VERMONT
DEPARTMENT OF HEALTH

Potential Impact on the Public's Health from Sound Associated with Wind Turbine Facilities

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Summary

The Vermont Department of Health conducted a literature review of the potential human health effects from exposure to sound and vibration from wind-powered electrical generating facilities, as requested by the Vermont Department of Public Service.

To do this, we convened a panel of public health scientists who are experienced in reviewing the quality of the scientific literature on health protection, and in assessing the adequacy of the evidence that an exposure can cause, or contribute to, an adverse health outcome. The Health Department panel drew primarily upon the most recent and most comprehensive literature reviews conducted by other expert panels. These included citations for hundreds of primary research studies on the health effects of exposure to sound generally, and to wind turbine sound specifically.

From this extensive review, the Vermont Department of Health concludes that there is no direct health effect from sound associated with wind turbine facilities. However, there is sufficient evidence of a secondary health effect from sleep disturbance due to excessive sound at night. The potential adverse health effects that can result from sleep disturbance include increased heart rate, sleep state changes and awakening, increased use of medications to aid sleep, increased body movements, insomnia, fatigue, accidents, reduced performance, cardiovascular illness and depression and other mental illness (WHO 1999). The 1999 WHO report also concludes that limiting sound exposure at night to reduce the probability of sleep disturbance can minimize these effects in the exposed population.

To protect public health, the Vermont Department of Health recommends that nighttime sound levels from wind turbines be limited 40 decibels or less, as measured at the exterior facade of the dwelling and averaged over 12 months of exposure. This is consistent with the most recent recommendations of the World Health Organization (WHO 2009).

This review and conclusions are general in nature. No specific wind turbine facility has been assessed.

Discussion

Sound from Wind Turbine Facilities

The frequency range of human hearing is between 20 and 20,000 hertz or Hz. Sounds from wind turbines may exist throughout that range, but are predominantly experienced at frequencies less than 1,000 Hz (Roberts and Roberts 2009). In addition to frequency, the intensity of the sound at specific frequencies is important to human sensation. Sound intensity, or more exactly, sound pressure level, is measured in decibels (dB). The term dBA is used for sound pressure levels weighted to the range of human hearing.

The sound pressure level as measured in decibels (dB) for a whisper is 30 dB, and for the sound of rustling leaves or soft music is 45 dB. Very loud sounds above 90 dB may be experienced as painful. A gunshot or police siren 100 feet away could reach 140 dB. (Colby *et al* 2009, Roberts and Roberts 2009, WHO 1999, WHO 2009). For frequencies predominant at wind turbine facilities, the hearing threshold is about 25 dB (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009).

"Infrasound" is sound below the normal frequency range of hearing unless experienced at high levels (Colby et al 2009). Infrasound and other low frequency sound below 100 Hz travel farther than higher frequencies, penetrate physical barriers such as walls and windows with little attenuation, and are associated most often with sound-induced vibrations (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009).

Sounds emitted from wind turbines are generally classified as mechanical (from the movements of the physical components) and aerodynamic. Aerodynamic sound from the movement of air by the turbine rotors is the dominant source of sound from wind turbines, and is in the lower frequency range of audible sound at 500 to 1,000 Hz (Roberts and Roberts 2009). An inaudible spectrum of frequencies, or infrasound, is also generated. Mechanical sound is unlikely to exceed aerodynamic sound, except when the turbine is not functioning properly (Minnesota Department of Health 2009).

Possible Health Effects of Sound from Wind Turbine Facilities

Given that the dominant source of sound from wind turbine facilities is low frequency, this review focused especially on the literature relating to health effects of low frequency sound and infrasound.

In a report for the Wisconsin Public Service Commission, Roberts and Roberts (2009) conducted a thorough review of this literature that included 156 articles. Of these, 99 dealt with low frequency sound and health effects, 16 with infrasound and health effects, 21 with wind turbines or wind power and sound, and 20 with wind turbines alone. They concluded that:

> The effects of low frequency noise and vibration have not been well characterized,[*sic*] objective body vibration results only from very high levels of low frequency noise, greater than those produced by wind turbines. Sleeplessness and insomnia have been associated with low frequency noise, but this finding has been poorly correlated and lacking in consistency. However the level of annoyance with low frequency noise was found to be correlated with insomnia.

In a review prepared for the American and Canadian Wind Energy Associations, Colby *et al* (2009) documented how low frequency sound and infrasound can only be heard at higher decibels compared to higher frequency and audible sound waves. They reviewed several studies that indicate wind turbine sound at typical distances of exposure are unlikely to be audible below 50 Hz. This review concluded that "the body of accumulated knowledge provides no evidence that the audible or subaudible sounds emitted by wind turbines have any direct adverse physiological effects."

Colby *et al* rejected "annoyance" as a direct adverse physiological effect, but recognized that annoyance could undermine coping and progress in some individuals to result in stress-related effects. They noted that a predominant stress-related effect is sleep disturbance, and that this may lead to other health consequences. The authors wrote that audible low frequency sound is unlikely to disturb sleep until it is 10 to 15 dB greater

than the hearing threshold. For low frequencies, predominant in wind turbine facility exposures, the hearing threshold starts in the 25 dB range (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009). Therefore, sleep disturbance may occur at sound levels from wind turbine facilities as low as 35 to 40 dB.

The Minnesota Department of Health (2009) described studies that supported a sound limit outside the home. These studies describe the results from survey questionnaires indicating higher numbers of complaints or self-reported symptoms of exposure for populations in Sweden and the Netherlands. In the two Swedish studies, reported annoyance doubled when exposures were calculated to be greater than 40 dBA, compared to 30 to 40 dBA. In the Dutch study, annoyance rose from 2 percent of the respondents who were exposed to 30 dBA or less to 25 percent for those with calculated exposures greater than 45 dBA.

Guidelines for the Protection of Human Health

The World Health Organization (WHO) published two reports, in 1999 and in 2009, on the protection of human health from all sources of sound exposure, but not specifically sound from wind turbines. These reports included comprehensive reviews of hundreds of scientific papers and set health protection guidelines.

In their 1999 report, *Guidelines for Community Noise*, an international expert panel established consensus guidelines for preventing interference with speech, hearing impairment, annoyance and sleep disturbance due to community noise. Their recommendations were also applied to various environments, including homes and schools both urban and rural. The report set guidelines for preventing sleep disturbance during the nighttime at 30 dBA in the bedroom averaged over eight hours, with a maximum of 45 dB (WHO 1999).

In 2009, the WHO published *Night Noise Guidelines for Europe* as an extension of its 1999 report. In this document, the expert panel identified 40 dB as the lowest observed

level for adverse health effects. This recommended limit is for an average exposure for a 12 month period, where the sound is measured or modeled at the outside facade of a dwelling where a person lives and sleeps. As with the earlier WHO guidelines, this recommended limit is for the prevention of adverse effects due to sleep disturbance. In the 2009 report, the WHO stated that there was a causal relationship between nighttime noise-generated disturbance of sleep and adverse health effects. In the WHO 1999 report, these associations were described only as weak. Epidemiological findings collected after the 1999 report (see below) provided the WHO stronger evidence of causality.

In both the 1999 and 2009 reports, the WHO identified populations that are more vulnerable to adverse health effects from noise, and should be considered when developing regulations or recommendations. In its Large Analysis and Review of European housing and health Status final report (*WHO LARES Final Report Noise Effects and Morbidity* 2004), the WHO presents data about the actual health experiences relative to noise for vulnerable populations, particularly children and the elderly. This report provides much of the epidemiological basis of the WHO 2009 conclusion that there is a causal relationship between sleep disturbance and adverse health effects. This relationship was especially the case for adverse effects on the cardiovascular, respiratory and musculoskeletal systems, and for depression.

The U.S. Environment Protection Agency (EPA) guidance published in 1974 is consistent with the more recent WHO 2009 40 dB nighttime yearly average guidelines. The EPA recommended that indoor day to night levels not exceed 45 dBA averaging over a 24-hour period, where 10 dB extra weight is given to nighttime sounds between 10 p.m. and 7 a.m., to minimize sleep disruption (EPA 1974).

Conclusions

The Vermont Department of Health concludes that there is no direct health effect from sound associated with wind turbine facilities. However, as determined in the 1999 WHO report, there is sufficient evidence of a secondary health effect from sleep disturbance due to excessive sound at night. The potential adverse health effects that can result from sleep

disturbance include increased heart rate, sleep state changes and awakening, increased use of medications to aid sleep, increased body movements, insomnia, fatigue, accidents, reduced performance, cardiovascular illness and depression and other mental illness (WHO 1999). The 1999 WHO report also concludes that limiting sound exposure at night to reduce the probability of sleep disturbance can minimize these effects in the exposed population.

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Note

The scope of this literature review is limited as described above, and does not review or elaborate on potential health effects from very high level sounds associated with acoustic trauma or hearing loss that is not likely to result from public exposures to wind turbines (Colby *et al* 2009; Minnesota Department of Health 2009; Roberts and Roberts 2009). The intensity of sound generally required for these effects are unlikely, except very near or inside a wind turbine as might be the case for occupational exposures at a wind turbine facility. This review is focused on protecting public health.

Glossary

The following definitions are taken from the 1999 publication of the World Health Organization referenced in this report (1999):

Adverse effect: A change in morphology and physiology of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences. This definition includes any temporary or long-term lowering of physical, psychological or social functioning of humans or human organs.

Acoustic trauma: Injury to hearing by noise, especially loud noise.

A-weighting: A frequency dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies.

Annoyance: A feeling of displeasure associated with any agent or condition known or believed by an individual or group to be adversely affecting them.

Cardiovascular: Pertaining to the heart and blood vessels.

Decibel (dB): Unit of level when the base of the logarithm in the tenth root of ten, and the quantities concerned are proportional to power.

dBA: A weighted frequency spectrum in dB, see A-weighting.

Frequency: For a function periodic in time, the reciprocal of the period.

Hearing impairment, hearing loss: A decreased ability to perceive sounds as compared with what the individual or examiner would regard as normal.

Hertz: Unit of frequency, the number of times a phenomenon repeats itself in one unit of time; abbreviated to Hz.

Mental health: In noise research, mental health covers a variety of symptoms, ranging from anxiety, emotional stress, nervous complaints, nausea, headaches, instability, argumentativeness, sexual impotency, changes in general mood and anxiety, and social conflicts, to more general psychiatric categories like neurosis, psychosis and hysteria.

Morphological: Pertaining to the science of structure and form of organisms without regard to function.

Noise: Undesired sound.

Stress: The sum of the biological reactions to any adverse stimulus, physical, mental or emotional, internal or external, that tends to disturb homeostasis.

References

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