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Revised:

A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin

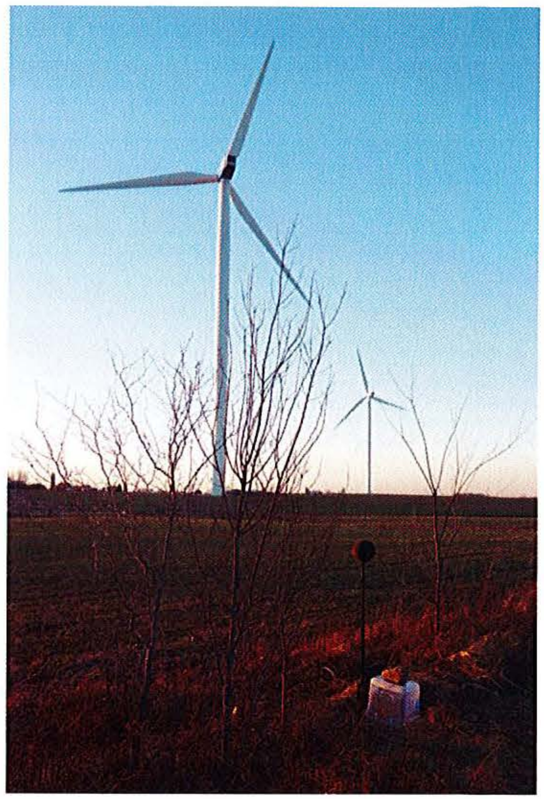

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EXHIBIT
Int. I-36

1.0_Introduction

Clean Wisconsin is a nonprofit environmental advocacy organization that works to protect Wisconsin's air and water and to promote clean energy. As such, the organization is generally supportive of wind projects. Clean Wisconsin was retained by the Wisconsin Public Service Commission (PSC) to provide an independent review of a proposed wind farm called the Highlands Project to be located in St. Croix County, WI (WI PSC Docket 2535-CE-100). Clean Wisconsin in turn retained Hessler Associates, Inc. (HAI) to provide technical assistance.

During the course of the hearings, attorneys representing groups opposed to the Highlands project, presented witnesses that lived near or within the Shirley Wind project in Brown County, WI. The Shirley wind project is made up of eight Nordex100 wind turbines that is one of the turbine models being considered for the Highlands projects. These witnesses testified that they and their children have suffered severe adverse health effects to the point that they have abandoned their homes at Shirley. They attribute their problems to arrival of the wind turbines. David Hessler, while testifying for Clean Wisconsin, suggested a sound measurement survey be made at the Shirley project to investigate low frequency noise (LFN) and infrasound (0-20 Hz) in particular.

Partial funding was authorized by the PSC to conduct a survey at Shirley and permission for home entry was granted by the three homeowners. The proposed test plan called for the wind farm owner, Duke Power, to cooperate fully in supplying operational data and by turning off the units for short intervals so the true ON/OFF impact of turbine emissions could be documented. Duke Power declined this request due to the cost burden of lost generation, and the homeowners withdrew their permission at the last moment because no invited experts on their behalf were available to attend the survey.

Clean Wisconsin, their consultants and attorneys for other groups all cooperated and persisted and the survey was rescheduled for December 4 thru 7, 2012. Four acoustical consulting firms would cooperate and jointly conduct and/or observe the survey. Channel Islands Acoustics (ChIA) has derived modest income while Hessler Associates has derived significant income from wind turbine development projects. Rand Acoustics is almost exclusively retained by opponents of wind projects. Schomer and Associates have worked about equally for both proponents and opponents of wind turbine projects. However, all of the firms are pro-wind if proper siting limits for noise are considered in the project design.

The measurement survey was conducted on schedule and this report is organized to include four Appendices A thru D where each firm submitted on their own letterhead a report summarizing their findings. Based on this body of work, a consensus is formed where possible to report or opine on the following:

- Measured LFN and infrasound documentation
- Observations of the five investigators on the perception of LFN and infrasound both outside and inside the three residences.
- Observations of the five investigators on any health effects suffered during and after the 3 to 4 day exposure.
- Recommendations with two choices to the PSC for the proposed Highlands project
- Recommendations to the PSC for the existing Shirley project

2.0_Testing Objectives

Bruce Walker employed a custom designed multi-channel data acquisition system to measure sound pressure in the time domain at a sampling rate of 24,000/second where all is collected under the same clock. The system is calibrated accurate from 0.1 Hz thru 10,000 Hz. At each residence, channels were cabled to an outside wind-speed anemometer and a microphone mounted on a ground plane covered with a 3 inch hemispherical wind screen that in turn was covered with an 18 inch diameter and 2 inch thick foam hemispherical dome (foam dome). Other channels inside each residence were in various rooms including basements, living or great rooms, office/study, kitchens and bedrooms. The objective of this set-up was to gather sufficient data for applying advanced signal processing techniques. See Appendix A for a Summary of this testing.

George and David Hessler employed four off-the-shelf type 1 precision sound level meter/frequency analyzers with a rated accuracy of +/- 1 dB from 5 Hz to 10,000 Hz. Two of the meters were used as continuous monitors to record statistical metrics for every 10 minute interval over the 3 day period. One location on property with permission was relatively close (200m) to a wind turbine but remote from the local road network to serve as an indicator of wind turbine load, ON/OFF times and a crude measure of high elevation wind speed. See cover photo. This was to compensate for lack of Duke Power's cooperation. The other logging meter was employed at residence R2, the residence with the closest turbines. The other two meters were used to simultaneously measure outside and inside each residence for a late night and early morning period to assess the spectral data. See Appendix B for a Summary of this testing.

Robert Rand observed measurements and documented neighbor reports and unusual negative health effects including nausea, dizziness and headache. He used a highly accurate seismometer to detect infrasonic pressure modulations from wind turbine to residence. See Appendix C for Rob's Summary.

Paul Schomer used a frequency spectrum analyzer as an oscilloscope wired into Bruce's system to detect in real time any interesting occurrences. Paul mainly circulated around observing results and questioning and suggesting measurement points and techniques. See Appendix D for Paul's Summary.

Measurements were made at three unoccupied residences labeled R1, R2 and R3 on Figure 2.1. The figure shows only the five closest wind turbines and other measurement locations. All in all, the investigators worked very well together and there is no question or dispute whatsoever about measurement systems or technique and competencies of personnel. Of course, conclusions from the data could differ. Mr. M. Hankard, acoustical consultant for the Highland and Shirley projects, accompanied, assisted and observed the investigators on Wednesday, 12/5.

Figure 2.1: *Aerial view showing sound survey locations*

The four firms wish to thank and acknowledge the extraordinary cooperation given to us by the residence owners and various attorneys.

3.0_Investgator Observations

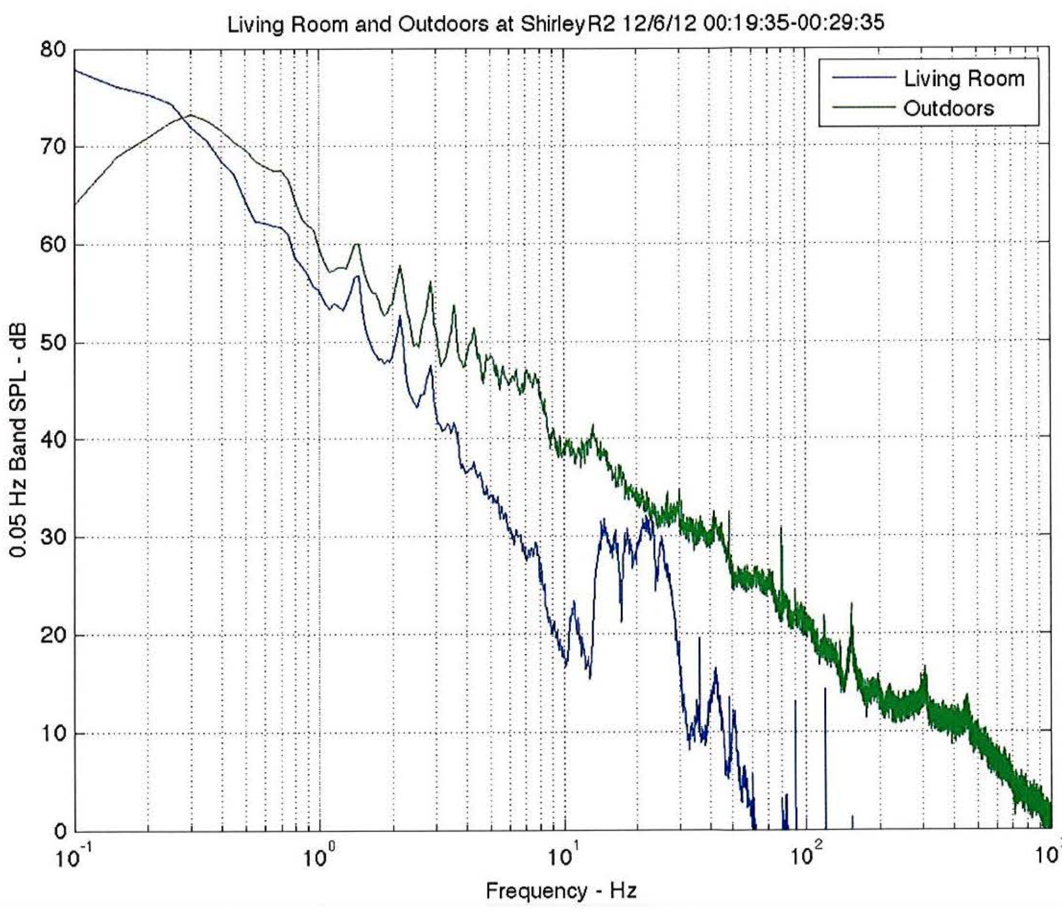
Observations from the five investigators are tabulated below: It should be noted the investigators had a relatively brief exposure compared to 24/7 occupation.

AUDIBILITY OUTSIDE RESIDENCES	
	Observations
Bruce Walker	Could detect wind turbine noise at R1, easily at R2, but not at all at R3
George Hessler	Could detect wind turbine noise at R1, easily at R2, but not at all at R3
David Hessler	Could detect wind turbine noise at R1, easily at R2, but not at all at R3
Robert Rand	Could detect wind turbine noise at all residences
Paul Schomer	Not sure at R1 but could detect wind turbine noise at R2, not at all at R3
AUDIBILITY INSIDE RESIDENCES	
	Observations
Bruce Walker	Could not detect wind turbine noise inside any home
George Hessler	Could not detect wind turbine noise inside any home
David Hessler	Could faintly detect wind turbine noise in residence R2
Robert Rand	Could detect wind turbine noise inside all three homes
Paul Schomer	Could not detect wind turbine noise inside any home
EXPERIENCED HEALTH EFFECTS	
	Observations
Bruce Walker	No effects during or after testing
George Hessler	No effects during or after testing
David Hessler	No effects during or after testing
Robert Rand	Reported ill effects (headache and/or nausea while testing and severe effects for 3+ days after testing
Paul Schomer	No effects during or after testing

4.0_Conclusions

This cooperative effort has made a good start in quantifying low frequency and infrasound from wind turbines.

Unequivocal measurements at the closest residence R2 are detailed herein showing that wind turbine noise is present outside and inside the residence. Any mechanical device has a unique frequency spectrum, and a wind turbine is simply a very very large fan and the blade passing frequency is easily calculated by RPM/60 x the number of blades, and for this case; 14 RPM/60 x 3 = 0.7 Hz. The next six harmonics are 1.4, 2.1, 2.8, 3.5, 4.2 & 4.9 Hz and are clearly evident on the attached graph below. Note also there is higher infrasound and LFN inside the residence in the range of 15 to 30 Hz that is attributable to the natural flexibility of typical home construction walls. This higher frequency reduces in the basement where the propagation path is through the walls plus floor construction but the tones do not reduce appreciably.



Measurements at the other residences R1 and R3 do not show this same result because the increased distance reduced periodic turbine noise closer to the background and/or turbine loads at the time of these measurements resulted in reduced acoustical emission. Future testing should be sufficiently extensive to cover overlapping turbine conditions to determine the decay rate with distance for this ultra low frequency range, or the magnitude of measurable wind turbine noise with distance.

The critical questions are what physical effects do these low frequencies have on residents and what LFN limits, if any, should be imposed on wind turbine projects. The reported response at residence R2 by the wife and their child was extremely adverse while the husband suffered no ill effects whatsoever, illustrating the complexity of the issue. The family moved far away for a solution.

A most interesting study in 1986 by the Navy reveals that physical vibration of pilots in flight simulators induced motion sickness when the vibration frequency was in the range of 0.05 to 0.9 Hz with the maximum (worst) effect being at about 0.2 Hz, not too far from the blade passing frequency of future large wind turbines. If one makes the leap from physical vibration of the body to physical vibration of the media the body is in, it suggests adverse response to wind turbines is an acceleration or vibration problem in the very low frequency region.

The four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies.

5.0_Recommendations

5.1_General

We recommend additional study on an urgent priority basis, specifically:

- A comprehensive literature search far beyond the search performed here under time constraints.
- A retest at Shirley to determine the decay rate of ultra low frequency wind turbine sound with distance with a more portable system for measuring nearly simultaneously at the three homes and at other locations.
- A Threshold of Perception test with participating and non-participating Shirley residents.

5.2_For the Highlands Project

ChIA and Rand do not have detail knowledge of the Highland project and refrain from specific recommendations. They agree in principle to the conclusions offered herein in Section 4.0.

Hessler Associates has summarized their experience with wind turbines to date in a peer-reviewed Journal[1] and have concluded that adverse impact is minimized if a design goal of 40 dBA (long term average) is maintained at all residences, at least at all non-participating residences. To the best of their knowledge, essentially no annoyance complaints and certainly no severe health effect complaints, as reported at Shirley, have been made known to them for *all* projects designed to this goal.

[1] Hessler G., & David, M., "Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States", Noise Control Engineering Journal, 59(1), Jan-Feb 2011

Schomer and Associates, using an entirely different approach have concluded that a design goal of 39 dBA is adequate to minimize impact, at least for an audible noise impact. In fact, a co-authored paper[2] is planned for an upcoming technical conference in Montreal, Canada.

Although there is no explicit limit for LFN and infrasound in these A-weighted sound levels above, the spectral shape of wind turbines is known and the C-A level difference will be well below the normally accepted difference of 15 to 20 dB. It may come to be that this metric is not adequate for wind turbine work but will be used for the time being.

Based on the above, Hessler Associates recommends approval of the application if the following Noise condition is placed on approval:

> With the Hessler recommendation, the long-term-average (2 week sample) design goal for sound emissions attributable to the array of wind turbines, exclusive of the background ambient, at all non-participating residences shall be 39.5 dBA or less.

Schomer and Associates recommends that the additional testing listed in 5.3 be done at Shirley on a very expedited basis with required support by Duke Energy prior to making a decision on the Highlands project. It is essential to know whether or not some individuals can perceive the wind turbine operation at R1 or R3. With proper resources and support, these studies could be completed by late February or early March. If a decision cannot be postponed, then Schomer and Associates recommends a criterion level of 33.5 dB. The Navy's prediction of the nauseogenic region (Schomer Figure 6 herein) indicates a 6 dB decrease in the criterion level for a doubling of power such as from 1.25 MW to 2.5 MW.

> With the Schomer recommendation, and in the presence of a forced decision, the long-term-average (2 week sample) design goal for sound emissions attributable to the array of wind turbines, exclusive of the background ambient, at all non-participating residences shall be 33.5 dBA or less.

There is one qualifier to this recommendation. The Shirley project is unique to the experience of the two firms in that the Nordex100 turbines are very high rated units (2.5 MW) essentially not included in our past experiences. HAI has completed just one project, ironically named the Highlands project in another state that uses both Nordex 90 and Nordex 100 units in two phases. There is a densely occupied Town located 1700 feet from the closest Nordex 100 turbine. The president and managers of the wind turbine company report "no noise issues at the site".

Imposing a noise limit of less than 45 dBA will increase the buffer distances from turbines to houses or reduce the number of turbines so that the Highlands project will *not* be an exact duplication of the Shirley project. For example, the measured noise level at R2 is approximately 10 dBA higher than the recommendation resulting in a subjective response to audible outside noise as twice as loud. Measured levels at R1 and R3 would comply with the recommendation.

We understand that the recommended goal is lower than the limit of 45 dBA now legislated, and may make the project economically unviable. In this specific case, it seems justified to the two firms to be conservative (one more than the other) to avoid a duplicate project to Shirley at Highlands because there is no technical reason to believe the community response would be different.

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[2] Schomer, P. & Hessler, G., "Criteria for wind-turbine noise immissions", ICA, Montreal, Canada 2013

5.3_For the Shirley Project

The completed testing was extremely helpful and a good start to uncover the cause of such severe adverse impact reported at this site. The issue is complex and relatively new. Such reported adverse response is sparse or non-existent in the peer-reviewed literature. At least one accepted paper at a technical conference[3] has been presented. There are also self-published reports on the internet along with much erroneous data based on outdated early wind turbine experience.

A serious literature search and review is needed and is strongly recommended. Paul Schomer, in the brief amount of time for this project analysis, has uncovered some research that *may* provide a probable cause or direction to study for the reported adverse health effects. We could be close to identifying a documented cause for the reported complaints but it involves much more serious impartial effort.

An important finding on this survey was that the cooperation of the wind farm operator is absolutely essential. Wind turbines must be measured both ON and OFF on request to obtain data under nearly identical wind and power conditions to quantify the wind turbine impact which could not be done due to Duke Power's lack of cooperation.

We strongly recommend additional testing at Shirley. The multi-channel simultaneous data acquisition system is normally deployed within a mini-van and can be used to measure immissions at the three residences under the identical or near identical wind and power conditions. In addition, seismic accelerometer and dedicated ear-simulating microphones can be easily accommodated. And, ON/OFF measurements require the cooperation of the operator.

Since the problem may be devoid of audible noise, we also recommend a test as described by Schomer in Appendix D to develop a "Threshold of Perception" for wind turbine emissions.

Bruce Walker

George F. Hessler Jr.

David M. Hessler

Robert Rand

Paul Schomer

[3] Ambrose, S. E., Rand, R. W., Krogh, C. M., "Falmouth, Massachusetts wind turbine infrasound and low frequency noise measurements", Proceedings of Inter-Noise 2012, New York, NY, August 19-22.

Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States

David M. Hessler[a)] and George F. Hessler Jr.[b)]

(Received: 2 April 2010; Revised: 21 June 2010; Accepted: 21 June 2010)

Potential impacts from operational noise produced by wind turbines is a major issue during the project planning and permitting process, particularly for projects east of the Mississippi River in fairly populous areas. While still an issue farther west, more buffer space and lower population densities sometimes make noise less of a factor. In general, however, noise may be the principal obstacle, from an environmental impact standpoint, to the more rapid growth of this renewable energy source in the United States. Proposed projects are frequently opposed on noise concerns, if not outright fear, usually aroused by the highly biased misinformation found on numerous anti-wind websites. While significant noise problems have certainly been experienced at some newly operational projects, they are usually attributable to poor design (siting units too close to houses without any real awareness of the likely impact) or to unexpected mechanical noises, such as chattering yaw brakes or noisy ventilation fans. A common theme at sites with legitimate complaints is that no one—not the developer, their consultants or the regulatory authority—really understood the import and meaning of the sound levels predicted at adjacent homes in project environmental impact statement (EIS) noise modeling. This paper seeks to address this lack of knowledge with suggested design goals and regulatory limits for new wind projects based on experience with the design of nearly 60 large wind projects and field testing at a number of completed installations where the apparent reaction of the community can be compared to model predictions and measurements at complainant's homes.

Primary subject classification: 69.3; Secondary subject classification: 14.5.4

1 INTRODUCTION

Typical wind turbine generators (WTG) used today are generally in the 1.5 to 3 MW range of electrical generation capacity and all of them produce a moderate amount of generally mid-frequency aerodynamic noise. All are three-bladed with the rotor forward, or upwind, of the supporting tower so that the blades do not pass through the tower wake avoiding the low frequency noise issues observed in the eighties[1] by downwind blades. This experience appears to have initiated the persistent but incorrect idea that wind turbines are substantial sources of low frequency noise, which, extensive field testing clearly shows, is not at all the case with modern units.

Subjectively, fairly close to a typical wind turbine, one can observe a "whoosh" or "swish" sound with periodicity of about 1 second generated by the down-coming blade. While the "frequency" of this sound is low at about 1 Hz this sound is not low frequency or infrasonic noise, but rather a repeating, mid-frequency sound (with its peak generally around 500 Hz).

This periodic sound becomes less distinct with distance and, usually together with neighboring units, blends into a more continuous low magnitude "churning" sound that is often likened to a plane flying over at fairly high altitude; particularly since the sound tends to fluctuate or fade in and out randomly in the same way that aircraft noise is usually perturbed by the intervening atmosphere. Wind turbine sound emissions sometimes contain minor tones associated with mechanical components (usually ventilation fans) but almost never produce prominent "pure tones" per the commonly used EPA definition[2].

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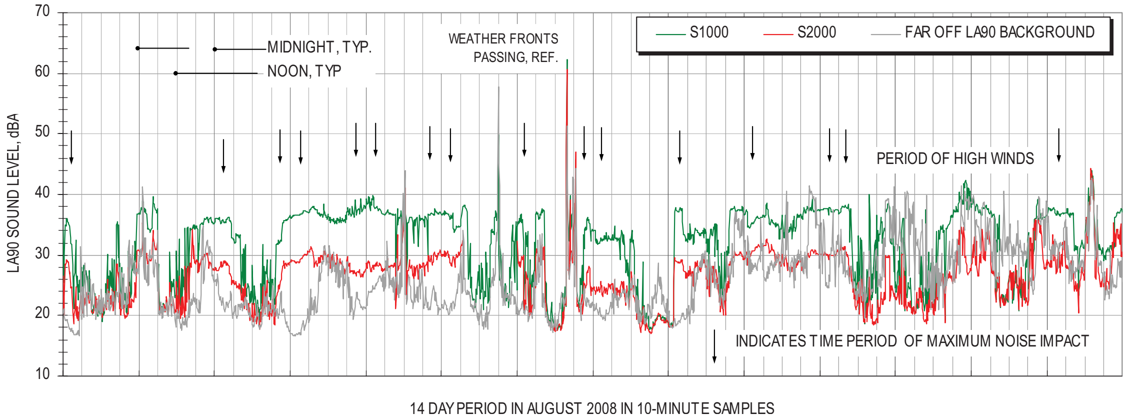

Fig. 1—Operational measurements over a 14-day period at two distances (1000 and 2000 feet south, 300 and 600 meters) from a single wind turbine compared to the prevailing macro area ambient sound level at the same locations for determining noise impact.

2 POTENTIAL FOR ADVERSE NOISE ANNOYANCE

Adverse impact in the form of annoyance and complaints can occur if facility noise emissions significantly exceed the prevailing environmental background sound level, as with any power project. Because wind turbine sites are typically in rural areas the existing background sound level is often very low, even when its dependence on wind speed and wind-induced sounds is taken into consideration.

As an example, Fig. 1 shows over 2000 ten minute residual measurements (LA_{90} Level exceeded 90% of the time) over a 14 day survey at distances of 300 and 600 meters from an operating single wind turbine compared to the average concurrent background level measured at several off-site locations. Hypothetical noise impacts exist wherever the turbine sound level significantly exceeds the background level. In Fig. 1, the maximum differential between the measured sound level and the background level often occurs at night on nights when the winds are fairly light. When it's windy the differential and the perceptibility of the project is usually less irrespective of time of day as wind generated sources of environmental sound become more dominant.

This time-of-day dependency can be explained by examining the typical wind speed gradient with elevation as a function of time of day. Figure 2 shows the shear exponent, a term that corresponds to the curvature of the gradient, measured empirically over a two year period at a planned wind project site in the Midwest. The shear exponent is low during the day time hours due to atmospheric mixing resulting in a more vertical gradient, as shown in Fig. 3, while the exponent is significantly higher at night due to thermal layering; a phenomenon that is more pronounced during lower wind conditions. As described and reported by van den Berg[3], at night the upper elevation wind speed can be high enough to operate the turbine while at ground level it is quite low, which can lead to relatively low sound levels, such as those observed most nights in Fig. 1.

It can be concluded from these data that the potential for annoyance is most likely during the evening and nighttime and less likely during the day implying that any design goal or regulatory limit should focus on the nighttime sound level.

As a final note on background levels, Fig. 4 shows a typical set of natural background sound levels (without any turbine noise) measured in a quiet rural environment plotted as a function of wind speed at a typical hub height elevation of 80 m. Modern wind turbines begin to produce power at a cut-in speed of roughly 3 m/s. The red lines on this graphic show an analytical model by Donovan[4] where the background sound has two components: the residual level (shown here at 38 dBA) and the wind generated level plotted as the 6th power of wind speed, which would be expected from a flow-induced acoustic source. The logarithmic summation

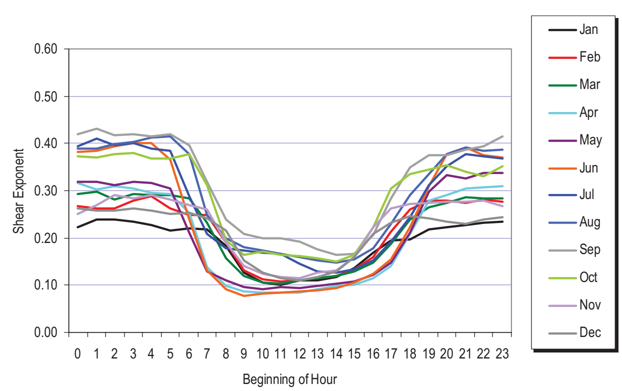

Fig. 2—Wind Shear Exponent, α, as defined by $V1/V2 = (H1/H2)^{\alpha}$ where V and H stand for velocity and height above grade.

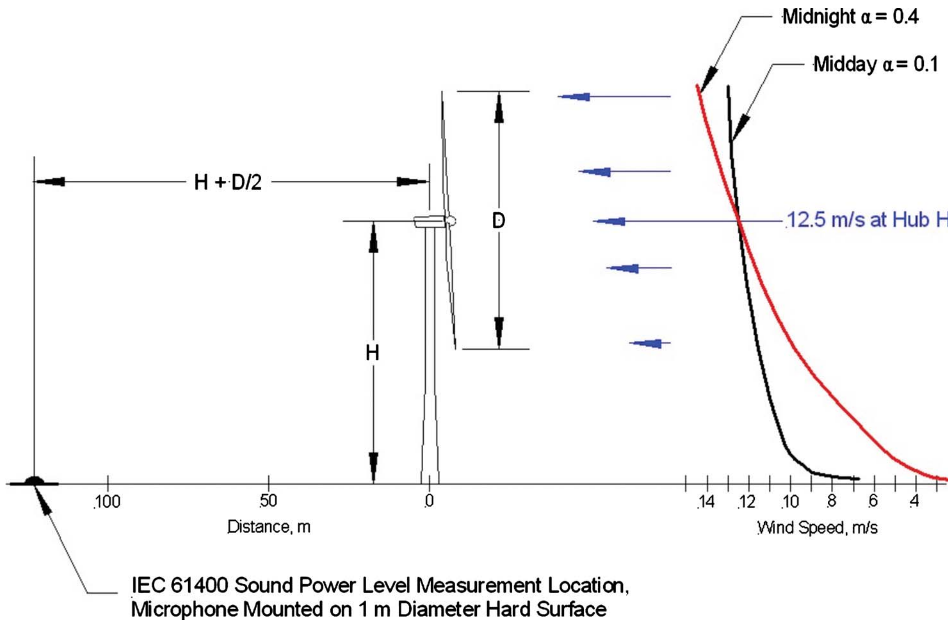

Fig. 3—Typical wind profiles for day and night periods. The figure also shows the measurement location for IEC 61400.

of these two components would closely track the mean linear trend of the measured data (black line).

3 NOISE LIMITS FROM THE LITERATURE

3.1 World Standards and Guidelines

The World Health Organization (WHO) published the following 1999 guidelines[5] for community noise in residential environments:

55 dBA Leq Daytime Levels: "Serious Annoyance, daytime and evening"

50 dBA Leq Daytime Levels: "Moderate Annoyance, daytime and evening"

45 dBA Exterior/30 dBA Interior Leq Nighttime Levels: To avoid sleep disturbance issues.

The nighttime sleep disturbance threshold has recently been reexamined by the WHO (2009)[6] and has been lowered from 45 dBA to 40 dBA outside of residences. No inside value is specified. The level is expressed as a design target to protect the public. Considering this guideline, nighttime sound levels from wind developments outside of residences should be generally targeted at 40 dBA as an ideal design goal to avoid sleep disturbance issues.

3.2 World Wind Turbine Noise Limits

Wind turbine development in European countries and in other parts of the world has been proceeding for

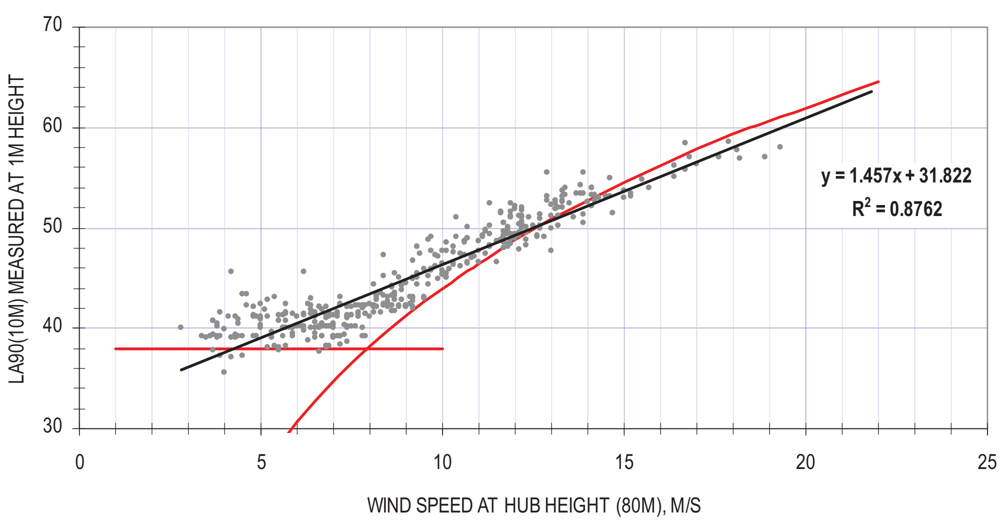

Fig. 4—Typical LA90 measurements as a function of wind speed at hub height.

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Table 1—Typical worldwide wind turbine noise limits.

LOCATION	CRITERIA VALUE(S)	METRIC	FEATURES
ALBERTA, CANADA	50D/40N	dBA	
QUEBEC, CANADA	45D/40N	dBA	
ONTARIO, CANADA	45D/40N	dBA	
MANITOBA, CANADA	60D/50N	MAX dBA	MAX ACCEPTABLE
MANITOBA, CANADA	55D/45N	MAX dBA	MAX DESIRABLE
DENMARK	40	L_{eq} dBA	DAY AND NIGHT
GERMANY	60D/45N	dBA	MIXED RESIDENTIAL/COMMERCIAL
	55D/40N	dBA	GENRAL LIVING AREAS
	50D/35N	dBA	PURE LIVING AREAS (1)
NETHERLANDS	40D/30N	L_{eq} dBA	
NEW ZEALAND	40	L90 dBA	PRIMARY, WHICHEVER
NEW ZEALAND	AMBIENT+5	L90 dBA	IS GREATER
UK	43N	dBA	
UK	35–40 (37.5 FOR AVERAGING)	dBA	FOR LOW NOISE ENVIRONMENTS
UK	AMBIENT+5	dBA	DAY AND NIGHT
UK	35	dBA	AVOIDS AMBIENT STUDY
ARITHMETIC AVERAGE	45D/40N		(1)-USE FOR AVERAGING

some time now while widespread development has only really started in the United States within the last 5 years or so. Thus, the question of allowable limits specifically for wind turbines has already been addressed by a number of other countries. Storm[7] presents a summary of world standards in Tables 3 and 4 of his paper, the core of which is reproduced here in Table 1.

3.3 U.S. Federal Standards

The U.S. federal government issues no standards for industrial noise but does promulgate noise regulations for major transportation systems. These regulations by the Federal Aviation Authority (FAA) and the Federal Highway Administration (FHWA) are fundamentally predicated on the idea that some noise annoyance is justified or offset by the public good provided by the systems. Generally, acceptable regulatory levels in the 60 to 65 DNL (day night sound level) range have been shown to "highly annoy" approximately 10 to 20% of affected residential receptors. However, these published standards are not particularly useful for wind turbine noise emissions, since the public good of a new power plant or industrial facility is not obvious to its immediate neighbors, and conscientious owners would ideally want no annoyed neighbors.

The U.S. EPA Office of Noise Abatement was unfunded in the late seventies but did issue a landmark report suggesting guidelines for environmental noise in residential communities from all environmental sources. The report[8] is often referred to as the "*Levels*" document for short and has become a de facto standard for such organizations as the World Bank and others. Unfortunately, this report is often misused and the cited recommended level of DNL=55 dBA for residential land use is commonly interpreted as an acceptable criterion level for new noise sources in any type of residential environment—whereas the intent was to provide a guideline, or national goal for total environmental noise (ambient noise including all industrial and transportation sources). The report acknowledges that no cost-benefit analysis was performed.

In addition, the report clearly indicates that the level of DNL=55 dBA is applicable to an urban residential background and must be normalized to the specific environments under consideration to obtain an acceptable level of correlation between DNL and community response. Without background normalization, correlation is very poor based on the analysis presented in the levels document and elsewhere. This is no surprise since a level of DNL=55 dBA cannot be expected to be satisfactory at the same time in both a very quiet rural and noisy urban residential setting. Schomer[9] suggests that an adjustment of 10 dBA should be subtracted for quiet rural environments and perhaps another 5 dBA if the project is newly introduced into such a long-standing quiet setting.

For a steady source, which a wind turbine could be broadly considered, a level of 39 dBA would be equivalent to DNL=55 dBA if reduced by 10 dBA; or 34 dBA if reduced by 15 dBA to compensate for a very quiet rural setting.

The EPA did conclude in the levels document that an outside sound level of 45 dBA at night (10 p.m. to 7

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Table 2—Tabulation of state nighttime noise regulations and siting standards.

STATE	NOISE LIMIT AT RESIDENTIAL RECEPTORS "A" WTD. EMISSION LEVEL	COMMENTS
MARYLAND	55	EMISSION LIMIT, ANY AMBIENT
DISTRICT OF COLUMBIA	55	EMISSION LIMIT, ANY AMBIENT
DELAWARE	55	EMISSION LIMIT, ANY AMBIENT
ILLINOIS	51	EMISSION LIMIT, ANY AMBIENT-EQUIVALENT A-WTD LEVEL FROM SPECIFIED OCTAVE BANDS
CONNECTICUT	51	EMISSION LIMIT, ANY AMBIENT
MINNESOTA	51	EMISSION LIMIT, ANY AMBIENT
NEW JERSEY	50	EMISSION LIMIT, ANY AMBIENT
OREGON	50	L50 IN ANY ONE HOUR IN "QUIET" ENVIRONMENTS
COLORADO	50	EMISSION LIMIT, ANY AMBIENT
MAINE	45	50 dBA WHEN AMBIENT LEQ > 35 dBA, 45 dBA BELOW (USE L_{eq}=33 dBA)
MASSACHUSETTS	40	MAXIMUM OF 5 TO 10 dBA ABOVE LOWEST L90 AMBIENT (USE MIN L90=33+7 dBA)
WASHINGTON	39	EMISSION LIMIT DEPENDING ON RURAL (39) OR RESIDENTIAL (42) ZONING
CALIFORNIA	38	MAXIMUM OF 5 dBA ABOVE L90 AMBIENT (FOUR QUIETEST CONSECUTIVE HOURS, USE MIN L90=33 dBA)
NEW YORK	38	MAXIMUM OF 5 dBA ABOVE UNDEFINED AMBIENT (USE MIN L90 OR L_{eq}=33 dBA)
MEAN STATE NIGHTTIME LIMIT:	50	
AVERAGE STATE NIGHTTIME LIMIT	47.7	

a.m.) is adequate to preclude sleep-interference issues. This was based on a typical noise reduction of 10 dBA with open windows that would result in an interior bedroom level of 35 dBA. The much later work by the WHO mentioned above now recommends an exterior background level of 40 dBA to avoid sleep issues.

Considering the EPA guidelines as published in the seventies and later analysis, DNL levels from wind developments outside of residences should ideally be targeted at DNL=45 dB, or preferably 5 dBA less. A DNL level of 45 dBA is equivalent to 45 dBA day/35 dBA night or a steady 24 hour level of 39 dBA. A 45 dBA CNEL (Composite Noise Equivalent Level with a 5 dBA evening weighting) would be even more ideal at 45, 40 and 35 dBA for day, evening and nighttime levels, respectively.

3.4 State Standards

Just over a dozen states have codified regulations, zoning guidance or siting standards, presented in Table 2, that fundamentally have the same result as regulations for industrial noise. Most allow a higher limit for daytime hours. The *nighttime* limits for industrial noise sources are tabulated in Table 2 for fourteen states. For the three states using an ambient based limit (CA, MA and NY), we use a representative background level of 33 dBA as an approximate, if somewhat conservative, design datum.

Clearly, there is a large variance, ranging from 38 dBA to 55 dBA, in what is considered "acceptable" for nighttime noise emissions at sensitive receptors. Not all can possibly be appropriate.

It should also be mentioned that the units and time periods of measurements for "emission limits" are not always well defined and one must refer to the actual standard for guidance.

Eight states use absolute 'maximum emission limits' for daytime and nighttime hours that are applicable at residential receptors regardless of the acoustic environment in those areas. While simple to codify and enforce, it is illogical that the same level could be satisfactory for any residential environment ranging from noisy urban to quiet rural residential locations. The state of Maryland[10] acknowledges this and has found

Table 3—Summary of existing guidelines and standards relevant to typical wind projects.

Source	Effective Limits	Comments
WHO	40 dBA Night	Sleep Disturbance Threshold
Consensus of Int'l Limits Specifically on Wind Turbine Noise	45 dBA Day/40 dBA Night	Arithmetic Average of all Standards
U.S. EPA	45 dBA Day/35 dBA Night	DNL=45 dBA
State Standards	38 to 40 dBA Night	Based on the 3 States using an Ambient-Based Approach

that fully 50% of excessive noise complaints occur in situations where the noise source is in compliance with the State's regulations. Maine and Washington acknowledge differing ambient environments by including a clause that reduces the allowable emission limit for "quiet" areas in Maine and "rural" areas in Washington.

The states of New York, Massachusetts and California use ambient-based emission levels, i.e., the allowable emission level is calculated based on a prescribed increase to the existing ambient, or background sound level. An ambient-based method is based on the *perception* of the new sound in the *specific* residential community. A perception-based method is clearly a better approach than a single absolute limit, and, in fact, many years of experience have shown that this approach is working well in these three states. Based on an assumed generic background level of 33 dBA for rural areas where wind projects are usually sited, the effective design level for a new project would range from 38 to 40 dBA in these three states.

3.5 Local Standards

Finally, it should be mentioned that countless counties and local municipalities have enacted noise laws and ordinances specifically with respect to wind turbine projects—usually in response to a proposed project. Most commonly an absolute limit of 50 dBA is prescribed. Field experience, which is discussed in further detail in Sec. 4, indicates that such a limit is insufficient to avoid annoyance from wind turbine noise if the actual project sound level closely approaches this limit.

3.6 Summary of Existing Guidelines and Standards

Table 3 summarizes the general noise limits and guidelines from all known existing entities domestic and foreign that would be relevant to typical wind turbine projects in rural areas.

4 DIRECT EXPERIENCE AND PREVIOUS ANNOYANCE STUDIES

It is only through field experience testing newly operational wind projects that the actual community reaction can be directly compared to the sound levels produced by a project. Over the last few years we have had the opportunity to conduct sound surveys at 8 new operational wind turbine sites, of which 7 may be considered representative of the typical U.S. domestic project in the sense that a fairly large number of turbines (50 to 100) are sited over a large area within which there is a fairly uniform distribution of farms and homes; i.e., the turbines and residences are thoroughly intermixed. Out of these 7 typical project sites long-term sound monitoring surveys were carried out at 5, usually over a 2 to 3 week period. The principal objective of these surveys was to determine whether the projects were compliant with the applicable regulatory noise limit (usually 50 dBA) but they also afforded important opportunities to quantify the sound levels produced exclusively by the project at a number of the closest homes and to compare these measurements with model predictions. In addition, the community reaction to each project could be generally discerned because monitors were deliberately placed at the homes of all those who were known to have complained or otherwise expressed concern about noise, whether participating in the project or not. Monitoring stations were also set up at other homes where no complaints had been received but where maximum project sound levels were expected based on modeling. Informal discussions about the resident's subjective reaction to project noise occurred at most monitoring positions.

In general, these studies involved continuous monitoring in 10 minute increments over at least a 14 day period at numerous on-site positions supplemented by a number of off-site monitors generally 2 miles beyond the project perimeter recording the likely concurrent background sound level without any project noise. In this way it was possible to reasonably correct the

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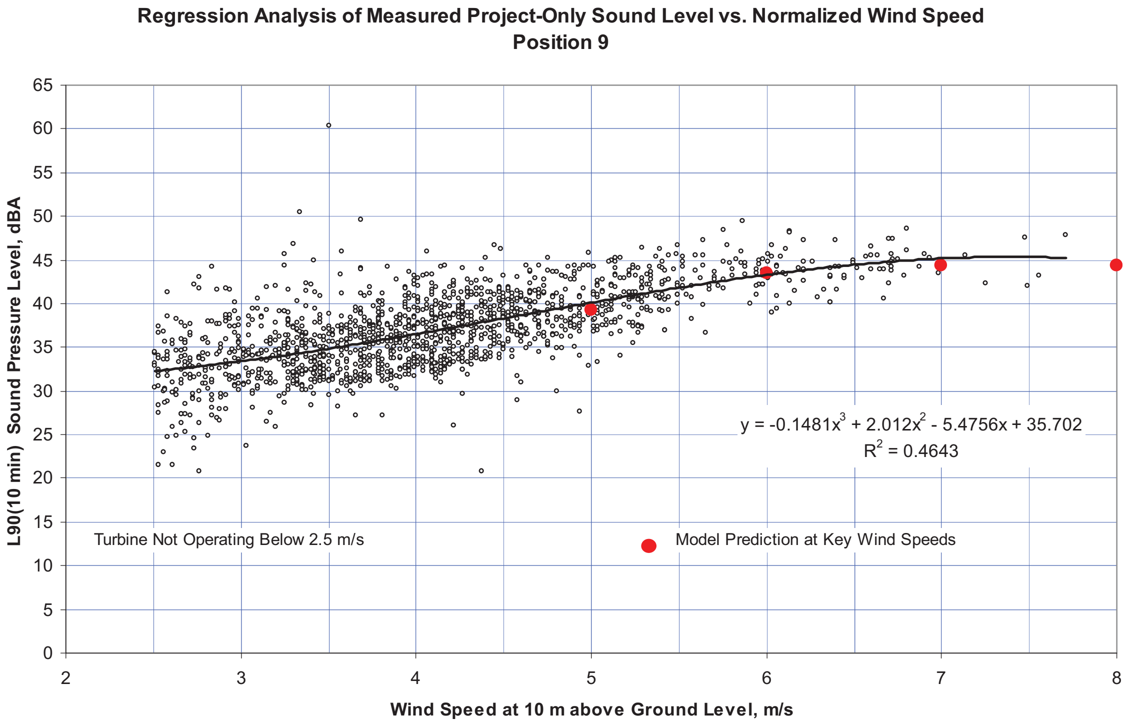

Fig. 5—Measured vs. modeled sound levels at a typical on-site receptor.

on-site sound levels for background noise contamination (which is often very significant during windy conditions) thereby deriving the project-only sound level at each position—the quantity predicted by analytical models. As an example, Fig. 5 is a typical plot that shows the corrected project-only sound level as a function of wind speed rather than time. The scatter in the data, which is typical and expected, is due to fluctuations in the project sound level at the observation point due to variations in atmospheric conditions (path effects) and fluctuations in the aerodynamic noise produced by the rotor due to inevitable inconsistencies in wind speed, gradient or direction (source effects). More importantly, Fig. 5 shows the essentially universal result from all positions in all the surveys that the model predictions at integer wind speeds agree extremely well with the mean trend through the measured performance, thus demonstrating that ISO 9613-2[11] (assuming a moderate 0.5 ground absorption coefficient) is a perfectly valid methodology for predicting wind turbine sound levels, recognizing that path and source effects will lead to levels that vary by about +/−5 dBA about the predicted mean.

In terms of noise impact, the results of these studies indicate that the actual degree of adverse impact, defined as the number of serious complaints relative to the total number of households in the project area (within 2000 ft. of the project perimeter), was fairly small at about 4%. The specific numbers associated with each project are tabulated in Table 4.

Just because the total number of complaints is fairly small in each case one should not be dismissive of these people, because there were usually one or two at each site that were profoundly disturbed by project noise. However, it must also be said that the vast majority of people apparently had no objections to noise, even people who consistently experienced turbine sound levels in the 45 to 50 dBA range. Based on discussions with non-participating and participating residents at more or less randomly selected monitoring positions in close proximity to turbines, the most common reaction was generally that operational noise was certainly audible, particularly during certain wind conditions or times of day, but that it was to be expected and they didn't pay any real attention to it. Of course, this general assessment is not the result of a rigorous scientific study on wind turbine annoyance; that was never the objective of the surveys, but a milder than anticipated reaction was observed at each site.

The low apparent rate of adverse reaction to projects where numerous residences were exposed to relatively high sound levels (up to 55 dBA in some cases) was surprising because it stood in stark contrast to the results of previous annoyance studies; in particular, the extensive work carried out from 2000 to 2007 in Sweden and the Netherlands by Pedersen and Persson Waye[12] and Persson Waye[13]. These studies generally predict an annoyance rate ranging from 10 to 45%, or more, for wind project sound levels in the 40 to 45 dBA range. For example, the earliest study[12], based on questionnaire responses collected in 2000 from residents living in proximity to five small wind projects in Sweden, found the annoyance rate as a function of sound level plotted in Fig. 6.

Table 4—Number of observed complaints relative to the total number of households in close proximity to turbines.

Project	Total Households in the Site Area (Approx.)	Number of Complaints as a Function of Project Sound Level (dBA) (1)			Total Number of Complaints	Percentage Relative to Total Households
		<40	40–44	45 or Higher		
Site A	107	0	2	1	3	3%
Site B	147	0	3	3	6	4%
Site C	151	0	3	0	3	2%
Site D	268	0	2	4	6 (2)	2%
Site E	91	1	1	4	6	7%
					Overall Average:	4%

(1) Sound levels expressed as long-term, mean values

(2) There were only 3 reported complaints at this site but others may have existed that we were not made aware of; hence a total number of 6 were assumed

This steeply rising curve apparently indicates that a sound level of 40 dBA, for instance, leads to a 26% annoyance rate, implying that out of the study population of 513, 133 were highly annoyed. However, this is not at all the case. On further analysis it turns out that the response curve percentage is not related to the overall study population—i.e., the total number of households within the project area with a predicted sound level of 30 dBA or more, whether they responded to the survey or not—but rather to the percentage of people exposed to a particular sound level that reported annoyance due to that sound level (see Table 5 of the paper). Now it must be pointed out that only 351 of the 513 individuals forming the study population returned the questionnaire, so the views of the missing 32% are not known, but in the 37.5 to 40 dBA category, for example, 20% of the 40 respondents exposed to that sound level range reported being highly annoyed—which is just 8 people. Viewed in terms of the overall population of 513 that is equivalent to a highly annoyed response of just over 1% for that particular sound level range (37.5 to 40 dBA). In general, across all sound level ranges the total number of people responding that they were highly annoyed was 31, or 6% of the total number of households. In contrast to the alarmingly steep response rate curve in Fig. 6, this 6% figure agrees much more closely with the 4% complaint rate (based on the total number of households) observed during our own field studies of projects in the United States. A further and much larger questionnaire study modeled on the 2000 study was performed in the Nether-

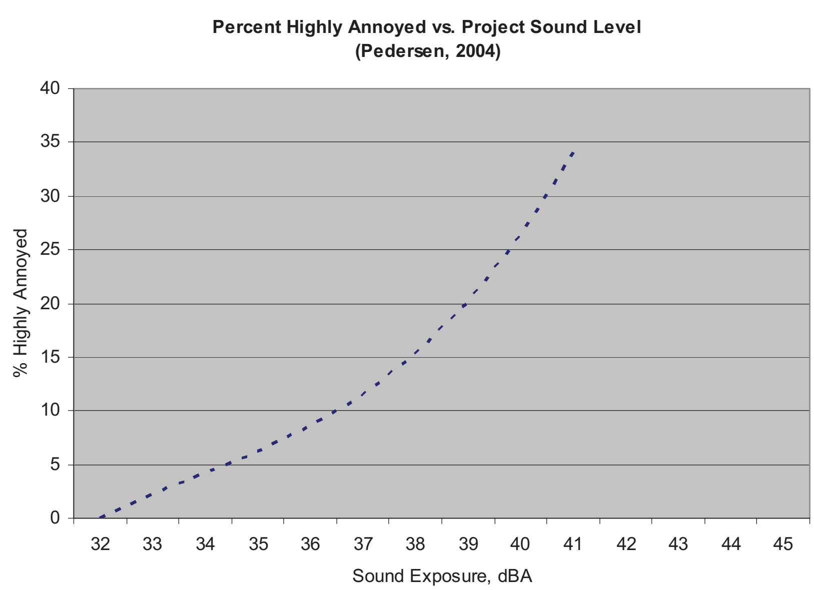

Fig. 6—Response analysis from Pedersen[14].

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lands in 2007 and reported in 2009 (Pedersen et al.[14]). This study is the most representative of current projects with large turbines and essentially flat topography. In this study out of 1948 queries sent out 708 were received. Across all sound level categories a total of 29 respondents (back-calculated from the results expressed as percentages in Table 2) reported being very annoyed. If only the 708 respondents are assumed to make up the pool of potentially affected residences in the project area (rather than 1948), this equates to a 4% rate of high annoyance.

On the other side of the coin, the number of individuals concerned about or annoyed by noise at each of the sites we studied may not have been definitive, since the number represents those who were troubled enough to call in and complain, as reported by project management, and any others we may have learned of indirectly in discussions with neighbors. The possibility that others were annoyed certainly cannot be ruled out and, in fact, seems likely but it appears that the actual rate of serious annoyance to noise from wind projects may not be nearly as high as previously supposed.

5 LOW FREQUENCY NOISE AND ADVERSE HEALTH EFFECTS

Harmful, or at least disturbing levels of low frequency or infrasonic noise and potential adverse health effects are almost always feared, based largely on internet misinformation, and cited as major reasons why proposed projects should not go forward. However, the fact of the matter is that wind turbines do not produce significant or even remotely problematic levels of low frequency noise and that a link between health complaints and turbine noise has only been asserted based on what is essentially anecdotal evidence without any valid epidemiological studies or scientific proof of any kind. The latter assertions are all the more suspect in that they are often predicated on or directly associated with the assumed existence of high levels of low frequency noise.

It is well outside the scope of this paper to go over the basis for these conclusions but readers are referred to a recent review by a panel of independent doctors on wind turbine health effects[15] and some extensive testimony by the leading experts in the field (now public record) regarding potential low frequency noise impacts recently filed in conjunction with a proposed wind project in Wisconsin[16].

Because low frequency noise from wind turbines, essentially irrespective of distance, is well below the point where it might begin to be audible or initiate perceptible vibrations (windows or dishes rattling, for example) there is no actual need for a design goal or regulatory limit. However, if one desires just to be on the safe side, so to speak, a limit of 65 dBC might be used. In over 30 years of investigating countless genuine low frequency noise complaints, usually associated with simple cycle combustion turbines, there was only one outlier below 65 dBC. A maximum regulatory limit of 70 dBC is recommended if one must have a low frequency limit.

Having said that, it must be strongly cautioned that C-weighted sound levels do not mix well with wind turbine applications because it is extremely difficult to accurately measure C-weighted sound levels in the presence of any kind of wind[17]. Self-generated, false signal noise, which occurs in the low frequencies, from wind blowing through even sophisticated windscreens and over the microphone tip will drastically elevate the apparent C-weighted sound level and, by extension, the *apparent* low frequency sound level. Consequently, it would be a significant technical challenge to accurately field verify the C-weighted performance of a wind turbine project. Any casual measurement in a windy field will ostensibly yield a relatively high C-weighted sound level, possibly in excess of the 65 to 70 dBC levels suggested above, whether a wind turbine is present—or not.

Finally, Fig. 3 also shows the measurement location prescribed in IEC 61400-11 for determining the sound power level from wind turbines. Sound pressure is measured on a reflective ground plane with the microphone on the surface where wind speed is theoretically zero, but a $\frac{1}{2}$ sphere wind screen will blow away unless attached securely. Still another common example is dry leaves blowing along the ground in fall. Even with this test set up, measurement of LFN is problematical.

6 RECOMMENDED DESIGN GOALS AND NOISE LIMITS

Based on the existing guidelines and limits outlined in Sec. 3, combined with our direct experience summarized in Sec. 4, the following design goals and regulatory limits given in Table 5 are recommended.

The nighttime level of 40 dBA is suggested as an ideal design goal rather than a firm regulatory limit because a legal limit must reasonably protect the public from legitimate annoyance and, at the same time, not stand completely in the way of economic development, which 40 dBA would tend to do in some instances. Because the actual number of complaints observed at sites where the project sound level exceeded, or even substantially exceeded, 40 dBA is small at 4%, a sound level of 45 dBA at residences, as an ordinance or legal limit, appears to balance the desire on everyone's part to avoid complaints and annoyance on the one hand with practical constructability on the other. Sound levels of less than

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Table 5—Recommended regulatory noise limits and design goals for wind turbine projects.

	Sound Level, dBA (1)	Applicable	Time of Day
Regulatory Limit:	45	Outside Residences	Day and Night
Design Goal:	40	Outside Residences	7 p.m. to 7 a.m.

(1) Long-term, mean project sound level (normally measured in terms of the L90(10 min) statistical sound level)

45 dBA would theoretically lead to a very low complaint rate of 2% based on the data in Table 4.

It is important to note that both of the levels above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value for brief periods. As illustrated in Fig. 5, project sound levels commonly fluctuate by roughly +/−5 dBA about the mean trend line but short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed (less than 1% of the time) that are ostensibly attributable to turbine noise—although the possibility exists that some or all are extraneous noise events. Because it would be completely impractical to design any project so that all such spikes would remain below the 40 and 45 dBA, these values are expressed as long-term mean levels, or the central trend line through the data scatter as shown in Fig. 5.

Some degree of dissatisfaction due to audibility is largely inevitable. The very definition of noise is unwanted (audible) sound. For example, in isolated incidences we are familiar with complaints have been engendered by wind project sound levels as low as 23 and 34 dBA. Therefore an objective of completely eliminating the possibility of any negative response is largely impractical and the imposition of extremely low regulatory noise limits or of vast minimum setbacks—as championed by James and Kamperman[18], for instance—would not necessarily eliminate all adverse impact but would, in fact, make most projects impossible to build, even in sparsely populated areas of the country.

During the design phase of a wind project, particularly for projects where the turbines are interspersed amidst a number of homes, there are several options, outlined below, that are available for mitigating potential project noise and bringing the project, hopefully, into conformance with one or both the recommended noise levels.

6.1 Site Layout Optimization

The most useful and effective method by far is the optimization of the site plan through iterative noise modeling. This technique, which has been successfully applied to a number of projects, involves developing a baseline model of the project as initially conceived in terms of a sound contour map and then hypothetically relocating or removing certain units in order to *ideally* place all of the potentially sensitive receptors within the site area outside of the 40 dBA contour line.

The baseline layout is usually driven by where participating land parcels are in general and where the wind resource is best on those parcels in particular, rather than by noise concerns. Consequently, some degree of improvement, i.e., a reduction in the predicted sound levels at residences, can almost always be realized—so long as it is early enough in the design process that significant changes can be made. In fact, the best time to start evaluating potential noise impacts is when a project has just begun to coalesce and is considered generally viable, even if only a hypothetical or estimated turbine layout is all that is available for modeling. All too often noise is only considered at the eleventh hour just prior to submittal of the permit application, or even construction, when the flexibility to move turbines has been utterly lost.

Because of the numerous other constraints that always exist on exactly where turbines can be built, it is often necessary to go through several iterations of noise modeling to find the optimal arrangement that minimizes noise and still satisfies all other concerns.

6.2 Low Noise Operating Modes

If physical changes to the turbine site plan cannot be made or are still insufficient to realize the desired performance, further targeted reductions can sometimes be made by operating specific units in low noise operating mode—something that can also be evaluated prior to construction through iterative modeling. While still not universally available as an option on all turbine makes and models, there now appears to be a trend towards incorporating this capability into most new units or retrofitting it on existing models. Noise reductions of up to 5 dB relative to normal performance (it is claimed by some manufacturers) can nominally be achieved primarily through electronic manipulation of the blade pitch. Although this operating mode could theoreti-

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cally be employed at all times, it adversely affects power production at higher wind speeds so it not desirable, or in some cases even economically unfeasible, to permanently de-rate the turbines; consequently, this option is more appropriate for use as a temporary measure under certain weather conditions or times of day, most likely during the critical nighttime hours when noise is typically more of an issue.

6.3 Operational Curtailment

Curtailment of operation, or temporarily shutting down specific turbines, is obviously onerous to the economics of a project that clearly involves a large capital investment, but it may be less devastating than first thought. The temporary shutdown of just one unit (overnight, for instance) can sometimes make a dramatic difference in the sound level at a particular point of interest. Depending on the geometry of the situation, model simulations taken from actual projects indicate that noise reductions from 2 to 8 dBA can be achieved by shutting down only the *single nearest* turbine to a particular house.

7 CONCLUSIONS

Measurements of operational wind turbine projects indicate that turbine noise is usually most perceptible relative to the background level at night suggesting that design goals and regulatory limits should either be focused on nighttime conditions or have differing goals for night and day

Existing guidelines and regulatory limits, interpreted within the context of the quiet rural environments in which wind projects are normally sited, generally point to a design goal sound level of 40 dBA at night and 45 dBA during the day.

Experience in measuring the sound levels produced by newly operational wind projects and comparing those levels to actual community reaction indicates that the number of complaints relative to the total number of potentially affected households within a given project area is fairly low at roughly 4% in cases where project sound levels exceed or even substantially exceed 40 dBA at residences. This finding was also found to generally agree with previous European research but only when the number of questionnaire responses reporting high annoyance is similarly viewed relative to the overall number of potentially affected households rather than by exposure levels.

Field surveys of operational projects also generally indicate that complaints engendered by wind turbine sound levels below 40 dBA are very rare therefore suggesting that new wind projects should use a nighttime sound level of 40 dBA as an ideal design goal at all residences to minimize the probability of annoyance and complaints with a higher level of 45 dBA applicable during the day. However, the low (2%) rate of complaints observed in the studies when the project sound level was below 45 dBA points to this value (45 dBA) as an appropriate regulatory limit, irrespective of time of day, since it appears to strike a balance between the reasonable prevention of annoyance and what is generally achievable in terms of project sound levels at typical project sites.

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