wind farms. The results of this study are to be published in 2014.⁴

Sound and noise

Sound from wind turbines is caused by the movement of mechanical parts near the central housing (nacelle) or the displacement of air caused by the turning blades. Wind turbines produce both broadband and tonal (distinct pitch) sound.⁵ At 300 to 350 m, the sound level associated with large wind turbines is normally in the range of 35 to 50 dBA, which is comparable to indoor background sound (Figure 2)^{5,6} and not sufficiently high to damage hearing.

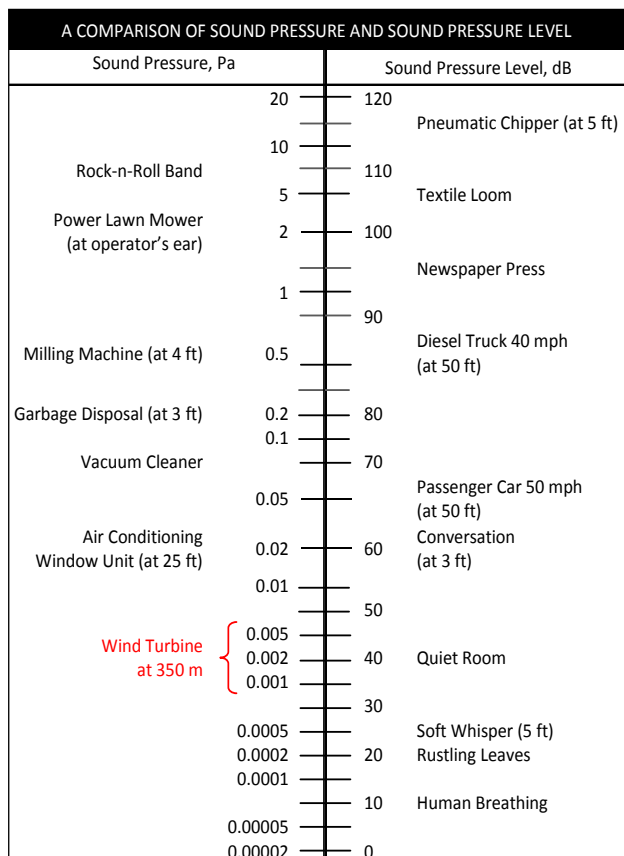


Figure 2. A comparison of sound pressure and sound pressure level (wind turbines in relation to other sources)

Source: Adapted with the permission of CCOHS⁸ with AWEA⁶ and RCMP⁹

Noise is defined as unwanted sound, and perception of noise differs among people and places. Sleep interruption has been associated with wind turbine sound among residents living less than 2.5 km from turbines, particularly when sound levels are above 45 dBA at night;¹⁰ however, some people report noise annoyance from wind turbines at outdoor sound levels below 40 dBA^{11,12} and at lower levels than other sources of environmental noise. When aerodynamic modulation

(swishing sound) occurs, wind turbine sound may be perceived as more annoying than steady sound or “white noise.”¹³ Studies in Sweden and the Netherlands have found dose–response relationships between measured dBA levels, perception of sound, and annoyance.^{10,11,14,15} An analysis of data from two surveys in Sweden and one survey in the Netherlands (N=1820) estimates that less than 14% of the exposed population will be highly annoyed indoors and less than 29% will be highly annoyed outdoors by wind turbines when emission levels, defined as the environmental concentration of a pollutant and usually synonymous with exposure,¹⁶ vary irregularly and unpredictably at a highest allowed emission level of 45 dBA.¹⁷ Annoyance with wind turbine sound is also modified by visual perception,^{11,12,14,18} the belief that turbines are intrusive,^{12,15} and a lack of direct economic benefit.¹⁰ It is also more common in rural areas and in complex versus flat landscapes.¹⁸

Low frequency sound, vibration, and infrasound

Concerns have been raised about human exposure to low frequency sound from wind turbines. Low frequency sound is normally defined as a frequency range from 20 Hz–200 Hz, and infrasound as that below 20 Hz. Although low frequency sound can be audible,¹⁹ human hearing is most sensitive between 1000 and 20000 Hz, which is the range of human speech. Low-level low frequency sound is ubiquitous in the environment (e.g., from wind).

The subjective quality of infrasound below 20 Hz loses tonality and is perceived as more discontinuous, and a sensation of eardrum pressure can occur. Infrasound between 1–20 Hz is measured using the G-weighting curve, and the normal hearing threshold for pure tones is in the level of 90–100 dBG. G-weighted levels below 90 dBG are generally not considered to be detectable by humans.²⁰ However, the measurement of infrasound presents challenges to public health officials because it is difficult to attribute specifically to wind turbines.^{21,22,23,24,25}

The Danish limit for indoor environmental infrasound is 85 dBG, just below the average threshold of hearing.²³ Schust²⁶ provides a comprehensive review of experimental studies, reporting effects such as ear pain, vibration sensations, respiratory effects, and delayed motor response from low frequency sound above 80

dBG. Low frequency and infrasonic sound from upwind^a turbines is lower, typically 50 to 70 dBG.^{23,24} Noise emitted by larger turbines decreases in frequency with increasing turbine size. Thus, if the noise has an outdoor A-weighted level, which corrects measurements to the low-level frequency sensitivity of the human ear, of 40 dBA, there is a risk that some residents will be annoyed by low-frequency noise even indoors. A small increase in sound level at low frequency can result in a large increase in perceived loudness and may be difficult to ignore, even at relatively low sound pressure levels,^{21, 27,28} increasing the potential for annoyance when there is a sizeable low frequency component.²¹ It is suggested that problems can be reduced with an outdoor limit of 35 dBA for large wind turbines.²⁰

A recent study from Australia measured indoor and outdoor infrasound levels at seven locations in urban areas and four locations in rural areas including two residences approximately 1.5 km away from wind turbines. They concluded that rural infrasound levels appeared to be controlled by localized wind conditions. The G-weighted infrasound levels at rural locations both near to and away from wind farms were not higher than levels measured in urban locations, where human activity and traffic appeared to be the main sources of infrasound.²⁹

Electromagnetic fields (EMF)

EMF around wind farms can originate from the grid connection lines, wind turbine generators, electrical transformers, and underground network cables.^{30,31,32} The grid connection lines are similar to other power lines and generate low levels of EMF, comparable to those generated by household appliances. Turbine generators are located inside the turbine's central housing, which is situated 60 to 100 m above ground, and results in little or no EMF at ground level.³¹ Transformers generate EMF which is highest within the wind farm itself. The underground cables that connect the turbines effectively generate no EMF at the surface because of the close placement of phase conductors and screening of the cables.^{30,31} Thus, wind turbines are not considered a significant source of EMF exposure.

^a Upwind turbines, the common modern configuration, are those with the rotor upwind of the turbine. Older "downwind" turbines produced much higher levels of low frequency and infrasound.

Shadow flicker

Shadow flicker occurs when the blades of a turbine rotate under sunny conditions, casting moving shadows on the ground that result in alternating changes in light intensity. The timing, intensity, and location of shadows are influenced by the size and shape of the turbine, landscape features, latitude, weather and layout of the wind farm. Moving shadows have their longest reach when the wind direction is parallel to a straight line between the sun, turbine, and object, and when the sun is low in the sky.^{5, 33}

Epilepsy affects approximately 0.6% of the Canadian population.³⁴ Prevalence of photosensitive epilepsy is estimated to be fewer than 5% of people with epilepsy.³⁵ People with photosensitive epilepsy are photosensitive to flicker frequencies between 5 and 30 Hz.³⁵ Large wind turbine shadow flicker is produced between 0.3–1 Hz and rotate slower than 3 Hz.^{36,37} In smaller turbines, the flicker frequency is at a line between the observer and the position of the sun in the sky.³⁷ In order to ensure shadow flicker frequency does not approach the photosensitivity range, turbine blades should be programmed to stop when blade rotation exceeds 3 Hz (1 hertz = 60 rpm and therefore less than 180 rpm for a three-blade turbine). However, large turbines operate at 18 to 45 rpm (0.3–0.75 hertz) and smaller turbines generally operate below 150 RPM (2.5 hertz).³⁶

Finally, although these moving shadows are not dangerous *per se*, they nonetheless may introduce a distraction hazard for drivers.⁵

Ice throw and ice shed

Ice may form on wind turbines, depending on the presence of low temperature, cloud cover, precipitation, and heavy fog. Ice and ice fragments can be thrown from moving turbine blades or break loose and fall to the ground.^{38,39} Ice throw (i.e., ice projected off the turbine blade) presents a potentially severe public hazard since the ice may be launched far from the turbine. In contrast, ice that sheds or drops from stationary components places service personnel near the wind farm most at risk.

Two types of ice can form on the blades of wind turbines. Glaze ice is smooth, transparent, and highly adhesive; it forms when moisture contacts surfaces colder than 0°C (e.g., ice storms at low elevation). It normally falls straight down shortly after formation. Rime ice, which is granular and opaque, forms at colder

temperatures and is less adhesive. It is sometimes thrown from moving turbines but often breaks into smaller pieces.^{39,40,41} A European survey found that ice fragments shed from wind turbine blades ranged in size from 0.1 to 1.0 kg and were found between 15 and 100 m from the base.³⁹ Reports from approximately 1,000 inspections of a single wind turbine in Ontario between 1995 and 2001 identified 13 occasions of ice build-up. On each occasion, ice fragments of up to 30 × 30 × 5 cm were found on the ground, mostly within 100 m of the turbine.³⁸ Ice throw distances therefore, appear to be well below setback regulations of 550 metres.

The extent of ice formation and resulting ice throw depends on a number of factors: climate conditions, wind speed and operational range of turbines, direction of blades in relation to people or structures, turbine dimensions, terrain, and structural factors such as anti-adhesive coatings or dark coloured (heat absorbing) blades.^{38,39,41} To minimize risk, turbines can be stopped during icy conditions and restarted only when no ice remains on the blades.³⁹

Key Gaps in Evidence

- Sleep disruption and health effects from long-term exposure to low levels of low frequency sound and infrasound
- Standards and practice for outdoor measurement methods for attributing sound specifically to wind turbines
- Optimum design and setback to avoid health effects
- Epidemiological data to assess physical and psychological health status before and after wind farm development

Structural hazards

In documented cases of wind turbine blade failure, the maximum reported throw distance is 150 m for an entire blade, and 500 m for a blade fragment. A Dutch handbook using 1980–2001 data³⁸ indicated the risk of partial blade failure was 1 in 4,000 turbines per year, and the risk of full blade failure was between 1 in 2,400 and 1 in 20,000 turbines per year, depending on rotor speed. There have been reported instances of turbine collapse and blade failure in Europe and the US.^{42,43} Because structural failure is potentially fatal, careful monitoring is essential.⁴² Other injuries and fatalities associated with wind turbines have been reported,^{44,45} mostly to workers during construction and in transport accidents. Wind turbine structures are designed to withstand ice loads on the blades, but ice and snow build-up can contribute to structural failure and hamper performance.^{40,46,47} Although most turbines are designed to withstand temperatures as low as –20 to –40°C, structural materials can be compromised by extreme cold.⁴⁷ Cold stress can cause steel and/or composite components to crack or deform, interfere with electrical equipment, or damage moving parts in the gearbox,^{41,46} increasing the risk of turbine failure.

Setbacks and operating conditions

Setbacks and operational guidelines can be used to address safety hazards, sound levels, land use issues, and impacts on people (see Table 2).

Table 1. Summary of potential wind turbine hazards and mitigation options

Hazard	Possible Sources	Evidence	Mitigation
Sound/Noise	Turbine mechanics or blade motion (aerodynamic)	<ul style="list-style-type: none"> • Sound levels are below health and safety limits • Annoyance and sleep disruption may occur when sound levels are 40 to 45 dBA • Noise perception is associated with visual impact, lack of direct economic benefit, and perception of turbines as intrusive 	<ul style="list-style-type: none"> • Utilize setbacks and land use planning to minimize sound levels and sound propagation
Low frequency sound Infrasound	Turbine mechanics or blade motion (aerodynamic)	<ul style="list-style-type: none"> • Evidence of health effects at levels > 80 dB • Lack of evidence regarding levels produced by wind turbines (< 70 dB) 	<ul style="list-style-type: none"> • Install turbines with rotor upwind of turbine base • Utilize setbacks to minimize sound levels
EMF	Generators Grid connection lines Transformers Underground cables	<ul style="list-style-type: none"> • No community exposure from turbine EMF • No EMF generated at surface from underground cables 	<ul style="list-style-type: none"> • N/A
Shadow flicker	Blade motion when sun is low in sky	<ul style="list-style-type: none"> • Flicker frequency (0.5–1 Hz) for large turbines is below range likely to induce epileptic seizures 	<ul style="list-style-type: none"> • Use of non-reflective and/or dark coloured blades • Maintain flash frequency below 3 Hz (< 180 rpm for 3-blade turbine)
Ice throw / Ice shed	Glaze or rime ice falling from stationary turbine or thrown from moving blades	<ul style="list-style-type: none"> • Physical danger to people or passing vehicles • Ice tends to fall straight down; usually falls well within setbacks 	<ul style="list-style-type: none"> • Utilize setbacks to minimize risk of injury from ice fall • Cease turbine operation during icing conditions • Use warning signs and/or gated access to alert anyone in the area of risk
Structural failure	Blade or tower cracking or falling	<ul style="list-style-type: none"> • Physical danger to people or passing vehicles • Cases of failure rare and normally contained within 500 m of base 	<ul style="list-style-type: none"> • Utilize setbacks to minimize risk of injury in the event of structural failure • Use warning signs and/or gated access to alert anyone in the area of risk

Table 2. Examples of Canadian wind turbine setback guidelines and regulations*

Reason	Setback/Guideline	Comments	Source																							
Sound	<p>≤ 6 m/sec wind speed:</p> <ul style="list-style-type: none"> • 40 dBA Class 3 (rural) • 45 dBA Class 1 (urban) & Class 2 (major centre with quiet nights) <p>10 m/sec wind speed:</p> <ul style="list-style-type: none"> • 51 dBA 	<ul style="list-style-type: none"> • Proposed minimum 550 m setback to ensure noise is less than 40 dB at the receptor (defined as centre of dwelling, or 30 m from the dwelling façade in the direction of the turbine, whichever has higher noise impact) • Distance depends on sound rating and number of turbines • Perceptible infrasound and low frequency sound should be monitored and addressed 	Ontario Ministry of the Environment (NPC-232) ^{48,49,50}																							
Sound	<table border="1"> <thead> <tr> <th rowspan="2">SPL (dBA)</th> <th colspan="3">Number of Turbines</th> </tr> <tr> <th>1–5</th> <th>6–10</th> <th>11–25</th> </tr> </thead> <tbody> <tr> <td>102</td> <td>550 m</td> <td>650 m</td> <td>750 m</td> </tr> <tr> <td>104</td> <td>600 m</td> <td>700 m</td> <td>850 m</td> </tr> <tr> <td>105</td> <td>850 m</td> <td>1000 m</td> <td>1250 m</td> </tr> <tr> <td>107</td> <td>950 m</td> <td>1200 m</td> <td>1500 m</td> </tr> </tbody> </table>	SPL (dBA)	Number of Turbines			1–5	6–10	11–25	102	550 m	650 m	750 m	104	600 m	700 m	850 m	105	850 m	1000 m	1250 m	107	950 m	1200 m	1500 m	<ul style="list-style-type: none"> • Proposed (September 2009) setbacks for compliance with MOE Noise Limits • Based on number of turbines in wind farm (5, 10, or 25) and sound power level (SPL) rating of turbines expressed as dBA 	Ontario Ministry of the Environment ⁵¹
SPL (dBA)	Number of Turbines																									
	1–5	6–10	11–25																							
102	550 m	650 m	750 m																							
104	600 m	700 m	850 m																							
105	850 m	1000 m	1250 m																							
107	950 m	1200 m	1500 m																							
Sound	<p>6–9 m/sec wind speed:</p> <ul style="list-style-type: none"> • 40 dBA (night, rural) 	<ul style="list-style-type: none"> • Noise impact assessments must be conducted to assess impact of energy projects on nearest or most impacted residence 	Alberta Directive ⁵²																							
Sound	<p>8–11 m/sec wind speed:</p> <ul style="list-style-type: none"> • 40 dBA (residential) 	<ul style="list-style-type: none"> • Based on wind speed at which power is constant, normally 8 to 10 m/sec. Otherwise 11 m/sec is used 	British Columbia <i>Land use operational policy, wind power projects on Crown Land</i> ⁵²																							
Sound	<ul style="list-style-type: none"> • < 45 dBA at receptor 	<ul style="list-style-type: none"> • Proposed guidelines for Canada • Designed to comply with WHO recommendation of sound levels indoors < 30 dBA for continuous background noise for good night's sleep (with 20 dB attenuation by dwelling) 	Keith et al. ⁵²																							
Structural failure	<ul style="list-style-type: none"> • 150 m to 500 m 	<ul style="list-style-type: none"> • To minimize risks from potential blade failure 	Garrad Hassan Canada Inc. ³⁸																							
Ice throw	<ul style="list-style-type: none"> • 200 m to 250 m 	<ul style="list-style-type: none"> • For protection from ice throw 	Morgan et al. ³⁹																							
	<ul style="list-style-type: none"> • 230 m to 350 m 		Jacques Whitford ⁴³																							
Public road safety	<ul style="list-style-type: none"> • 1 blade length + 10 m from public road 	<ul style="list-style-type: none"> • Risk assessment required for towers within 50 to 200 m of public road 	CanWEA																							
Physical safety	<ul style="list-style-type: none"> • 1 blade length + 10 m from all property lines 	<ul style="list-style-type: none"> • To minimize risk from ice or blade fragments • Setback not necessary if all property owners agree 																								

*Setbacks for wind farms in Canada are often managed through municipal by-laws, which are too numerous to list here.

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