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# Wind Farm Noise and Regulations in the Eastern United States

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## Abstract

Recent advancements in the wind turbine technology, combined with available federal and state incentives, have greatly enhanced the development of wind powered electric generation facilities in the Eastern United States. Particularly ridges of the Allegany Mountains in New York, Pennsylvania, Maryland, West Virginia, and Virginia have become attractive sites for commercial wind farm developers. The fast development of commercial wind farms is currently an important issue in these regions due to environmental impacts.

The paper describes the demographic structure of the Allegany Mountains and presents an assessment of the audible noise at residences near actual wind turbines. The noise level recommendations of the USA Environmental Protection Agency (US-EPA) and local noise ordinances that apply to wind turbines are compared with the acceptable noise levels in various countries. The current status and trend of the wind power development in the Eastern USA, the expected benefits, and public concerns are discussed.

## Introduction

Since the beginning of the 21st century, wind power development in the eastern part of the United States has grown significantly due to recent improvements in the wind turbine technology and financial incentives provided by the federal government and states. Data collected by American Wind Energy Association (AWEA) indicates that the total capacity of wind farms installed in 14 states east of the Mississippi river, which was 29 MW in 1999, has reached 843 MW in the end of 2006 (Flowers, L., 2007). Total 605 MW wind power plants were developed in New York, Pennsylvania, and West Virginia between 2000 and 2006. While the proportion of electricity generated by wind farms is still relatively small compared to the other sources, wind seems to be a potential clean energy alternative to the fossil fuels used in the region.

Environmental concerns about the wind power development include interactions with wild life, visual impacts, and annoyance due to the audible sound level. This paper focuses on the acoustic issues related to wind turbines and the associated public concerns in eastern United States.

## Wind Power Development in the USA and Demographics

Wind farms are perhaps one of the most visible power generation facilities and have triggered significant public attention and discussions over the past several years. Because of substantial social interactions, demographic characteristics of the regions where the wind farms are located must be considered when evaluating the consequences of the wind power development.

Wind power development in the United States is summarized in Figure 1 (Wiser, R. et al., 2007). The map presents the wind projects above 1 MW that became online prior to 2006 and added in 2006.

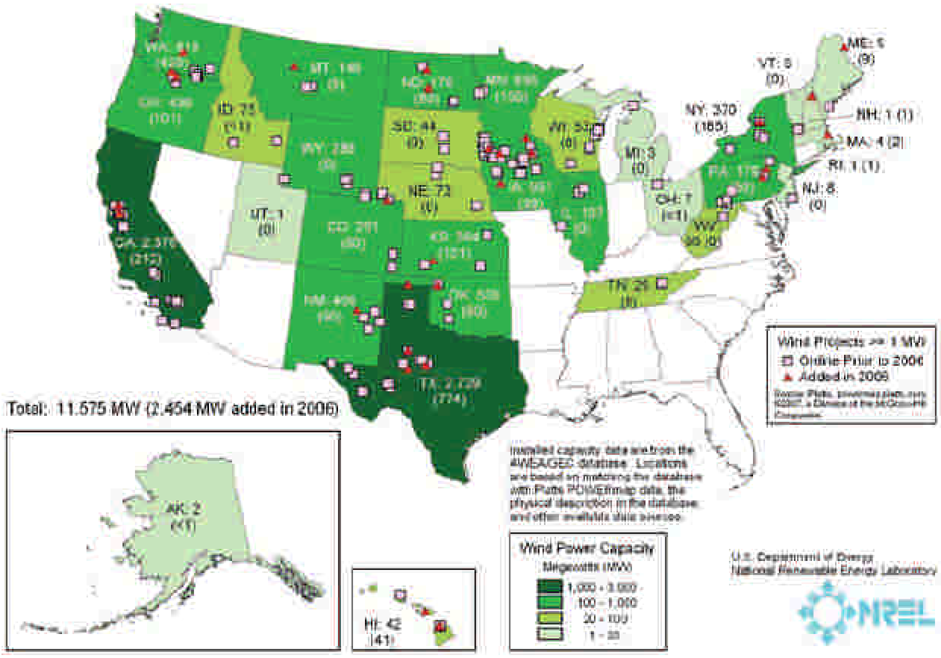



Figure 1 Installed wind power generation facilities as of December 31, 2006

Table 1 shows the major wind developments and the population density of the states grouped based on their location in respect to the Mississippi river. The wind development in the western part of the USA is significantly higher than the eastern part. On the other hand, the population density in eastern states is in general above the national density and significantly higher than the western states except California.

Wind development on the ridges of the Appalachian Mountains in New York, Pennsylvania, and West Virginia started after the year 2000. The wind farms are mostly located near agricultural and recreational areas where residences are sparsely distributed. The wind turbines are therefore close to many farms and residences and visible from small towns.

The effects on the wildlife, visual impact, and audible noise of the wind turbines have been the major issues discussed during the planning and approval process of the commercial wind generation facilities in eastern states, particularly in New York, Pennsylvania, Maryland, West Virginia, and Virginia.

Table 1 Major wind development and population density by states

| | State | Installed Capacity, MW | | Incremental Capacity 2000 to 2006 | Population Density Persons/square mile |
|---|---|---|---|---|---|
| | | End of 1999 | End of 2006 | | |
| East of Mississippi | New York | 0 | 370 | 370 | 402 |
| | Pennsylvania | 0 | 179 | 179 | 274 |
| | Illinois | 0 | 107 | 107 | 223 |
| | West Virginia | 0 | 66 | 66 | 75 |
| | Wisconsin | 23 | 53 | 30 | 99 |
| West of Nississippi | Texas | 180 | 2,739 | 2559 | 80 |
| | California | 1646 | 2,376 | 730 | 217 |
| | Iowa | 243 | 931 | 688 | 52 |
| | Minnesota | 273 | 895 | 622 | 62 |
| | Washington | 0 | 818 | 818 | 89 |
| | Oklahoma | 0 | 535 | 535 | 50 |
| | New Mexico | 1 | 496 | 495 | 15 |
| | Oregon | 25 | 438 | 413 | 36 |
| | Kansas | 2 | 364 | 362 | 33 |
| | Colorado | 22 | 291 | 269 | 42 |
| | Wyoming | 73 | 288 | 215 | 5 |
| | North Dakota | 0 | 178 | 178 | 9 |
| | Montana | 0 | 146 | 146 | 6 |
| | Idaho | 0 | 75 | 75 | 16 |
| | Nebraska | 3 | 73 | 70 | 22 |
| | USA | 2500 | 11,575 | 9075 | 80 |

## Characteristics of Wind Turbine Sound

The characteristics of the wind turbine sound are studied in many publications in detail. The “White Paper” prepared by the Renewable Energy Research Laboratory (Rogers, A. L. and Manwell, J. F., 2002) classifies the wind turbine noise in four types as

1. Tonal noise, which is a combination of components at discrete frequencies

2. Broadband noise is characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is usually modulated by low frequency fluctuations and described as a characteristic "whooshing" sound.
3. Low frequency noise is within the frequency range below 100 Hz.
4. Impulsive noise is described by short acoustic impulses or thumping sounds that vary in amplitude with time.

The operation of mechanical parts such as gearbox, generator, hydraulics, pneumatics and various control mechanisms generates mechanical noise. Rotating parts usually produce sound components at discrete frequencies related to the rotation speed, which result in tonal noise. Some mechanical parts can also generate broadband noise. This type of noise can be reduced by improving the design of the mechanical parts and using more effective acoustic insulation. However, the mechanical noise can be transmitted to the environment through the vibrations of the hub, rotor, and tower.

The interaction of the wind flow with the blades produces the aerodynamic noise. Aerodynamic noise is associated with various complex air flow phenomena and has both broadband and low frequency components. The interaction of the blades with the disturbed air flow around the tower results in low frequency and impulsive sound components. Changing wind speed around the blades can also produce low frequency and impulsive noise. This type of noise is usually bigger in downwind turbines, where the rotor is located on the downwind side of the tower.

Van Den Berg (2005) discusses the significance of the low frequency modulation of the broadband noise under stable atmospheric conditions. The study shows that the fluctuations become stronger especially during night time because of the stable atmosphere resulting in a bigger difference between the rotor averaged and near-tower wind speeds. Although the human ear is less sensitive to low frequency sound components, the modulation effect makes them more perceptible, creating a “whooshing” or “swishing” sound as described by residents who live near wind turbines.

The level of the sound generated by wind turbines depends on a number of factors such as

- Design characteristics of the wind turbine such as tower height, number of the blades, rotation speed, blade control mechanism – that is whether the blades are attached at a fixed or variable angle along their long axis (fixed or pitched)
- Distance to the source, sound blocks, obstructions, and uneven geometry of the terrain
- Sound absorption of the propagation medium between the source and location of the observer
- Acoustic characteristics of the ground surface affecting the sound propagation such as reflection, absorption of sound waves. Sound propagation depends on the physical properties of the ground surface, rock and soil composition, and vegetation covering the terrain.
- Frequency composition of the sound waves
- Weather conditions such as wind speed, direction, temperature, humidity, precipitation, etc.

## Ambient Noise Recorded at a Residence near Wind Turbines

A number of tests were conducted between 2004 and 2005 near wind turbines located in Meyersdale, PA, to analyze the characteristics of the generated sound and determine the noise levels under various conditions.
The wind powered electric generation plant located in Somerset County near Meyersdale is a typical wind power facility (wind farm) with main characteristics similar to others constructed in the South Western Pennsylvania and Northern West Virginia over the last five years. New wind farms planned to be constructed in the region will have similar blade design, but possibly bigger turbines and higher towers.
The plant consists of twenty wind turbines installed on 262 feet tall towers on the mountain ridge. The NM72 type turbines are manufactured by Neg-Micon in 2003. The NM72 is a three blade upwind turbine generating electricity by an induction machine. It has a rated power of 1500 kW and an apparent power of 1667 kVA.
A number of tests were performed around a residence located at a distance of 900m (0.55 miles or 3000ft) to the windmills. Four windmills were visible from the residence. The tests are presented below in two parts: ambient noise recordings and sound level measurements.

The noise generated by wind turbines was recorded at a distance of approximately 3000 ft from the nearest turbine. Four turbines were visible at

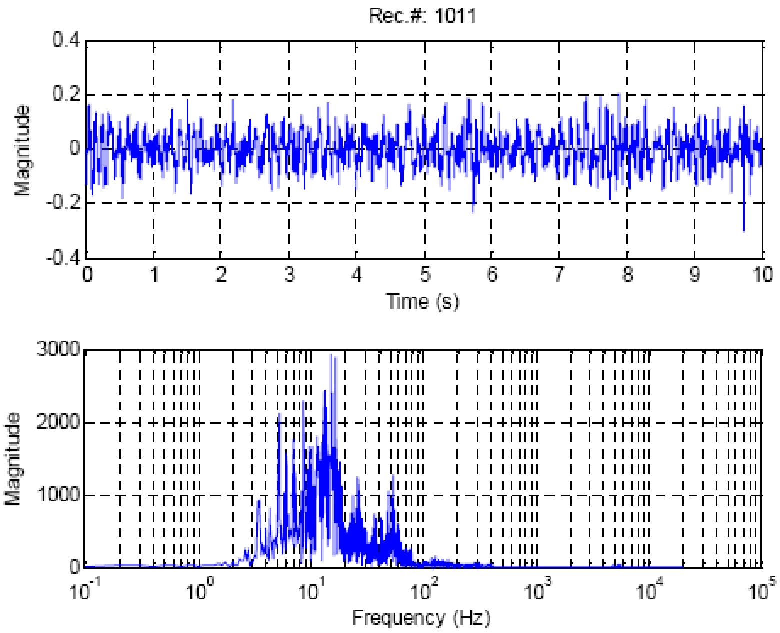
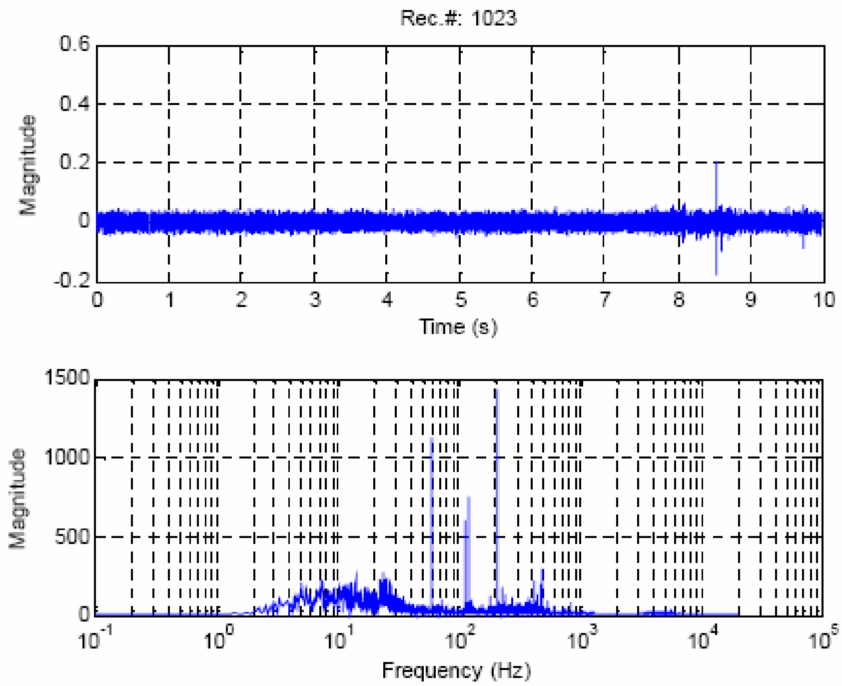



Figure 2 Sound recorded at a distance of 3000 ft from the wind turbines

the recording point, three of them were operating. Several recordings were made between 11:00 AM and 4:00 PM at different days. Wind speed was moderate (3 – 5 miles/hr) at the recording point (ground level) during the tests. A solid state digital recorder was used to obtain the waveform data. An example 10-s fragment is shown in Figure 2. The frequency distribution obtained by discreet Fourier transform indicates a dominance of low frequency components below 100Hz. Examination of the time variation of the sound waveform shows a periodic change of the magnitude, which is translated as “low frequency modulation.”

Figure 3 shows the ambient noise recorded in another location without wind turbines. Light traffic noise from distance was contributing to the natural sound of wind and trees. The time variation of the noise shown in Figure 3 is random and uniform over the 10-s recording time. The Fourier transform indicates significant tonal and broadband components above 100 Hz. This represents a typical suburban




residential ambient noise without industrial noise sources.

Figure 3 Ambient noise containing natural sounds and light traffic noise

The decibel level of the ambient noise was measured at the same location (3000 ft from the closest wind turbine). Figure 4 shows a set of plots obtained during short intervals at different times of a day.

The instrument used to record sound levels is an Extech Datalogging Sound Level Meter, model # 407764. The instrument can record up to 16,000 records to the internal memory with a sampling rate from 1 to 86,400 seconds per record. The sampling rate is selected depending on the type of test. The instrument is equipped with dBA and dBC weighting filters.

The international standard IEC 61400 (Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques) [5] indicates that the annoyance caused by noise dominated by low frequencies is often not adequately described by the A-weighted sound pressure level (p. 35, Annex A). According to the standard, this is likely the case if the difference between A and C-weighted sound level pressure levels exceeds approximately 20 dB. The plots in Figure 4 reflect the dominance of low frequency components since the difference between dBA and dBC levels is generally around 20 dB. This is also consistent with the spectrum analysis presented in Figure 2

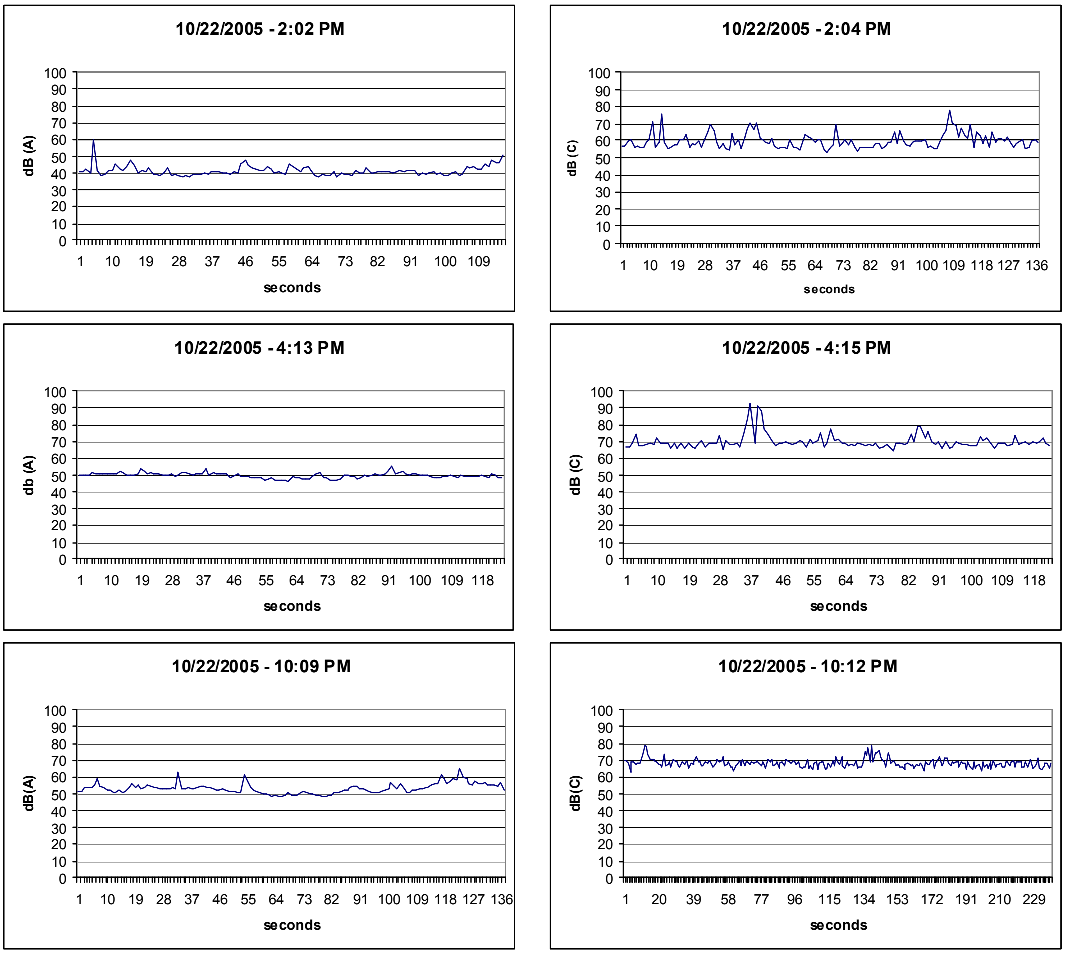
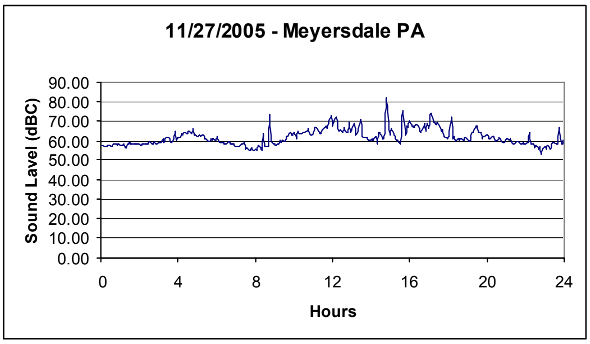



Figure 4 Noise level measurements at a distance of 3000ft from the nearest wind turbine



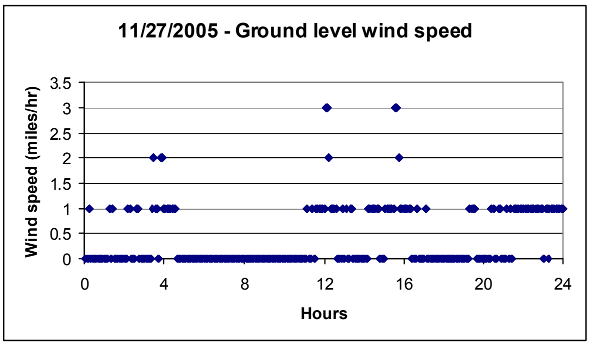




Figure 5 One-day record of noise level and wind speed

Figure 5 shows a one-day C-weighted noise pressure level recorded at the same location. The wind speed measured near the sound level meter is also plotted.

The plots shown above represent the sound of windmills combined with the natural ambient noise from wind, trees, bushes, and animals. Other noise sources such as traffic, machines, and commercial sources were occasional and minimal at the test location. In order estimate the contribution of the wind, noise levels are plotted in Figure 6 versus wind speed near the wind farm and at another rural location without windmill noise.

It should be noted that the wind speed at the test location may be very different than the wind speed at the turbine height. This explains why at lower wind speeds the noise level near wind turbines is much higher compared to the location where there is no windmill noise.

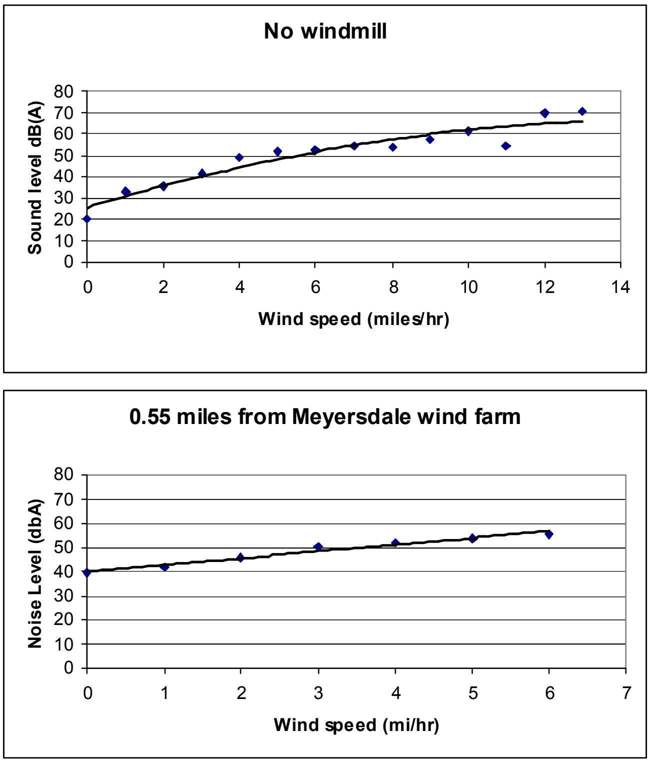



Figure 6 Noise levels with and without windmills

**Assessment of the Nuisance Caused by Wind Turbine Noise**

The tests performed near wind farms confirm the observations of several residents describing the windmill sound. The following psycho-physical characteristics of the windmill sound distinguish it from the typical urban and occupational noise.

- Windmill sound has dominant low frequency components
- The windmill sound is often periodic and rhythmic
- The very low frequency and infrasound components, for which human ear is normally not sensitive, are highlighted and become perceptible due to the low frequency modulation (fluctuations) of the broadband noise (Van Den Berg, 2005). This effect is usually described as swishing or whooshing sound.
- Low frequency modulation effect is stronger in stable atmosphere due to the interaction of the blades with the steady wind around the tower. This mostly occurs during night and early morning (Van Den Berg, 2005).

- The windmill sound is present day and night and can be disturbing at night because other sources of noise are reduced.

For the reasons listed above, the noise levels defined for urban and occupational noise may not represent the effects of the windmill sound. The A weighting network may be inadequate because of the dominant low frequency components and the modulation of the weak broadband noise.

## Codes and Regulations Concerning Wind Turbine Noise

A nationwide applicable limit for windmill noise is not available in the USA. Instead of imposing standard noise limits, the US Environmental Agency (US-EPA) recommends that local governments develop their own noise regulations or zoning ordinances. The publication EPA-550/9-74-004 (EPA 1974) is one of the most detailed studies to date on disturbances and activity interference caused by various sources of noise. The publication presents data collected for 55 community noise problems between 1949 and 1974. The noise sources considered in the document are transportation vehicles, single-event operations (such as circuit breaker testing, shooting, rocket testing and body shop), steady state neighborhood sources, and industrial operations.

The day-night averaged A-weighted noise level is one of the parameters commonly used to assess the wind turbine noise. EPA added correction factors to the measured day-night sound level (Ldn) to obtain a normalized chart. The correction factor for a quiet suburban or rural community (remote from large cities and from industrial activity and trucking) is +10 dB. Whereas the night time noise is considered differently than day time, this parameter does not reflect the disturbing effects caused by the low frequency modulation of the background noise. In addition, the low frequency components are significantly suppressed in A weighting. In fact, IEC 61400-11 recommends the comparison of the A and C weighting to assess the presence of low frequency noise. The IEC standard recommends using C weighting if the difference is usually equal or above 20 dB.

Local governments in the USA are currently developing county noise ordinances based on the guidelines suggested by Environmental Protection Agency (EPA) and American Wind Energy Association. The ordinances are typically concerned with neighborhood, construction, and industrial noise. The strength of such regulations and ordinances is the consideration of the characteristics and tolerance limits of local communities. The residents living in counties where noise ordinances have not been established are currently unprotected from development of wind generation facilities near their homes and farms. The lack of noise limits increases the public reaction to wind farms, mostly motivated by subjective opinions.

The permissible noise levels applicable to wind turbines in various countries are listed in Table 2. While many countries do not specify the noise sources, Denmark clearly distinguished the noise limits for different sources. The noise limits for wind turbines are specified by the Ministry of the Environment (statutory order no. 304 of 14 May 1991) in open outdoor areas as 45 dB in open country and 40 db in residential and noise sensitive zones.

**Table 2**

**Permissible $L_{eq}$ Noise Levels in dBA applicable to wind turbines**

(compiled from various sources)

| Country | Commercial | | Mixed | | Residential | | Rural | |
|---|---|---|---|---|---|---|---|---|
| | Day | Night | Day | Night | Day | Night | Day | Night |
| Germany | 65 | 50 | 60 | 45 | 55 | 50 | 50 | 35 |
| Netherlands (EPA) | | | 50 | 40 | 45 | 35 | 40 | 30 |
| Denmark (EPA) | | | | | 45 | | 40 | |
| Australia | 65 | 60 | | | 52 | 45 | 47 | 40 |
| Ghana | 75 | 65 | 65 | 60 | 65 | 48 | | |
| USA | No federal noise regulations, US-EPA established guidelines. Most states (including VA) do not have noise regulations. Local governments have noise ordinances (Rogers and Manwell, 2002). | | | | | | | |

## Conclusions

Sound generated by wind turbines has particular characteristics and it creates a different type of nuisance compared to usual urban, industrial, or commercial noise. The interaction of the blades with air turbulences around the towers creates low frequency and infrasound components, which modulate the broadband noise and create fluctuations of sound level. The low frequency fluctuations of the noise is described as “swishing” or “whooshing” sound, creating an additional disturbance due to the periodic and rhythmic characteristic.

A set of permissible limits for windmill noise that can be uniformly applicable over the nation is not available in the USA. Instead of imposing standard noise limits, the US Environmental Agency (US-EPA) suggests local governments developing their own noise regulations or zoning ordinances. Many countries developed national noise limits applicable to wind turbines.

Specific noise limits need to be developed by considering the characteristics of wind turbine noise. Especially the low frequency sound components and the modulation of the background noise resulting must be considered to represent the activity interference of the wind turbine sound. Adequate criteria to assess the wind turbine sound will greatly help the development of the wind industry by reducing the community reaction based on subjective opinions.

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