Wind Turbine Noise: Effects on Human Health

Zoning Board of Appeals
Christian County, Illinois
June 23, 2020

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LBGA
EXHIBIT
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Abbreviations

AHEs: Adverse health effects
IWTs: Industrial wind turbines
WHO: World Health Organization
WTN: Wind turbine noise

Topic Outline

- Physical nature of WTN
- Common health effects of WTN exposure
- Research evidence that WTN causes AHEs
- Methods of limiting WTN
- Standards and guidelines relevant to WTN

Professional Background

- Educational background
  - BA, Wake Forest University, Psychology
  - MS, Vanderbilt University, Hearing and Speech Sciences
  - PhD, Northwestern University, Audiology
- Clinically certified in Audiology (American Speech-Language-Hearing Association)
- 50+ years experience as audiology clinician, researcher, teacher, and administrator in academic, clinical, professional association, hospital, and industrial settings (last 30 years at MSU); retired from MSU faculty (2011)
- Numerous research publications and conference presentations, including several recent papers on wind turbine noise
- Chair of Technical Work Group to revise Michigan guidelines for siting onshore wind turbines
- Legal consultant as expert witness on matters of health in variety of cases in multiple states
- (Details in CV; available on request)

Wind Turbine Noise: Professional Experience

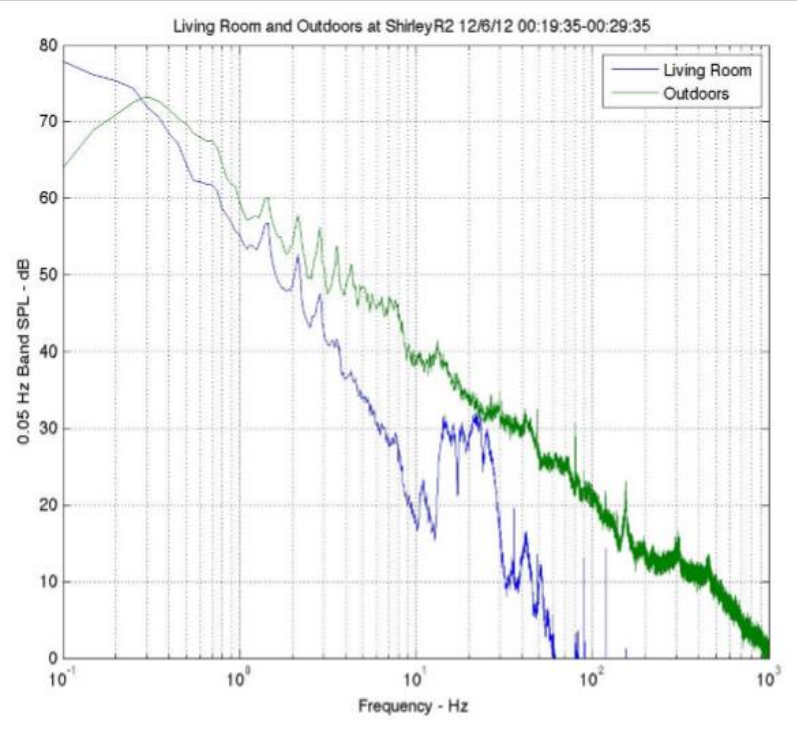
- Visited wind project in Huron County, MI (2009)
- Read book by Paul Gipe, *Wind Energy Comes of Age*
- Published literature review article in *Audiology Today* in 2010
- Chaired Wind and Health Technical Work Group, MI Department of Energy
- Presented invited comments in public meetings and hearings of zoning boards and commissions in several states (MI, IL, IN, NY)
- Co-authored three-part, invited article (hearinghealthmatters.org)
- Qualified legally as health expert in Daubert hearing (MI)
- Served or serving as witness, as health expert, in legal cases (OH, WI, MI, IA, IL, OR, IN, NY, SD), before or after turbine construction
- Interviewed individuals and families who had abandoned, or about to abandon, their homes (MI, IA, OR)
- Co-authored 2016 literature review (with R. James): *Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks*

My First View of IWTs (Huron County, Michigan)

Family Home in Huron County, Michigan

This family was sleeping in a motel during nights when the turbines were fully operational.

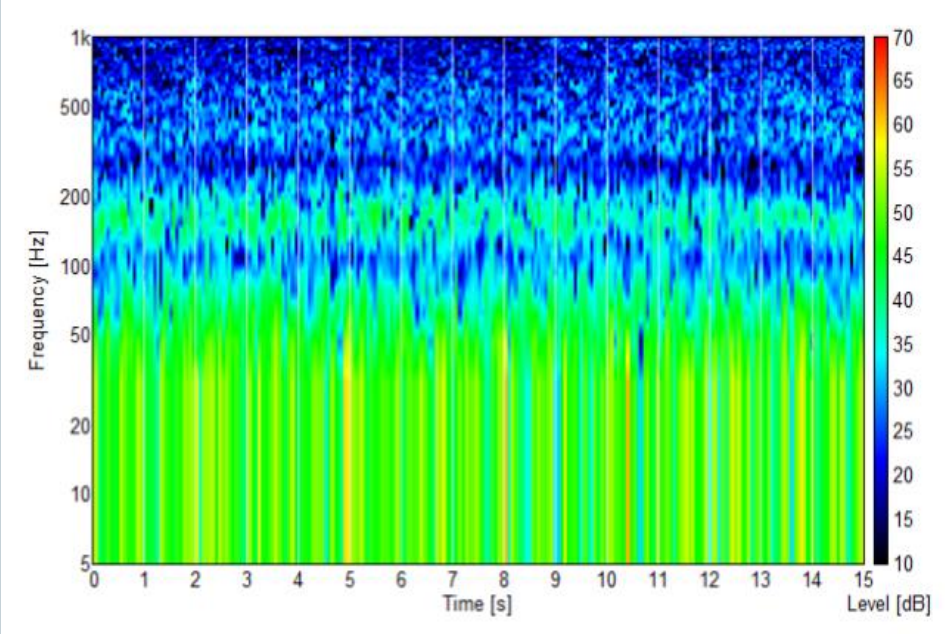
Physical Nature of WTN



Acoustical measurements taken at a home in proximity to Shirley Wind Project, Brown County, Wisconsin.

- The frequency response of WTN consists of extremely high levels of low-frequency energy.
- Due to room resonance effects, WTN can often be more intense indoors than outdoors.
- Because IWTs operate mostly at night, WTN can be especially bothersome in a closed bedroom.

Physical Nature of WTN (Continued)



Spectrogram of WTN at Shirley Wind Project, Brown County, Wisconsin (James & Bray, 2010).

- WTN is amplitude modulated over very short periods of time. In that respect, it is different from other industrial noises and transportation noises.
- Interactions of the blades with the air and tower result in blade-pass energy that produces intermittent tonal energy that often 10 dB or more higher than average values.
- These high levels of pulsating energy occur at infrasonic rates, typically 1/sec or less, making it more disturbing than most other noises.
- These characteristics result in both auditory and non-auditory sensations. A whooshing sound can usually be heard, along with a perception of vibration, either of which can disrupt sleep.

Nuisance, Annoyance, and Health

- A term used mainly in state and local noise-control regulations to protect the use and enjoyment of personal property; a nuisance can be annoying but carries a stronger connotation of being legally actionable.
- The WHO treats nuisance and annoyance as essentially the same thing, defining *annoyance* as "any sound that is perceived as irritating or a nuisance."
- The WHO defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." It considers long-term annoyance induced by noise to be an AHE.
- Many scientific studies, along with the WHO, have described WTN to be annoying to a substantial percentage of the population.

Numerous research studies link annoyance and low-frequency noise

- Kelley et al (1982)*
- Kelley et al (1985)*
- Kelley (1987)*
- Bradley (1994); HVAC systems
- Leventhall (2004); occupational settings
- Pedersen & Waye (2004)*
- van den Berg (2004)*
- Pedersen & Waye (2007)*
- Pedersen et al (2009)*
- Janssen et al (2010)*
- Harrison (2011)*
- Shepherd et al (2011)*
- Palmer (2013)*

*Study dealt specifically with low-frequency noise from wind turbines. See Punch & James, 2016, for full references.

IWTs have many annoying characteristics

- ***Industrial wind turbines produce pulsed, amplitude-modulated, tonal sounds that are unpredictable, uncontrollable (by receptors), and sleep-disturbing.***
- *Amplitude-modulated* and *impulsive* noises are more easily perceived and more annoying than constant-level noise (Sutherland & Burke, 1979; Bradley, 1994).
- *Tonal sounds* are more annoying than sounds containing energy across a broad range of frequencies (Moorhouse et al, 2005; Bray, 2007; Swinbanks, 2012).
- Sounds that are *unpredictable* and *uncontrollable* increase noise annoyance (Geen & McCown, 1984; Hatfield et al, 2002).
- *Nighttime noise* is more annoying than daytime noise (Berger et al, 2015; Berglund et al, 1999; WHO, 2009).
- *Rural noise* is more annoying than urban noise (Pedersen & Waye, 2007).

Annoyance from Wind Turbines

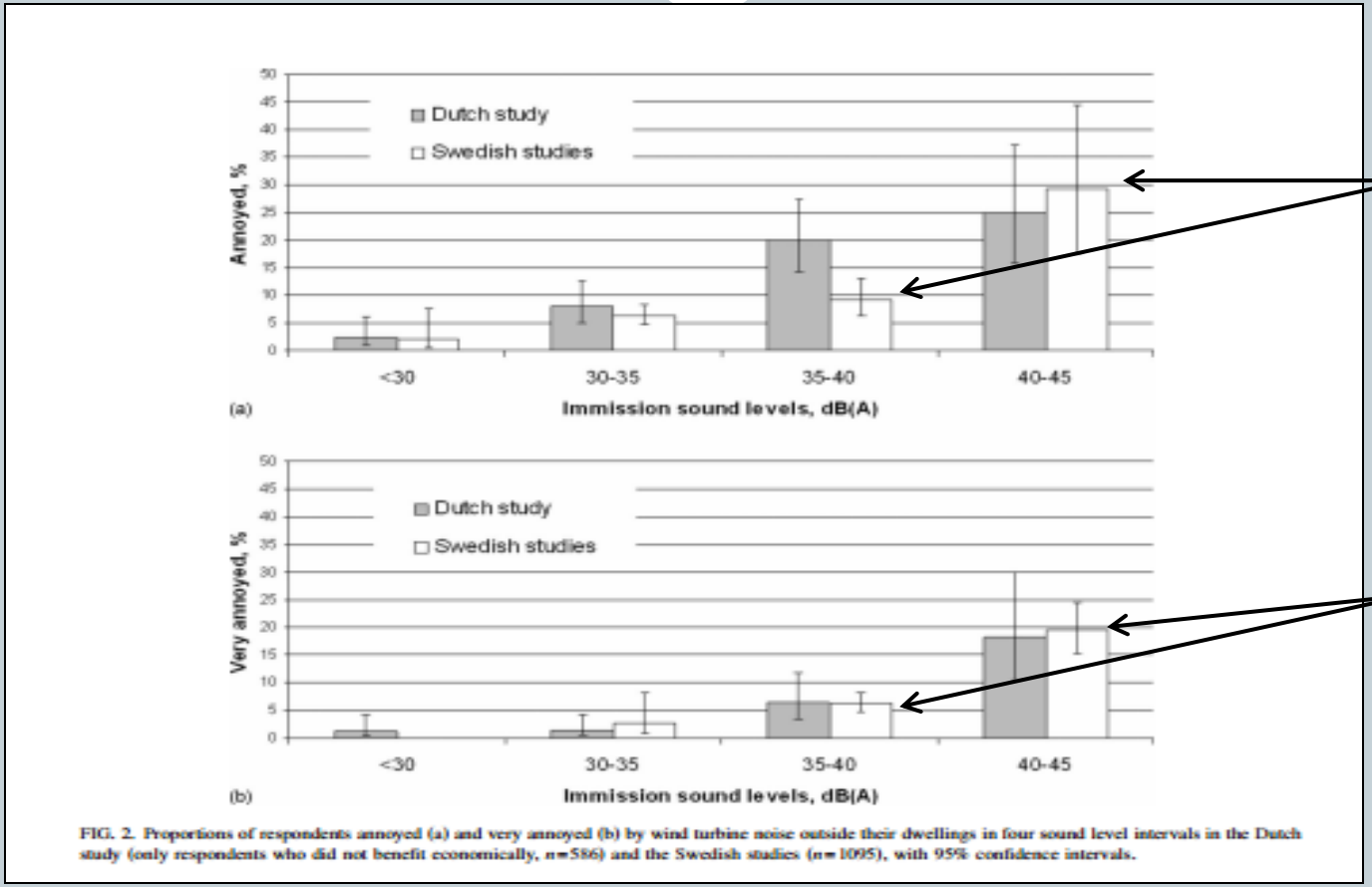


FIG. 2. Proportions of respondents annoyed (a) and very annoyed (b) by wind turbine noise outside their dwellings in four sound level intervals in the Dutch study (only respondents who did not benefit economically, $n=586$) and the Swedish studies ($n=1095$), with 95% confidence intervals.

Source: Pedersen, E. et al (2009). Response to noise from modern wind farms in The Netherlands. *Journal of the Acoustical Society of America*, *126*, 634-643.

IWT noise is much more annoying than aircraft, traffic, or rail noise

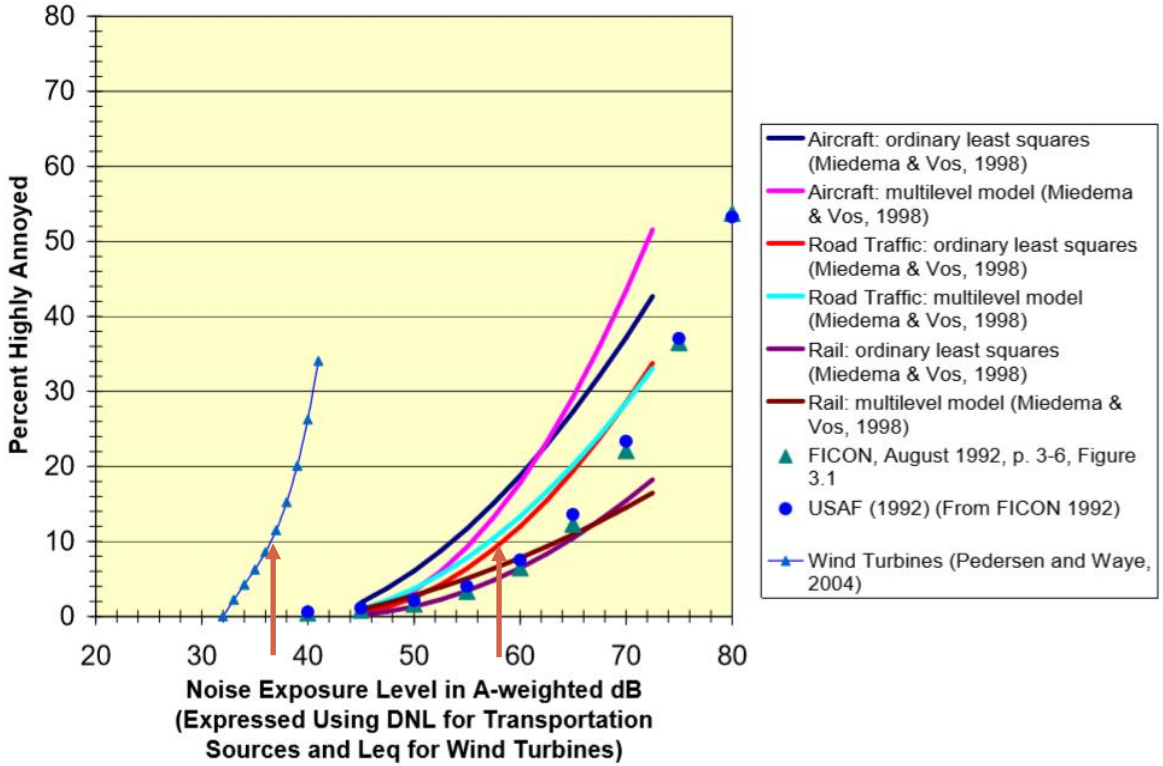
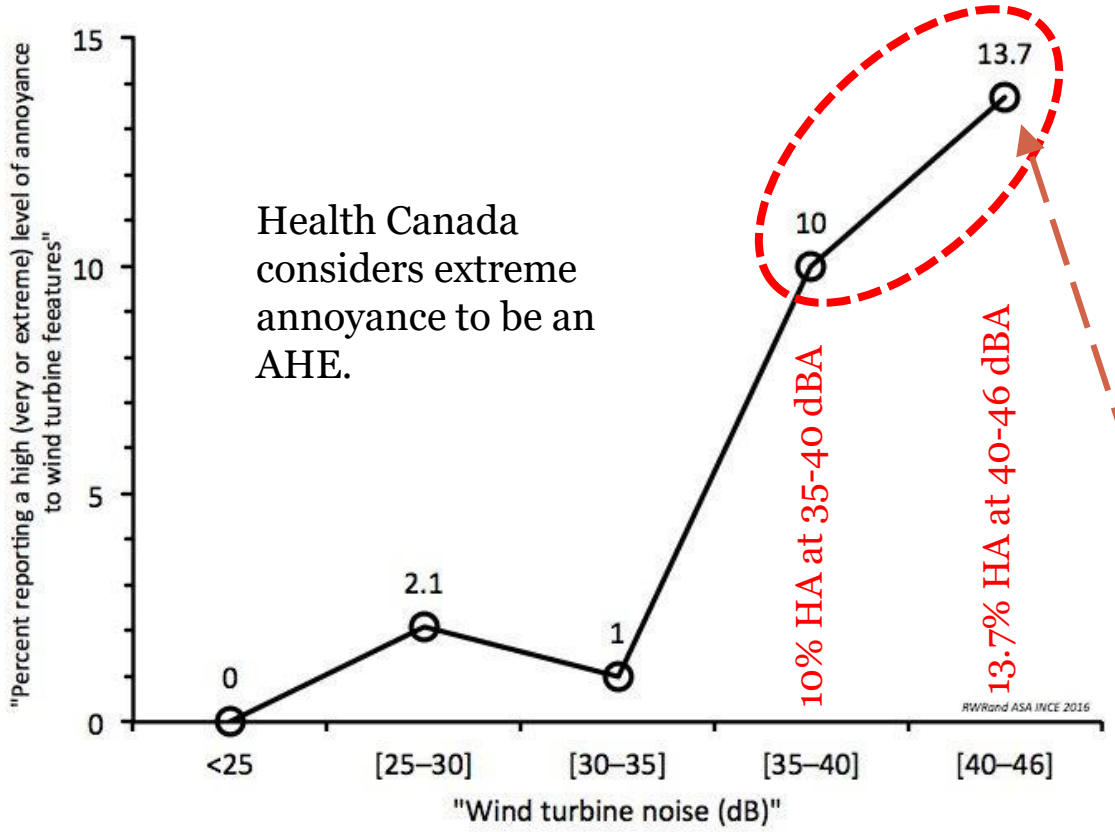


Figure 1: Dose-response relationships for transportation sources and wind turbines

Source: Graph replotted from Pedersen, E., & Persson Waye, K. P. (2004). Perception and annoyance due to wind turbine noise—a dose-response relationship. Journal of the Acoustical Society of America, 116, 3460-3470.

The Health Canada study found IWT noise highly annoying in a substantial number of people



Health Canada considers extreme annoyance to be an AHE.

Data source: "Exposure to wind turbine noise: Perceptual responses and reported health effects", TABLE IV. Perception of community noise and related variables, Variable "Reporting a high (very or extreme) level of annoyance to wind turbine features: Noise", D.S. Michaud et al, Health Canada, J. Acoust. Soc. Am. 139 (3), March 2016.

At least 1 out of 10 people in project area who were exposed to levels >35 dBA were highly annoyed.

Almost 14% of people who are exposed to levels between 40-46 dBA will experience high annoyance.

Common Human Reactions to IWT Exposure

Nina Pierpont, M.D., Ph.D., and a pediatric neurologist, described 10 symptoms, labeled *Wind Turbine Syndrome*, in a 2009 book by the same name; many other researchers have since observed similar symptoms.

- Sleep disturbance
- Headache
- Visceral Vibratory Vestibular Disturbance (VVVD)
- Dizziness, vertigo, unsteadiness
- Tinnitus
- Ear pressure or pain
- External auditory canal sensation
- Memory and concentration deficits
- Irritability and anger
- Fatigue and loss of motivation

Sleep disturbance is the most well-documented symptom*

- Leventhall (2003)
- Minnesota Department of Health (2009)
- Pedersen (2009, 2011)
- Masotti & Hodgetts (2011)
- Shepherd & Billington (2011)
- Shepherd et al. (2011)
- Thorne (2011, 2013)
- Krogh et al. (2012)
- Nissenbaum et al. (2012)
- Jeffery et al. (2013)
- Nissenbaum (2013)
- Paller et al. (2013)
- Palmer (2013)
- Taylor (2013)
- Kasprzak (2014)

*See Punch & James, 2016, for full references.

Sleep disturbance adversely affects health: National Institutes of Health

- Hypertension
- Negative effects on memory, temperament, heart rate, heart health, and hormones
- Reduced capacity to learn new information, concentrate, and recall information
- Lowered immunity to disease, weight gain; negative effects on childhood growth and development, muscle growth and tissue repair in children and adults
- Negative effects on puberty and fertility

Cape Bridgewater Study: Australia

- In a controlled, visually blinded field study and a separate laboratory study, Australians Steven Cooper and Chris Chan showed that inaudible sound pulsations of wind turbines, occurring at infrasonic rates, caused unpleasant perceptible "sensations" that were synchronized with wind turbine operation.
- Sensations included headache; pressure in the head, ears, or chest; ringing in the ears; heart racing; or a sensation of heaviness.
- Alternative explanations, such as the so-called *nocebo effect*, have been refuted by finding a direct cause-effect relationship between infrasound and AHEs.

Additional Documented Reactions to IWT Noise

- Anxiety
- Migraine headaches
- Motion sickness
- Reduced quality of life
- Visual blurring
- Vomiting, nausea

Observations from Personal Interviews: Michigan Family Residents

Comparison with Pierpont's Wind Turbine Syndrome Criteria

(Information obtained based on checklist of 72 health-related conditions)

Symptom	*Mother*	*Father*	*Son*
Sleep disturbance	✓	✓	✓
Headache			✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓		✓
Dizziness, vertigo, unsteadiness	✓		
Tinnitus		✓	
Ear pressure or pain	✓	✓	✓
External auditory canal sensation	✓	✓	
Memory and concentration deficits	✓		✓
Irritability, anger	✓	✓	
Fatigue, loss of motivation	✓	✓	✓

Observations from Personal Interviews: Individual Oregon Resident

Comparison with Pierpont's Wind Turbine Syndrome Criteria

Symptom	*Adult Male*
Sleep disturbance	✓
Headache	✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓
Dizziness, vertigo, unsteadiness	✓
Tinnitus	
Ear pressure or pain	
External auditory canal sensation	
Memory and concentration deficits	✓
Irritability, anger	✓
Fatigue, loss of motivation	✓

An Additional Concern

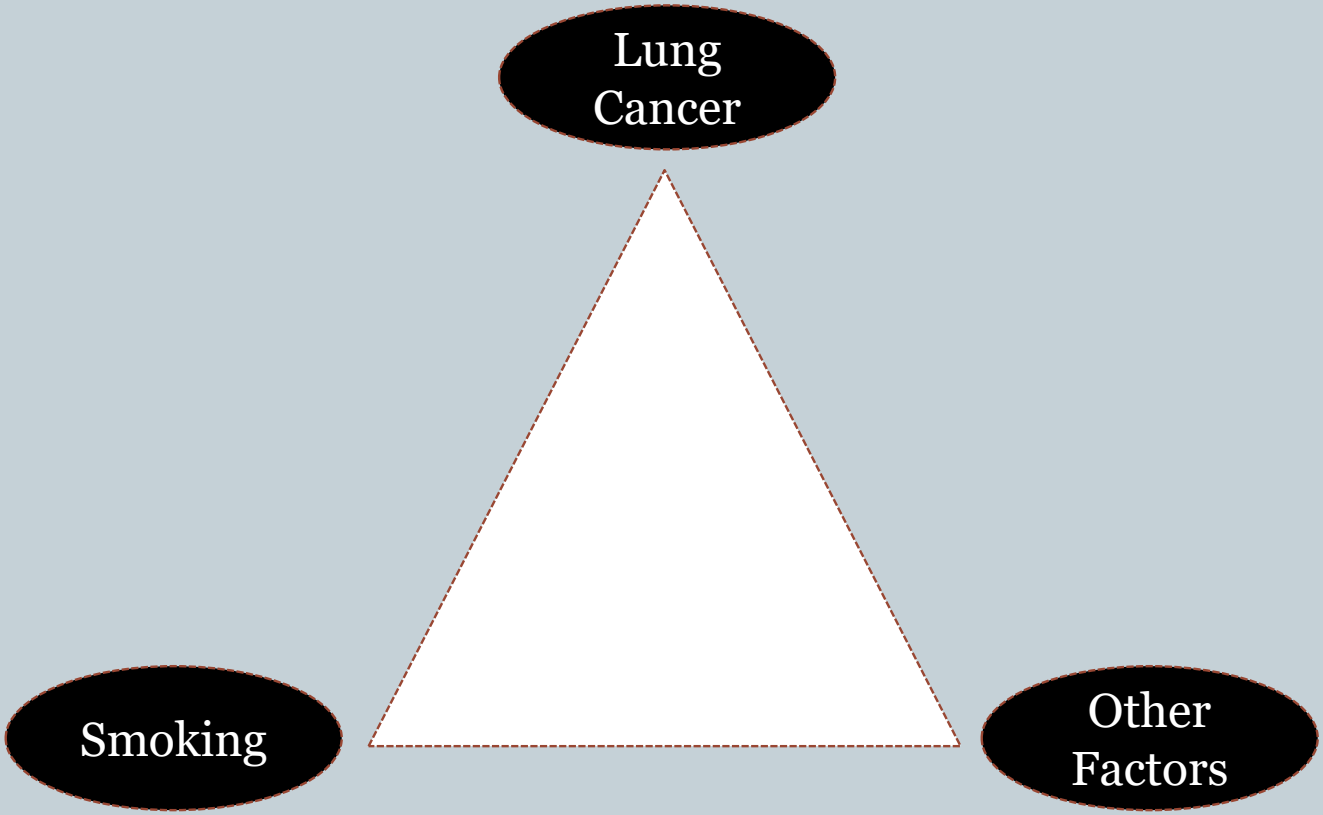
- Alves-Pereira and colleagues: “Airborne pressure waves are ubiquitous in all human environments and have played vital roles in the survival, evolution, and development of the human species. Under certain conditions, airborne pressure waves can be perceived as “sound” by the human auditory system. Under other conditions, they may be perceived as a whole-body or partial-body vibration.“ (p. 1)
- Based on a series of laboratory and field studies of lower animals: “Exposure to infrasonic and lower frequency airborne pressure waves can cause cellular and tissue damage depending on frequency, dB-level, and exposure time….” (p. 17)
- Biological systems affected include these organs, tissues, and systems:
  - Fascia
  - Connective tissue
  - Inflammatory processes
  - Vascular systems throughout body, including eye, liver, lungs, tracheae, coronary arteries
  - Cognitive deficits (probably due to brain damage and sleep deprivation)
  - Focal collagenous growths and hemorrhagic events
  - Changes in immune response, reproductive system, inner ear (vestibular and cochlear)
  - Genotoxicity

Source: Mariana Alves-Pereira, Bruce Rapley, Huub Bakker and Rachel Summers (January 9th 2019). Acoustics and Biological Structures, Acoustics of Materials, Zine El Abiddine Fellah and Erick Ogam, IntechOpen, DOI: 10.5772/intechopen.82761. Available from: https://www.intechopen.com/books/acoustics-of-materials/acoustics-and-biological-structures.

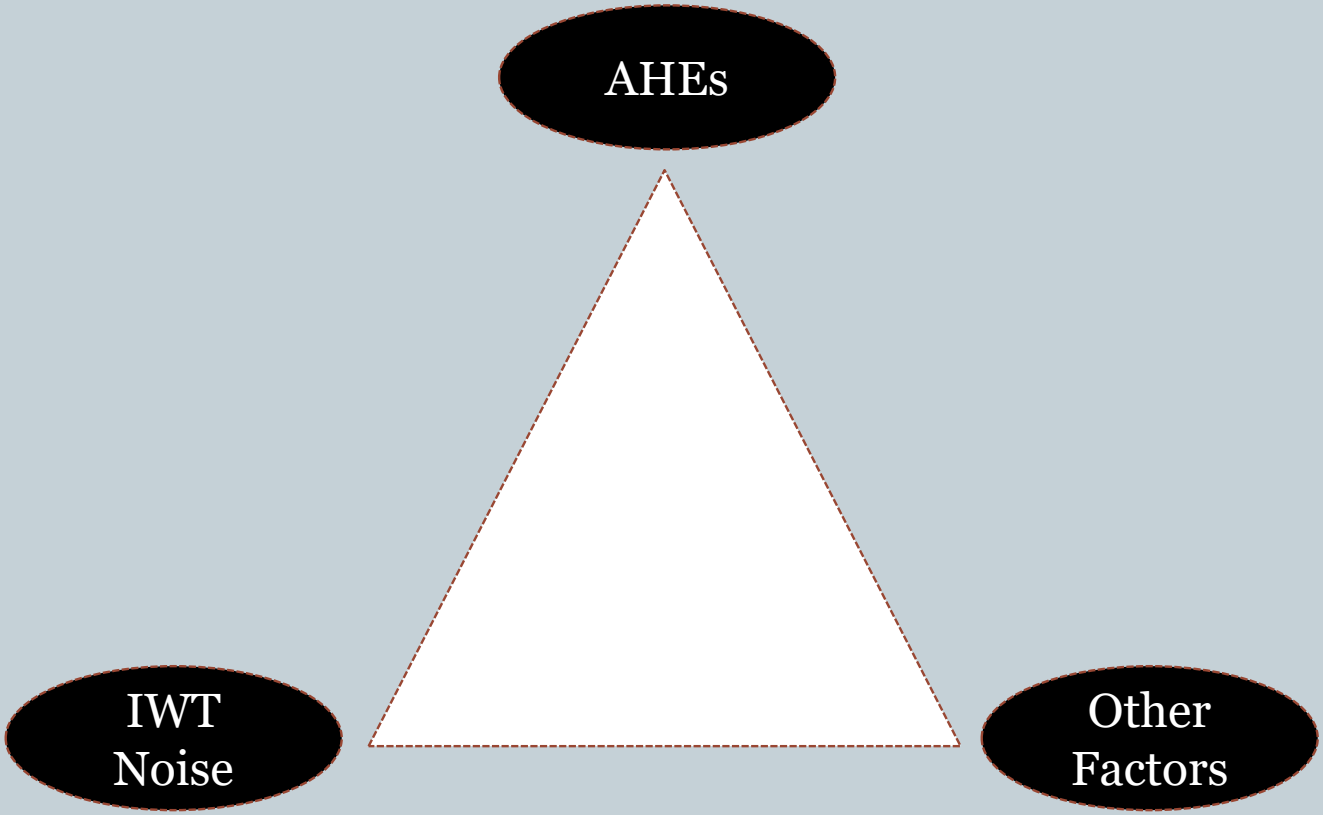
Specific vs. General Causation

- *Specific causation* usually requires that a physician determine what is causing the symptoms of an individual patient (e.g., abdominal pain is caused by a gall bladder attack).
  - Minimum requirements (IWT cases): Medical education, patient contact, knowledge of acoustics and its effects on people
- *General causation* usually requires that a scientist (or other expert) determine what is causing symptoms of people in a particular population (e.g., cigarette smoking causes lung cancer in a significant number of people).
  - Minimum requirements (IWT cases): Education in epidemiology or other health-related field, research background, site visits, resident interviews, knowledge of acoustics and its effects on people

Correlation vs. Causation



Correlation vs. Causation



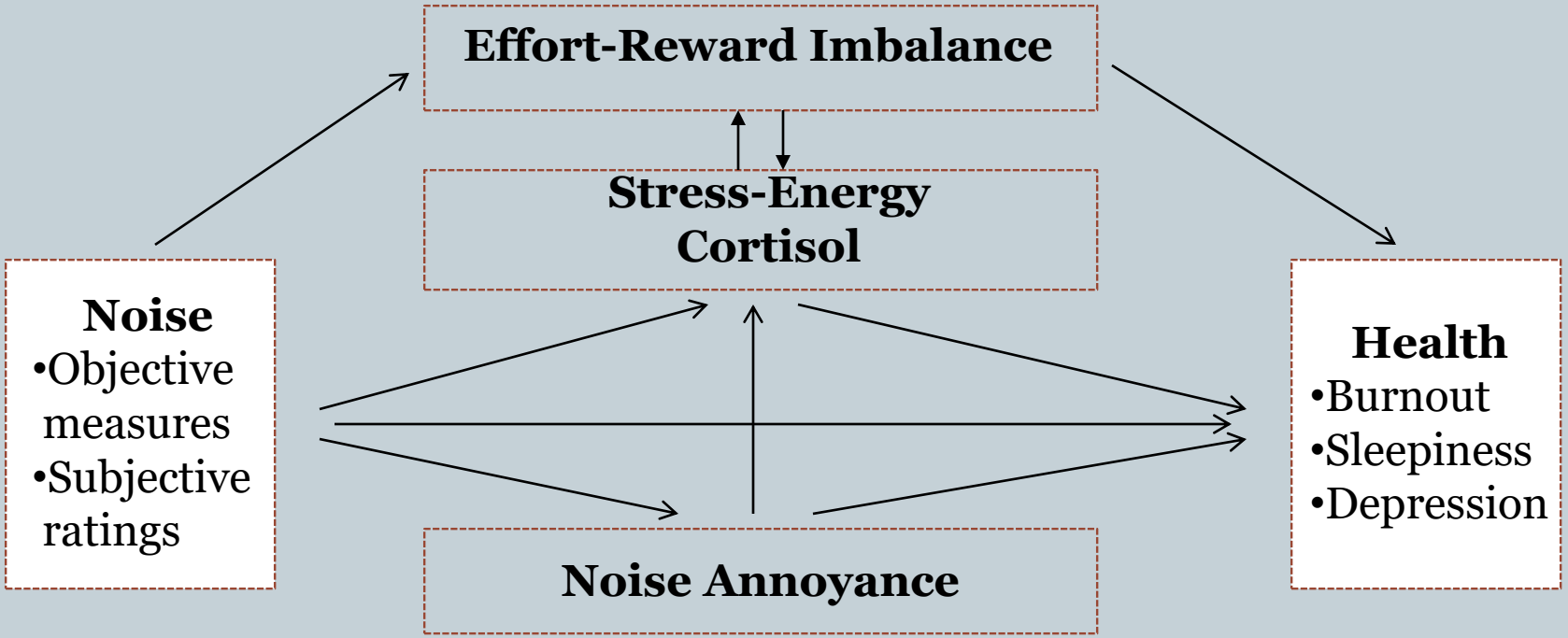
Bradford Hill Criteria (1965)

- These criteria are widely used to establish a causal link between environmental factors and disease (relevant WTN conditions in parentheses):

(1) Strength of association (widespread reports of complaints)
(2) Consistency (consistency of reported symptoms across individuals)
(3) Specificity (consistency of symptoms across individuals and sites, without other known linkages)
(4) Temporality (concurrence of symptoms with IWT operation)
(5) Biological gradient (dose-response relationship between symptoms and exposure levels or distance)
(6) Biological plausibility (identification of role of hearing and balance mechanisms of inner ear in causing specific symptoms)
(7) coherence (coherence with WHO, U.S., and some state noise guidelines)
(8) experimentation (cross-sectional studies, as well as multiple observations that symptoms subside when individuals leave area and recur when they return to area)
(9) analogy (noise-induced Sick Building Syndrome)

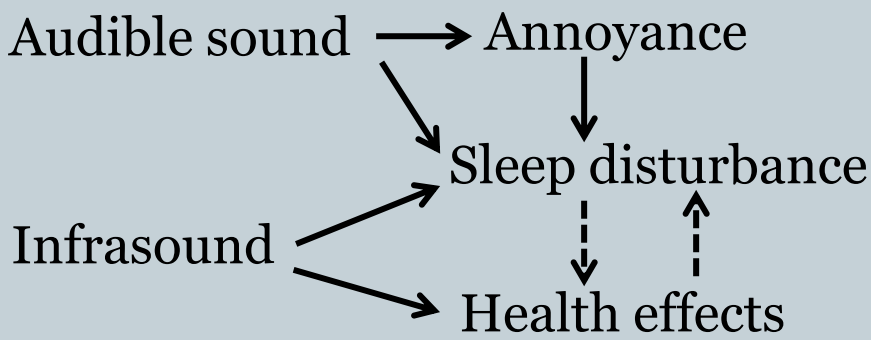
- All these factors have been shown, to various degrees, to link WTN and AHEs.

Noise and health are linked directly and indirectly



Schomer classifies the effects of audible noise and infrasound on health (modified)

Example: Wind turbine noise can cause awakenings, and chronic awakenings can lead to AHEs.



→ Direct pathway

⇢ Indirect pathway

How *can* WTN be limited?

- Setback Distance: To protect human health, recommendations in the literature include minimum distances ranging from 0.5-2.5 miles. The distance recommended most often by researchers is 1.25 mi (2 km), but some now recommend longer setbacks.
- Noise levels: Recommendations in the literature typically limit noise levels to 30-40 dBA Leq. Some regulatory agencies and local zoning ordinances support limiting noise levels to 5-10 dB above prevailing background noise levels.

How *should* WTN be limited?

- Maximizing setback distance
  - Noise levels vary based on distance, but not in a predictable dose-response relationship.
  - Noise levels also depend on terrain, number and size of turbines, weather patterns, and turbine array. Turbine size and distance from the receiver are two of the most influential factors.
  - Typical setbacks of a half mile or less, intended to protect physical safety from mechanical failure or ice throw, are NOT adequate to protect general health and well-being.
- Minimizing noise levels
  - This approach is generally more effective than using a specific setback distance, but regulations based on noise levels are somewhat more difficult to implement.
  - Prior to project construction, *noise modeling* is often used to predict noise levels; after project construction, *direct noise measurements* are used. Because modeling is imprecise and often underestimates noise levels, the levels should always be verified post-construction.

Additional Considerations

- Infrasound and low-frequency noise levels are typically not masked by wind or other noises, and *cannot* be controlled effectively by erecting barriers, insulating homes, or wearing earplugs, so distance is the only practical means of achieving acceptable sound levels.
- WTN easily crosses property lines, so setback distances should be based on the acceptable noise levels at property lines, not residences (i.e., enjoyment of property, with waiver an option).

Physicians advocate for longer IWT setbacks, but ….

- Dr. Nina Pierpont and many others have recommended a setback distance of 1.25 miles (2 km).
- Dr. Ben Johnson, a cardiologist, recently advocated for a 1.5 mile setback in Madison County, Iowa:

"Resolved that the Madison County Board of Health determines that there is the potential for negative health (e)ffects associated with commercial wind turbines and that current setbacks are inadequate to protect the public health. The Board encourages those entities with jurisdiction within the County to require a one and one-half (1-1/2) mile setback for future wind turbine projects."

Madison County, Iowa
August 8, 2019

A comprehensive list of recommended setbacks in the U.S. and other countries is available at: http://www.wiseenergy.org/Energy/Wind_Ordinance/Setbacks.pdf.

Some major U.S. and international guidelines are used to limit noise exposure

- **U. S. Environmental Protection Agency (EPA)**

Noise Control Act (1972) and Quiet Communities Act (1978)
Not updated, but link noise to stress-related illnesses and other AHEs

- **ISO 1996-1 and ANSI S12.9 Part 4 Standards**

Recommend 15-dB penalty for new noise sources in quiet, rural communities

- **National Association of Regulatory Utility Commissioners (NARUC, 2011) and NY Department of Environmental Conservation (DEC, 2001)**

Recommend limiting noise levels to 5 or 6 dB above background levels; given rural background levels of ≤30 dBA (1-hr. Leq) at night, nighttime IWT noise often exceeds guidelines

- **WHO (1999, 2009, 2018)**

Developed in Europe and used worldwide to limit noise levels for the purpose of limiting annoyance and AHEs

- **Schomer and Pamidighantam (2017)**

Recommend maximum permissible levels averaging 36-38 dBA, measured over a 24-hour period, to protect against substantial annoyance and AHEs from WTN (based on four independent studies)

The WHO noise guidelines limit community, transportation, and industrial noise levels

- WHO (Berglund et al., 1999; community noise)
  - For continuous nighttime noise, indoor levels should not exceed 30 dB LAeq, and outdoor levels should not exceed 45 dB LAeq. Single noise events should not exceed 45 dB LAmax.
  - Special attention should be given to noise when background noise is low, when noise is combined with vibrations, and when noise consists of low-frequency components.
- WHO (2009; nighttime transportation noise)
  - Outside night noise levels should be limited to 40 dB LAeq, and night, inside noise should be limited to 35-42 dB LAmax (based on transportation noises).
- WHO (2018; environmental noise, including IWT noise)
  - Wind turbine noise level should be limited to 45 dB Lden, which equates to ~38 dB LAeq.
  - This guideline does not provide a specific LAmax recommendation.

The 2009 WHO noise guidelines recommend minimizing sleep disturbance and AHEs

Leq(night,outside)	Health Effects
<30 dBA	No substantial biological effects
30-40 dBA	Affects sleep: body movements, awakening, self-reported sleep disturbance, arousals; vulnerable groups (young children, elderly adults, persons with chronic health conditions) more susceptible
40-55 dBA	AHEs observed (with vulnerable groups more severely affected)

World Health Organization

The above levels are long-term averages and are not based specifically on wind turbine noise, which contains more low-frequency noise than most other industrial and transportation sources, on which these levels are based.

IPCB Regulations

- Developed in the late 1960s and early 1970s to regulate levels of non-transportation noise sources in Illinois, with emphasis on nighttime noise
- Based on limiting noise levels in narrow (octave) bands of the frequency spectrum (1 hr, Leq)
- If levels are at allowable limits in all bands, overall level equates to 51.2 dBA
- Dr. Paul Schomer, former Director of Standards for the Acoustical Society of America, contributed directly to development of IPCB (900-901) regulations
- Schomer has described the IPCB noise limits as a never-to-exceed regulation, applicable to each octave band, and has indicated they should not be applied to WTN

IPCB Regulations (Continued)

"The state regulations are these octave band limits that were created 60 years ago. If I were creating them today, I wouldn't use them."

Paul Schomer, Ph.D.
Emeritus Director of Standards
Acoustical Society of America

Source: McLean County Zoning Board of Appeals, February 22, 2018, McLean County Government Center, 115 East Washington Street, Bloomington, Illinois, Case Number SU-18-02, p. 508.

Illinois Case Example: Post-Construction

- The acoustician for the wind company indicated compliance with IPCB noise regulations at all frequencies *except* at 2000 Hz at 10 residences that would be exposed to the loudest levels.
- My analysis indicated that, at one or more frequencies, IPCB regulations were exceeded at 178 of 228 (78%) residences.
- Noise levels at residences of 17 plaintiffs who filed a post-construction lawsuit ranged from 41-47 dBA.

Kansas Case Example: Pre-Construction

	40 dBA Leq	38 dBA Leq/45 dBA Lden	36 dBA Leq
Non-Participants	186 (41.8%)	300 (67.4%)	337 (75.7%)
Participants	62 (88.6%)	66 (94.3%)	66 (94.3%)
Total	248 (48.2%)	366 (71.1%)	403 (78.3%)

Number and percentage of 445 non-participating residences and 70 participating residences at which noise limits established by three authoritative sources will be exceeded.

40 dBA Leq (WHO 2009)	38 dBA Leq/45 dBA Lden (Schomer & Pamidighantam, 2017; WHO, 2018)	36 dBA Leq (Schomer & Pamidighantam, 2017)
13 (46.4%)	22 (78.6%)	24 (85.7%)

Number and percentage of residences of 28 plaintiffs at which noise limits established by three authoritative sources will be exceeded.

A highly substantial percentage of residents overall, as well as plaintiffs in this case, would be exposed to noise levels that exceed any of the three limits recommended by national and international authorities.

Conclusions

1. WTN is a unique source of low-frequency noise that can lead directly or indirectly to a variety of AHEs.
2. Infrasound has been linked directly to negative sensations and AHEs.
3. Noise limits and setbacks advocated by the wind industry are harmful to the health of a substantial percentage of people.
4. Researchers have most often recommended a setback of 1.25 mile (2 km) to minimize annoyance and AHEs; some scientists and regulatory authorities now recommend longer setbacks.
5. WHO guidelines (2009, 2018) recommend limiting noise levels to 38-40 dB LAeq; the 2009 WHO guidelines recommend limiting nighttime low-frequency noise to 42 dB LAmax (inside) to protect against sleep disturbance, the most common complaint.
6. While maximizing setback distance can effectively reduce noise levels, limiting noise levels to those recommended by authoritative sources is the most effective way to protect public health.

Punch & James (2016): Summary Statements

- "The available literature, which includes research reported by scientists and other reputable professionals in peer-reviewed journals, government documents, print and web-based media, and in scientific and professional papers presented at society meetings, is sufficient to establish a general causal link between a variety of commonly observed AHEs and noise emitted by IWTs." (p. 54)
- "A pro-health view is that there is enough anecdotal and scientific evidence to indicate that ILFN from IWTs causes annoyance, sleep disturbance, stress, and a variety of other AHEs to warrant siting the turbines at distances sufficient to avoid such harmful effects, which, without proper siting, occur in a substantial percentage of the population."(p. 55)

For more information, see:

Punch, J.L. & James, R.R. (2016), Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks. Available from: *http://hearinghealthmatters.org/journalresearchposters/files/2016/09/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf*

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