EXHIBIT A

Information
about
Richard R. James, INCE

Summary of Experience Related to Wind Turbines and Community Noise

I am the Owner and Principal Consultant of E-Coustic Solutions (E-CS) and have previously been qualified as an expert witness involving hearings related to wind turbine noise, its measurement and characterization, and, its effects on people in the States of Michigan, Illinois, New York, Ohio, Maine, Vermont, Wisconsin, and West Virginia. In addition I have qualified as an expert witness in Ontario, Canada and in New Zealand.

I have a Bachelor of Science degree in Mechanical Engineering from the General Motors Institute, (1981 renamed to Kettering University), and my c.v. is attached hereto as Attachment 1.

I have been a practicing acoustical engineer for 40 years. I have been actively involved with the Institute of Noise Control Engineers (INCE) since I started my career in the early 1970s. I have full Member status in the Institute. INCE is the primary certifying body for acoustician's both in the U.S. and internationally. Full Member is granted to those passing the certification requirements which are based on qualifications for education and proficiency in the field.

My clients include many large manufacturing firms, such as, General Motors, Ford, Goodyear Tire & Rubber, and others who have operations involving both community noise and worker noise exposure. In addition, I have worked for many small companies and private individuals.

My academic credentials include current appointments as Adjunct Professor and Instructor to the Speech and Communication Science Departments at Michigan State University and Central Michigan University.

Specific to wind turbine noise, I have worked for clients in over 60 different communities. I have provided written and oral testimony in approximately half of those instances. I have authored or co-authored four papers covering topics such as how to set criteria to protect public health, and others demonstrating that wind turbine sound emissions are predominantly comprised of infra sounds (*i.e.*, sounds that that are between 0 and 10 Hz, such that they are felt and not heard).

I am the author (or co-author) of:

- "*Simple guidelines for siting wind turbines to prevent health risks*,"
- "*The 'How To' Guide To Siting Wind Turbines To Prevent Health Risks From Sound*,"
- "Wind *Turbine Noise, What Audiologists should know*,"
- "*Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception*,"
- "*Wind Turbine Infra and Low Frequency Sound: Warning Signs that were not Heard*," and,
- several other publications, fact-sheets white papers, and reports regarding wind turbine noise, and its impact on residential land-use and people.

A list of these papers is attached to this Exhibit.

I have made presentations on wind turbine noise and its impact on people and other topics related to the proper siting of wind turbines if risks to public health are taken into consideration at the INCE conference NoiseCon 2008 held in Detroit, MI ("*Simple guidelines for siting wind turbines to prevent health risks*") and at a number of public venues in a less technical form as: "*The 'How To' Guide To Siting Wind Turbines To Prevent Health Risks From Sound*" first released in 2008.

I co-authored a paper describing the analysis of wind turbine noise measured and recorded at a residential home located approximately 1300 feet from the closest wind turbine using methods that can resolve the short duration, high amplitude pulsations that characterize the bursts of infra and low frequency sound emitted by wind turbines due to commonly occurring weather conditions. This paper: "Dynamic *measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception*," was presented at the 2011 NoiseCon Conference by my coauthor, Wade Bray, of HEAD Acoustics, Brighton, MI. The paper demonstrated that acoustic energy in the very low frequency range produced by wind turbines during commonly occurring weather conditions were sufficiently strong to be perceived by as much as 10% or more of the general population.

I have recently had a peer reviewed paper published in the April 2012 Journal of the Bulletin of Science, Technology, and Society, titled: "*Wind Turbine Infra and Low Frequency Sound: Warning Signs that were not Heard*" that compares the characteristics of acoustical emissions from industrial scale wind turbines of the type commonly used in utility scale projects to the sounds of other large machines with slowly rotating blades, such as, the fans used in high rise office buildings for heating and ventilating that were found to be the cause of noise induced sick building syndrome. Dynamic modulation (pulses) of infra and low frequency sound that were generally inaudible to occupants of these buildings caused adverse health effects of the type reported by people living near industrial scale wind turbines. This paper presents information that shows the acoustical experts commonly hired by the wind industry were aware of and in some cases participated in the studies that led to solving the question of what was causing noise induced sick building syndrome. It demonstrates that some of these same experts have other experience with noise sources emitting sound with similar characteristics to wind turbine sound emissions where modulating infra and low frequency noise was found to cause adverse health effects. Yet, these experts now deny that the health effects reported by people living in the footprint of utility scale wind energy projects could have a similar cause. This time the source of the disturbing acoustical energy is utility scale wind turbines, not HVAC fan systems. Finally, it reviews the history of a ten year study of wind turbine noise conducted for the DOE/NASA during the 1980's that reported that industrial scale modern upwind wind turbines of the type commonly used in utility scale projects would be expected to produce these very low frequency sounds and that such sounds would be a source of annoyance and indoor noise problems for people if wind turbines were located too close to their homes. It also anticipated that the problem would be worse inside homes than outside them as a result of the way the building structure interacted with the wind turbine noise.

I am currently conducting research with colleagues at Central Michigan University on wind turbine noise and installation issues. This study is using a Michigan wind energy project as its initial test community.

With respect to my services related to wind energy systems, I provide consulting services for municipalities and the private sector on issues related to the installation and siting of industrial scale modern upwind wind turbines; assist in conducting reviews of proposed wind turbine utility projects and the documents submitted by the developer when applying for permits and other permissions; and adoption of zoning ordinances regulating the same. The focus is on whether the proposed or anticipated wind turbine project's noise, audible and inaudible sound, is a potential source of annoyance; sleep disturbance; or other adverse health effects such as vestibular disturbances, mood changes, headaches; and ear, head, and body sensations, etc..

I am the Owner and Principal Consultant for E-Coustic Solutions, of Okemos, Michigan (P.O. Box 1129, Okemos MI 48805). I have been a practicing acoustical engineer for 40 years. Attached as Exhibit A is a summary of my experience demonstrating my work in addressing a broad range of problems for my clients and a narrative that provides more detail about my work on wind turbine noise. A summary of my wind related projects and testimony are also provided in Exhibit A. I have been actively involved with the Institute of Noise Control Engineers (INCE) since I started my career in the early 1970s. I have Full Member status in INCE. My clients include many large manufacturing firms, such as, General Motors, Ford, Goodyear Tire & Rubber, and others who have operations involving both community noise and worker noise exposure. In addition, I have worked for many small companies and private individuals.

My academic credentials include appointments as Adjunct Professor and Instructor to the Speech and Communication Science Departments at Michigan State University and Central Michigan University. Specific to wind turbine noise, I have worked for clients in over 60 different communities. I have provided written and oral testimony in approximately half of those cases.

Of specific relevance to work in Ontario, CA, in 2011 I was accepted as an expert witness on the topic of wind turbine noise and its effects by the Ontario Environmental Review Tribunal in the appeal of the Kent Breeze Wind Farms (Suncor Energy Services, Inc.) Renewable Energy Approval Cases No: 10-121/10-122. The hearings were held during February, March and May of 2011.

The Tribunal's decision in that case, set a higher hurdle for Noise Assessments in Ontario by concluding:

> "While the Appellants were not successful in their appeals, the Tribunal notes that their involvement and that of the Respondents, has served to advance the state of the debate about wind turbines and human health.
>
> "This case has successfully shown that the debate should not be simplified to one about whether wind turbines can cause harm to humans. The evidence presented to the Tribunal demonstrates that they can, if facilities are placed too close to residents. The debate has now evolved to one of degree. The question that should be asked is: What protections, such as permissible noise levels or setback distances, are appropriate to protect human health? ……. Just because the Appellants have not succeeded in their appeals, that is no excuse to close the book on further research. On the contrary, further research should help resolve some of the significant questions that the Appellants have raised."
>
> (Page 207 of Environmental Review Board Decision, Erickson V. Director, Ministry of the Environment, July 18, 2011) (**Emphasis added**)

EXHIBIT A

BIOGRAPHICAL SKETCH

NAME	POSITION TITLE	BIRTHDATE
Richard R. James	Principal Consultant, E-Coustic Solutions	3/3/48
	Adjunct Instructor, Michigan State University Adjunct Professor, Central Michigan University	

EDUCATION

INSTITUTION	DEGREE	YEAR	FIELD OF STUDY
General Motors Institute, Flint, MI	B. Mech. Eng.	1971	Noise Control Engineering

RESEARCH AND PROFESSIONAL EXPERIENCE:

Richard R. James has been actively involved in the field of noise control since 1969, participating in and supervising research and engineering projects related to control of occupational and community noise in industry. In addition to his technical responsibilities as principal consultant, he has developed noise control engineering and management programs for the automotive, tire manufacturing, and appliance industries. Has performed extensive acoustical testing and development work in a variety of complex environmental noise problems utilizing both classical and computer simulation techniques. In 1975 he co-directed (with Robert R. Anderson) the development of SOUND™, an interactive acoustical modeling computer software package based on the methods that would be later codified in ISO 9613-2 for pre and post-build noise control design and engineering studies of in-plant and community noise. The software was used on projects with General Motors, Ford Motor Company, The Goodyear Tire & Rubber Co., and a number of other companies for noise control engineering decision making during pre-build design of new facilities and complaint resolution at existing facilities. The SOUND™ computer model was used by Mr. James in numerous community noise projects involving new and existing manufacturing facilities to address questions of land-use compatibility and the effect of noise controls on industrial facility noise emissions. He is also the developer of ONE*dB(tm) software. He was also a co-developer (along with James H. Pyne, Staff Engineer GM AES) of the Organization Structured Sampling method and the Job Function Sound Exposure Profiling Procedure which in combination form the basis for a comprehensive employee risk assessment and sound exposure monitoring process suitable for use by employers affected by OSHA and other governmental standards for occupational sound exposure. Principal in charge of JAA's partnership with UAW, NIOSH, Ford, and Hawkwa on the HearSaf 2000tm software development CRADA partnership for world-class hearing loss prevention tools.

1966-1970	Co-operative student: General Motors Institute and Chevrolet Flint Metal Fabricating Plant.
1970-1971	GMI thesis titled: "Sound Power Level Analysis, Procedure and Applications". This thesis presented a method for modeling the effects of noise controls in a stamping plant. This method was the basis for SOUND™.
1970-1972	Noise Control Engineer-Chevrolet Flint Metal Fabricating Plant. Responsible for developing and implementing a Noise Control and Hearing Conservation Program for the Flint Metal Fabricating Plant. Member of the GM Flint Noise Control Committee which drafted the first standards for community noise, GM's Uniform Sound Survey Procedure, "Buy Quiet" purchasing specification, and guidelines for implement-ing a Hearing Conservation Program.
1972-1983	Principal Consultant, Total Environmental Systems, Inc.; Lansing, MI. Together with Robert R. Anderson formed a consulting firm specializing in community and industrial noise control.
1973-1974	Consultant to the American Metal Stamping Association and member firms for in-plant and community noise.
1973	Published: "Computer Analysis and Graphic Display of Sound Pressure Level Data For Large Scale Industrial Noise Studies", Proceedings of Noise-Con '73, Washington D.C.. This was the first paper on use of sound level contour 'maps' to represent sound levels from computer predictions and noise studies.
Nov. 1973	Published: "Isograms Show Sound Level Distribution In Industrial Noise Studies", Sound&Vibration Magazine
1975	Published: "Computer Assisted Acoustical Engineering Techniques", Noise-Expo 1975, Atlanta, GA which advanced the use of computer models and other computer-based tools for acoustical engineers.
1976	Expert Witness for GMC at OSHA Hearings in Washington D.C. regarding changes to the "feasible control" and cost-benefit elements of the OSHA Noise Standard. Feasibility of controls and cost-benefit were studied for the GMC, Fisher Body Stamping Plant, Kalamazoo MI.
1977-1980	Principal Consultant to GMC for the use of SOUND(tm) computer simulation techniques for analysis of design, layout, and acoustical treatment options for interior and exterior noise from a new generation of assembly plants. This study started with the GMAD Oklahoma City Assembly Plant. Results of the study were used to refine noise control design options for the Shreveport, Lake Orion, Bowling Green plants and many others.

1979-1983	Conducted an audit and follow-up for all Goodyear Tire & Rubber Company's European and U.K. facilities for community and in-plant noise.
1981-1985	Section Coordinator/Speaker, Michigan Department Of Public Health, "Health in the WorkPlace" Conference.
1981	Published: "A Practical Method For Cost-Benefit Analysis of Power Press Noise Control Options", Noise-Expo 1981, Chicago, Illinois
1981	Principal Investigator: Phase III of Organization Resources Counselors (ORC), Washington D.C., Power Press Task Force Study of Mechanical Press Working Operations. Resulted in publishing: "User's Guide for Noise Emission Event Analysis and Control", August 1981
1981-1991	Consultant to General Motors Corporation and Central Foundry Division, Danville Illinois in community noise citation initiated by Illinois EPA for cupola noise emissions. Resulted in a petition to the IEPA to change state-wide community noise standards to account for community response to noise by determining compliance using a one hour L_{eq} instead of a single not-to-exceed limit.
1983	Published: "Noise Emission Event Analysis-An Overview", Noise-Con 1983, Cambridge, MA
1983-2006	Principal Consultant, James, Anderson & Associates, Inc.; Lansing, MI. (JAA), Together with Robert R. Anderson formed a consulting firm specializing in Hearing Conservation, Noise Control Engineering, and Program Management.
1983-2006	Retained by GM Advanced Engineering Staff to assist in the design and management of GM's on-going community noise and in-plant noise programs.
1984-1985	Co-developed the 1985 GM Uniform Plant Sound Survey Procedure and Guidelines with James H. Pyne, Staff Engineer, GM AES.
1985-Present	**Adjunct Instructor, Michigan State University, Department of Communicative Sciences and Disorders**
1986-1987	Principal Consultant to Chrysler Motors Corporation, Plant Engineering and Environmental Planning Staff. Conducted Noise Control Engineering Audits of all manufacturing and research facilities to identify feasible engineering controls and development of a formal Noise Control Program.
1988-2006	Co-Instructor, General Motors Corporation Sound Survey Procedure (Course 0369)
1990	Developed One*dB$^{(tm)}$, JAA's Occupational Noise Exposure Database manager to support Organizational structured sampling strategy and Job Function Profile (work-task) approach for sound exposure assessment.
1990-1991	Co-developed the 1991 GM Uniform Plant Sound Survey Procedure and Guidelines with James H. Pyne, Staff Engineer, GM AES. Customized One*dB$^{(tm)}$ software to support GM's program.
1990-2006	Principal Consultant to Ford Motor Company to investigate and design documentation and computer data management systems for Hearing Conservation and Noise Control Engineering Programs. This included bi-annual audits of all facilities.
1993-2006	GM and Ford retain James and JAA as First-Tier Partners for all non-product related noise control services.
1993	Invited paper: "An Organization Structured Sound Exposure Risk Assessment Sampling Strategy" at the 1993 AIHCE
1993	Invited paper: "An Organization Structured Sound Exposure Risk Assessment Database" at the Conference on Occupational Exposure Databases, McLean, VA sponsored by ACGIH
1994-2001	Instructor for AIHA Professional Development Course, "Occupational Noise Exposure Assessment"
1996	Task Based Survey Procedure (used in One*dB$^{(tm)}$) codified as part of ANSI S12.19 Occ. Noise Measurement
1995-2001	Coordinate JAA's role in HearSaf 2000^{tm} CRADA with NIOSH, UAW,Ford, and HAWKWA
1997-Present	Board Member, Applied Physics Advisory Board, Kettering Institute, Flint Michigan
2002-2006	Member American National Standards Accredited Standards (ANSI) Committee S12, Noise
2005-Present	Consultant to local communities and citizens groups on proper siting of Industrial Wind Turbines. This includes presentations to local governmental bodies, assistance in writing noise standards, and formal testimony at zoning board hearings and litigation.
2006	Founded E-Coustic Solutions
2008	Paper on "Simple guidelines for siting wind turbines to prevent health risks" for INCE Noise-Con 2008, co-authored with George Kamperman, Kamperman Associates.
2008	Expanded manuscript supporting Noise-Con 2008 paper titled: "The "How To" Guide To Siting Wind Turbines To Prevent Health Risks From Sound"
2009	"Guidelines for Selecting Wind Turbine Sites," Kamperman and James, Published in the September 2009 issue of Sound and Vibration.

2010 Punch, J., James, R., Pabst, D., "Wind Turbine Noise, What Audiologists should know," Audiology Today, July-August 2010

2011 Jerry L. Punch, Jill L. Elfenbein, and Richard R. James , "Targeting Hearing Health Messages for Users of Personal Listening Devices," Am J Audiol 0: 1059-0889_2011_10-0039v1

2011 Bray, W., HEAD Acoustics, James, R., "Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception," invited paper for Noise-Con 2011, Portland OR

2012 James, R., "Wind Turbine Infra and Low Frequency Sound: Warning Signs that were not Heard," April 2012, Bulletin of Science, Technology and Society

2012 Appointed to a three year position as Adjunct Professor in the Department of Communication Disorders at Central Michigan University.

Professional Affiliations/Memberships/Appointments

Research Fellow - Metrosonics, Inc.		American Industrial Hygiene Association (through 2006)
National Hearing Conservation Association (through 2006)		Institute of Noise Control Engineers (Full Member)
American National Standards Institute (ANSI) S12 Working Group (through 2006)		Founder and Board Member of the Society for Wind Vigilance, Inc.
Adjunct Professor, CMU 2012-2015		Adjunct Instructor, MSU 2011-2014 (since 1985)

EXHIBIT A

E-Coustic Solutions

Noise Control ● Sound Measurement ● Consultation
Community ● Industrial ● Residential ● Office ● Classroom ● HIPPA Oral Privacy
P.O Box 1129, Okemos, MI, 48805
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Principal
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Fax: (866) 461-4103

Summary of Court and Administrative Agency Cases for Richard R. James, INCE[1]

Jurisdiction	Date	Case No.	Topic
Huron County, MI Zoning Board	04-04-2007	N/A	Oral testimony at Hearing on Permit Application before ZB by Noble Env. for Michigan Wind I on why 50 dBA criteria will result in complaints and litigation
Calumet County Board of Supervisors, WI	10-30-2007	N/A	Oral Testimony to County Board of Commissioners on requirements for sound criteria in a License and its Appendices related to Wind Energy Systems.
Logan County, IL, ZB/PC	05-01-2008	N/A	Oral Testimony on Wind Turbine Siting, Illinois Noise Regulations, and rebuttal of reports prepared on behalf of the Rail Splitter Wind LLC
Tazewell County, IL, ZB/PC	05-14-2008	N/A	Oral Testimony on Wind Turbine Siting, Illinois Noise Regulations, and rebuttal of reports prepared on behalf of the Rail Splitter Wind LLC
Laurel Mtn, WV (PSC)	08-05-2008	08-0109-E-CSCN	Oral Testimony on Wind Turbine Siting, background sound levels, and rebuttal of reports prepared on behalf of AES Laurel Mountain, LLC
Wellington, NZ (Hearing)	09-05-2008	N/A	Provide written and oral testimony at hearing to rebut reports prepared on behalf of Meridian Energy Ltd for Mill Creek Wind Utility
Beech Ridge, WV (PSC)	10-16-2008	05-1590-E-CS	Oral Testimony on Wind Turbine Siting, background sound levels, and rebuttal of reports prepared on behalf of Beech Ridge Energy, LLC
Record Hill Wind, ME (DEP)	02-18-2009 08-17-2009	#L-24441-24-A-N/L-24441-TF-B-N	Written Testimony on Wind Turbine siting and rebuttal of reports prepared on behalf of Record Hill wind, LLC
DeKalb County, IL	05-11-2009	Public Hearing	Oral Testimony on Wind Turbine Siting, background sound levels, and rebuttal of reports prepared on behalf of Florida Power and Light
Ontario, CA	07-24-2009	MOE EBR – 010 – 6708 and EBR-10-6516	Comments on behalf of APPEC (Association to Protect Prince Edward County), Proposed Ministry of the Environment Regulations to Implement the Green Energy and Green Economy Act, 2009
Buckeye Wind, Champaign-Urbana, Ohio	Oct.-Dec. 2009	OPSB Case No: 08-666-EL-BGN	Hearing on Application for Permit by Buckeye Wind before OPSB.
Glacier Hills, WI.	Sept.-Nov. 2009	WPSC Case 6630-CE-302	Hearing on Application for Permit by WEPCO for Glacier Hills project before Wisconsin PSC.
Record Hill Wind, Roxbury Pond, Me	March 2010	L-24441-24-A-Z L-24441-TF-B-Z	Hearing on Appeal before Maine DEP Board
Georgia Mountain Wind, VT	March 2010	PSB Docket No. 7508	Hearing before Public Services Commission
Goodhue, MN	July 21, 22, 2010	MPUC Docket No. IP/6701/CN-09-1186 and IP-6701/WS-08-1233	Hearing before PUC ALJ on application for Certificate of Need and Large Wind Energy System Site Permit for 78 MW Goodhue Wind Project
Madison, WI for CWESt	October 10, 2010	Clearinghouse Rule 10-057,	Senate Committee on Commerce, Utilities, Energy, and Rail Public Hearing onp Siting Wind Energy Systems
Georgia and Milton, VT	Nov. 2010	Hearing before Public Services Commission, Docket No. 7508	Hearing before PUC on application for permit to build wind turbine utility on Georgia Mountain

[1] Version: February 8, 2013 List covers primary work.

Jurisdiction	Date	Case No.	Topic
Saddleback Ridge Wind, Carthage, ME for Friends of Maine's Mountains	Nov. 2010	Hearing on Application L-25137-24-A-N	Application approval process before Maine's Dept. of Env. Prot. for ridge mounted turbines.
Chatham Ontario, Kent Breeze Wind	February 2011	Hearing before Ontario Environmental Board of Review: Case No: 10-121/10-122	Hearing on whether project complies with Ontario regulations to protect health under the Green Energy Act.
Town of Albany, VT	February 2011	Hearing before Public Services Commission, Docket No. 7628	Hearing before PUC on application for permit by Green Mountain Power Corp. for Kingdom Mountain Wind, LLC.
State of Maine	July 7, 2011	Hearing before the Maine Board of Environmental Protection	Hearing before the BEP on a Petition for Rule Change for Maine's Chapter 375 Noise Regulations to add specific Rules for wind turbine noise.
State of Michigan Circuit Court of Leelanau county	Nov. 8-10, 2011	Michigan Circuit Court, Leelanau County. Case No: 11-8456-CZ	Complaint of Nuisance Noise and other effects of a 100kW Residential class wind turbine
Illinois, Bureau County, Friesland Farms, LLC, Pierson, Plaintiff, v. Big Sky Wind, LLC)	Dec. 30, 2011 (filed testimony) Feb. 1, 2012 Deposed	US District Court, Central District of Illinois, Peoria. Case No. 10-01232	Complaint of noise annoyance and adverse health effects. Case to be heard in early 2013.
Vermonters for a Clean Environment vs. U.S.D.A. Forest Service,	July 23, 2012 filed testimony for Appeal of Decision	US District Court, District of Vermont Civil Action No. 1:12-cv-73	USFWS Failed to properly consider impact of Deerfield Wind Project on Aiken Wilderness Area in its Decision to Approve said project.
Intervenors opposing Application for Certification: Pursuant to RSA 162-H of ANTRIM WIND ENERGY, LLC	PFT and oral testimony presented Aug. 23, 2012. Additional oral testimony on Nov. 29, 2012.	State of New Hampshire Site Evaluation Committee. Docket No. 2012-01	Application for Certification: Pursuant to RSA 162-H of ANTRIM WIND ENERGY, LLC. Testimony on behalf of North Branch Residents Intervenors Group, Abutting Property Owners Intervenors Group, and Katharine Elizabeth Sullivan. Case to be heard Oct. 2012.
Union Neighbors United, Intervenors opposing Application of Champaign Wind LLC before Ohio Power Siting Board	PFT and oral testimony presented Nov. 2012	State of Ohio, Power Siting Board Case No: 12-0160-EL-BGN	Testimony on behalf of Union Neighbors United in opposition to 2nd Phase of Buckeye Wind project. Champaign County, Ohio.
Private lawsuit by Wiltzer family against Stoney Creek Wind Project, McBain, Michigan	Affidavits and other documents	Lawsuit pending	Testimony on behalf of family who has vacated their home as a result of a 2.5 MW wind turbine being operated at 1350 feet from their home.
Private Lawsuit by Zawadzki family vs. Noble Bliss Wind Park and Town of Eagle, New York	Affidavits, noise studies and other related testimony.	Before the State of New York, Supreme Court, Wyoming County, NY, Index No. 43260/10	Testimony on behalf of family who allege that the subject wind utility causes sleep interference and other adverse effects from operation of wind turbines located approximately 1500 feet from home.
MOE Public Hearing for St. Columban Wind Project,	Critical review of Noise Impact Assessment conducted by Zephyr North for St. Columban Wind.	Ontario EBR Registry Number 011-7629, Ministry Reference Number: 6602-8V9P97	Written testimony on behalf of residents living in or near the foot print of the St. Columban project, Huron County, Ontario, Canada

Jurisdiction	Date	Case No.	Topic
Wisconsin, Public Service Commission, Hearing on Application of Highland Wind Farm, Towns of Forest and Cylon, Wisconsin.	Supplemental Direct Testimony and additional statements to WPSC. Oral testimony pending on January 17, 2013.	WPSC Docket No. 2353-CE-100	Testimony on behalf of Forest Voice on advanced analysis methods and findings from use of those methods to analyze the calibrated audio files collected by the PSC selected Team at homes of affected families in Shirley Wind Project, Glenmore, Wisconsin.

List of Communities Where Other Services Were Performed:

California

1. East County (Tule Wind) (Citizens)
2. Ocotillo Wind (Citizens)
3. Avalon Wind, Kern County (Citizens)
4. Shu'Luuk Wind, (Citizens)

Illinois

5. Tazewell, County Zoning Board (Railsplitter) (Citizens and attorney)
6. Logan County Zoning Board (Railsplitter) (Citizens and attorney)
7. McLean County (White Oaks) (Citizens and attorney)
8. DeKalb County (Next Era) (Citizens and attorney)
9. Libertyville (Community Wind) (Citizens and attorney)
10. Bureau County Zoning Board (Citizens and attorney)
11. Lee County Zoning Board (Citizens and attorney)

Iowa

12. Harris (Endeavor Wind) (Citizens and attorney)

Maine

13. Roxbury Pond (Attorney and Citizens)
14. Mars Hill (Citizens)
15. Oakfield (Citizens and attorney)
16. Vinalhaven (Citizens and attorney)
17. Spruce Mountain (Citizens)
18. Saddleback Ridge (Citizens and attorney)

Michigan

19. Bingham Twp., Ubly, Huron County (Michigan Wind I) (Citizens)
20. Lake Township, Huron County (Planning Commission) (Citizens)
21. Allegan County (citizens)
22. Clinton County (citizens)
23. Dallas and Essex Townships, Clinton County (Township P/C and Board)
24. Emmet County (Board and Planning Committee)
25. Sherman Twp, (Citizens)
26. Benzie County (Citizens)
27. Mason County (Citizens)
28. Reading Township (Planning Committee)
29. Riga Township (Citizens)
30. Michigan Public Service Commission (Public Hearing on behalf of citizens)
31. Merritt Township (Public Hearing before PC on FPL application) (Citizens and attorney)
32. Gilford Township (Public Hearing before PC) (Citizens and attorney)

Minnesota

33. Goodhue County (Goodhue Wind) (Citizens)

New York

34. Cohocton (Citizens)
35. Prattsburg (Citizens and Attorney)
36. Bliss, (Citizens and Attorney)
37. Town of Italy (Citizens and Attorney)
38. Machias, Yorkshire, Ashford (Cattaraugus County Citizens and Attorney)

39. Town of Allegany, Olean (Attorney)
40. Jordanville, ((OSTEGO 2K and attorney))
41. Varysburg, (Citizens)
42. Orangeville, (Attorney)
43. Town of Malone (PSC Filings)

New Zealand

1. Mill Creek (Ohariu Preservation Society)

Ohio

1. Champaign-Urbana (Citizens and Wind Committee)
2. Logan County (Citizens)

Ontario

1. Prince Edward County (Citizen and Attorney)
2. Amaranth-Shelburne (APPEC and Attorney)
3. Port Burwell and Clear Creek (APPEC and Attorney)
4. Ripley, (APPEC and Attorney)
5. Kent Breeze (Attorney)
6. Huron County (H.E.A.T. and Attorney)

Pennsylvania

1. Fayette County, (Citizens-South Chestnut Wind)
2. Schuylkill County (Citizens- Butler Wind Farm)
3. Juniata (Attorney for Citizens)
4. Folmont, (Citizens (SOAR))
5. Dunning, (Citizens (SOAR))

Vermont

6. Georgia Mountain (Citizens)
7. Albany (Town of Albany)
8. Rutland (Public Presentation for Vermonters for Clean Environment)
9. DeerField (Appeal)

Washington

1. Skamania County (Public Hearing)

West Virginia

2. Laurel Mountain (Citizens)
3. Beech Ridge (Citizens)

Wisconsin

1. Calumet County (Board of Supervisors)
2. Town of Calumet (Supervisors)
3. Town of Union, (Wind Committee)
4. Trempealeau County (Wind Committee)
5. Coalition for Wisconsin Environmental Stewardship (CWESt)
6. City of Green Bay, (City Council)
7. Shirley Wind, Denmark WI, on behalf of home owner(s)
8. Forest Voice, Forest Wisconsin (Citizens)

Wyoming

10. Sweetwater County (P/C and Board Advisor for Wind Turbine Noise Regulation)

EXHIBIT A

E-Coustic Solutions

Noise Control ● Sound Measurement ● Consultation
Community ● Industrial ● Residential ● Office ● Classroom ● HIPPA Oral Privacy
P.O Box 1129, Okemos, MI, 48805
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Richard R. James
Principal
Tel: 517-507-5067

List of Recent Publications

Feb. 8, 2013

2008 Paper on "Simple guidelines for siting wind turbines to prevent health risks" for INCE Noise-Con 2008, co-authored with George Kamperman, Kamperman Associates.

2008 Expanded manuscript supporting Noise-Con 2008 paper titled: "The "How To" Guide To Siting Wind Turbines To Prevent Health Risks From Sound"

2009 "Guidelines for Selecting Wind Turbine Sites," Kamperman and James, Published in the September 2009 issue of Sound and Vibration.

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2012 James, R., "Wind Turbine Infra and Low Frequency Sound: Warning Signs that were not Heard," April 2012, Bulletin of Science, Technology and Society, http://bsts.sagepub.com, DOI:10.1177/0270467611421845

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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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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

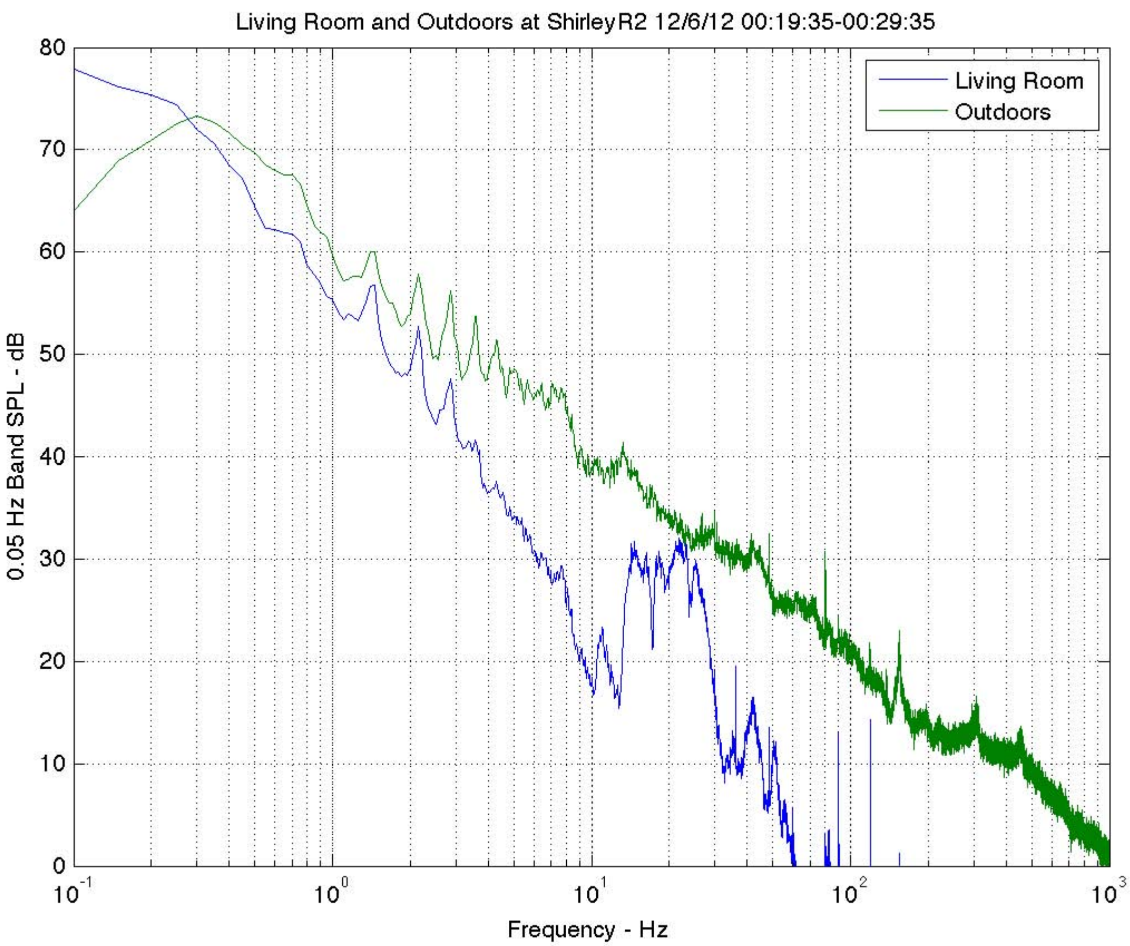
Observations from the five investigators are tabulated below: It should be noted the investigators had a relatively brief exposure compared to 24/7 occupation.

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.

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Ontario

April 9, 2010

MEMORANDUM

TO: Jane Glassco, District Manager, Guelph District Office and Dave Bray, Supervisor, Guelph District Office

FROM: Cameron Hall, Senior Environmental Officer, Guelph District Office

Re: Comments - March 1, 2010 draft document, "Renewable Energy Approvals Technical Bulletin Six Required Setbacks for Wind Turbines"

I have reviewed the subject document per your request and offer the following comments.

The Technical Bulletin is essentially an interpretation of the requirements already spelled out in the Renewable Energy Approvals Regulation, Ontario Regulation 359/09. As such, any comments about the Technical Bulletin must ultimately be comments about the Renewable Energy Approvals Regulation, Ontario Regulation 359/09.

The setbacks were reportedly determined in accordance with the Ministry of Environment's 2009 Publication "Development of Noise Setbacks for Wind Farms" ("2009 Ministry Setback Development Publication"). The setbacks were determined using a computer model which reportedly has an output error of +/- 3 dB. The computer model uses sound level emissions data provided by the manufacturer of the wind turbines generators (WTGs). In the case of the Melancthon Ecopower Centre General Electric WTGs the sound level emissions are reported to have an error of +/- 2 dB. So in fact, the Ministry is using a computer program with an output error of +/- 3 dB, where the data input into the computer program may have a +/- 2 dB error. It is not clear if these errors are added, subtracting, multiplied or divided by each other. If the errors are simply added, then the potential error in the predicted sound level limit at the receptor is +/- 5 dB. In the Melancthon Ecopower Centre case, an approval was issued where the predicted sound levels at most of the receptors was 40 dBA (rounded-off). If a 5 dB error is applied, then the predicted sound level at the receptor could actually be as low as 35 dBA or as high as 45 dBA. Given the errors involved in the computer modelling it appears reasonable to suggest that a conservative approach might be to only establish setbacks and approve locating WTGs where the predicted sound levels at the receptors are 35 to 37 dBA.

The setback distances were determined on the assumption that the sound discharged from WTGs does not have a special quality of sound. In other words it is assumed the sound contamination discharged into the natural environment from WTGs does not have a tonal quality or a cyclic variation quality. The assumption that the sound contamination discharged from WTGs does not have a tonal characteristic or a cyclic variation characteristic is not supported by our field observations. Furthermore, the assumption that the sound contamination discharged from WTGs does not have a cyclic variation characteristic is not supported in the report, Acoustic Consulting Report prepared for the Ministry of the Environment Wind Turbine Facilities Noise Issues, by Ramani Ramakrishnan, December 28, 2007 (the "Ministry 2007 Acoustic Consulting Report").

The Ministry's Publication Noise Pollution Control 104 states, "(1) Tonality If a sound has a pronounced audible tonal quality such as a whine, screech, buzz or hum then the observed value shall be increased by 5"; "If a sound has an audible cyclic variation in sound level such as beating or other amplitude modulation then the observed value shall be increased by 5"; and, "(4) One Adjustment Only An adjustment may be made under one only of subsections (1), (2) and (3), provided that, if subsection (3) applies, it shall be used in preference to subsection (1) or (2)."

Our field observations at the Melancthon Ecopower Centre and those reported by HGC on behalf of Canadian Hydro Developers, Inc. conclude some of the WTGs at the Melancthon Ecopower Centre have an audible tonal characteristic. This tonal characteristic does not appear to be properly identified as a result of the manufacturer's testing done in accordance with the testing procedures deemed acceptable in the 2008 NPC Guidelines Interpretation and consequently the Technical Bulletin. It appears reasonable to suggest that a 5 dB penalty for tonal quality of the sound discharged into the natural environment from the WTGs may be required. I also noted tonal characteristics when making observations of the sound contamination discharged into the natural environment from the Vesta manufactured WTGs at Clear Creek.

Most of the complainants who have contacted the Ministry about sound contamination from the Melancthon Ecopower Centre WTGs identify the characteristic "blade swoosh" or "swishing" sound contamination discharged into the natural environment from the WTGs as a quality of the WTG sound contamination which they find offensive. Provincial Officers have confirmed the "blade swoosh" quality of the sound contamination discharged into the natural environment from the WTGs throughout the Melancthon Ecopower Centre wind plant.

The Ministry 2007 Acoustic Consulting Report discusses the sound contamination characteristics of WTGs and includes discussing "the swishing (thumping) sound normally termed as the amplitude modulation phenomenon". The Ministry 2007 Acoustic Consulting Report includes the following:

> "Due to the nature of the amplitude modulation phenomenon, the swishing or thumping exists all the time.";
>
> "Reference 30 has addressed the issues connected with modulation. One of its principle findings is and we quote, "the common cause of complaint was not associated with low-frequency noise, but the occasional audible modulation of aerodynamic noise, especially at night."; and,

> "Finally, Reference 30 discussed the many possible mechanisms that can cause the amplitude modulation as well as provided measurement results to show that modulation can produce changes in noise levels of the order of 10 dB."

It should be noted that the more recent 2008 NPC Guidelines Interpretation differs from the 2004 NPC Guidelines Interpretation by stating no adjustment should apply to the cyclic variation quality "swishing sound" of the noise contamination discharged from the WTGs. The 2008 NPC Guidelines Interpretation suggests the blade swish noise is temporal. This conclusion is not supported by our field observations, or the findings in the Ministry 2007 Acoustic Consulting Report.

It is appears it is reasonable to suggest the setback calculations should have included a 5dB addition to the sound level emissions from the WTGs to account for the amplitude modulation or blade swooshing sound of the WTGs. A 5 dB addition would address the Ministry observations and the Ministry 2007 Acoustic Consulting Report finding that the sound contamination from WTGs has a blade swoosh or amplitude modulation characteristic. A 5 dB addition for this cyclic variation of the quality of the sound discharged into the natural environment from WTGS would also be consistent with the Ministry's Publication Noise Pollution Control 104.

The Ministry's Publication Noise Pollution Control 104 only allows for one 5 dB adjustment. It appears reasonable to suggest that a conservative approach to calculating setback distances might have been to include a 5 dB adjustment to the predicted sound levels at the receptors to account for the tonal and cyclic variation of the qualities of the sound contamination discharged into the natural environment from WTGs.

If a 5 dB adjustment is added to the 3 to 5 dBA error in the computer modelling results, then the acceptable sound level at the receptor would be 30 to 32 dBA (40 dBA minus 10 or 8 dB). Observations by several Provincial Officers at the Melancthon Ecopower Wind Plant indicate sound levels at the receptors below 35 dBA and in the range of 30 to 32 dBA would not cause or be likely to cause adverse effects in the opinion of the Provincial Officers. As such, it appears reasonable to suggest the setback distances should be calculated using a sound level limit of 30 to 32 dBA at the receptor, instead of the 40 dBA sound level limit.

Observations at the Melancthon Ecopower Wind Plant and at Clear Creek in Hamilton District indicate the sound contamination discharged into the natural environment from WTGs is directional. This directional nature of the sound contamination from WTGs is also reported in the scientific literature. EAAB was advised about our observations that the sound contamination was directional, but has not replied. It is not clear if the directional nature of the sound contamination discharged into the natural environment from WTGs has been considered in the development of the setbacks.

The setbacks were established using computer modelling where the receptor location was located to one side of an array of WTGs where the WTGs were located in a grid pattern with 400 metre separation between the WTGs. As such, only one WTG would be the stated setback distance away from the receptor in the model used to develop the setbacks. All other WTGs would be located a distance greater than the setback distance from the receptor. For example, the calculation for the 600 metre setback, for five 104 dBA WTGs in the 2009 Ministry Setback Development Publication shows the first WTG located 605 metres from the receptor, the second and third WTGs located 725 metres from the receptor, and the fourth and fifth WTGs located 1003 metres from the receptor. The total calculated sound level at the receptor for these 5 WTGs is shown as 39.6 dBA.

The approach used to establish the setbacks failed to account for locating multiple WTGs the same setback distance from the receptor (the receptor could be located within the wind plant and not off to the side of the wind plant). If a receptor is located within a wind plant and five 104 dBA WTGs are each located 605 metres from the receptor, then the resultant sound level at the receptor is 42 dBA.

It appears reasonable to suggest a conservative approach might be to calculate the setback distances where the receptor is located within the wind plant and not off to the side of the wind plant.

The setbacks and modelling continue to use wind speeds at 10 metres above the ground level to establish sound levels at ground level receptors. Our field observations at the Melancthon Ecopower Centre wind plant suggest there are many occasions where there is little or no ground level wind at the receptor and yet the nearby WTGs are producing electricity and discharging sound contamination at unacceptable levels. The use of wind speeds at 10 metres above the ground level appears to not address ground level wind speeds which may be significantly less than 10 metre wind speeds, and which therefore may not result in the assumed increase in background noise at the receptor. It appears reasonable to suggest that consideration should be given to modifying the approach of increasing acceptable sound level limits at the receptors with increasing wind speed at 10 metres above the ground level. This may require increasing the setback distances to ensure sound levels at the receptors do not exceed the applicable sound level limits.

The sound level limits used to establish the setbacks fail to recognize the potential quietness of some rural areas. As a consequence, meeting the minimum sound level limits may still result in significant sound contamination levels intruding into the rural environment.

The Ministry 2007 Acoustic Consulting Report referred to a study which produced an "annoyance table". The annoyance table reportedly provides an estimated community response to the actual wind turbine generator sound levels measured at a receptor compared to the background sound level. The referenced study was reportedly conducted in the early 1980s using old type wind turbine generators; and the Ministry 2007 Acoustic Consulting Report suggests a more modern study is required to assess the threshold for modern wind turbine generators. Notwithstanding these limitations, the annoyance table suggests a 10 dB increase in sound level above background would result in estimated "widespread complaints"; a 15 dB increase in sound level above background would result in estimated threats of "community action"; and a 20 dB increase in sound level above background would result in estimated "vigorous community action".

Sound measurements undertaken by HGC and the Ministry within the Melancthon Ecopower Centre wind plant during periods when there was little or no ground level wind and when the nearby WTGs were not operating have found background sound levels to be equal to or less than L_{90} equal to 20 dBA and L_{eq} equal to 23 dBA. The 2008 NPC Guidelines Interpretation approved maximum sound level limits for the sound contamination discharged into the natural environment from WTGs is 40 dBA with 10 metre height wind speeds less than 6 m/s, rising to 51 dBA with 10 metre height winds speeds of 10 m/s or greater. The 2008 NPC Guidelines Interpretation approved sound limits, without adjustment for tonal or cyclic variation qualities of the sound contamination, would allow the sound contamination discharged into the natural environment from WTGs to exceed the background sound level by 17 to 28 dBA. According to the report referenced in the Ministry 2007 Acoustic Consulting Report, the estimated community response would be "threats of community action" to "vigorous community action" where the sound contamination from wind turbine generators intrudes 15 to 20 dB above background levels.

Developing the setbacks in accordance with the 2009 Ministry Setback Development Publication 2009 might have including considering the details provided in the Ministry 2007 Acoustic Consulting Report with respect to allowing the intrusion of sound levels greater than 7 to 10 dB above background. An intrusion of 7 to 10 dBA above background in our case would result in sound level limits at the receptors in the range of 30 to 33 dBA. As noted earlier, observations by several Provincial Officers indicate sound levels at the receptor in the range of 30 to 32 dBA would not cause or be likely to cause adverse effects in the opinion of the Provincial Officers.

Given all of the above, the following statement in the Technical Bulletin on page 6 should likely be amended: "While the minimum setback of 550 m must be met in all cases, proponents are given the option of conducting a noise study to prove that siting turbines closer than the setbacks in Table 1 will not cause an adverse effect." It appears compliance with the minimum setbacks and the noise study approach currently being used to approve the siting of WTGs will result or likely result in adverse effects contrary to subsection 14(1) of the EPA. As such the sentence might be changed to read as follows: "While the minimum setback of 550 m must be met in all cases, proponents are given the option of conducting a noise study to prove that siting turbines closer than the setbacks in Table 1 will not cause exceedances of the applicable sound level limits."

Yours truly,

Cameron Hall

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Propagation Modeling Parameters for Wind Turbines

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ABSTRACT

Propagation modeling for wind turbines is done using similar algorithms in different nations. Most take into account some sort of geometric divergence at either 3 or 6 dB per doubling of distance, and some go further to include attenuation from the atmosphere, ground, vegetation, and intervening berms, barriers, and terrain. The ISO 9613 standard includes these factors for modeling, but includes two alternatives for ground attenuation and is limited as to the meteorology that it is valid for. This paper evaluates the various ISO 9613 ground attenuation parameters using monitoring data from industrial scale wind farms. It also evaluates whether additional adjustments may be necessary to account for higher wind speeds, for example, such as those recommended by CONCAWE.

1. INTRODUCTION

ISO 9613 [1,2] is one of the most commonly used methods for calculating outdoor sound propagation. In most standard noise problems when ISO 9613 is applied to sound propagation modeling, it yields fairly accurate and reasonable results.

One case that is becoming increasingly common applies to propagation modeling for wind turbines. Wind turbines can be a special case in that they generate sound over a large area, from a high elevation, and make the most noise in very high wind conditions. For ISO 9613, these factors directly relate to how ground attenuation and meteorology are accounted for.

To study how ground attenuation and wind speed affect the accuracy of propagation modeling for wind turbines, data was gathered at an existing industrial scale wind farm and propagation modeling was conducted using Cadna A modeling software by Datakustik, GMBH for the same site under the same operating conditions in which monitoring was carried out. By adjusting the type of ground attenuation used in the model and the meteorological conditions, the best combinations for modeling propagation for wind turbines were determined with comparisons to the monitored data.

2. BACKGROUND

A. Standards Background

ISO 9613-2 (1996)[2] provides two methods for calculating ground effect (A_{gr}). The first method divides the ground area between the source and the receiver into three regions: a source region, a receiver region, and a middle region. The source region extends from the source towards the

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receiver at a distance equal to 30 times the height of the source. For a tall wind turbine, this can be up to 2 to 3 km. The receiver region extends from the receiver towards the source at a distance equal to 30 times the height of the receiver. If the source and receiver regions do not overlap, the distance between the two regions is defined as the middle region. The ISO standard goes on to define ground attenuation for each octave band utilizing a ground factor (G) for each region depending on how reflective or absorptive it is. For reflective, hard ground G=0, and porous, absorptive ground suitable for vegetation, G=1. If the ground is a mixture of the two, G equals the fraction of the ground that is absorptive. The ISO standard states that "This method of calculating the ground effect is applicable only to ground which is approximately flat, either horizontally or with a constant slope."

The second method provided in ISO 9613-2 is for modeling A-weighted sound pressure level over absorptive or mostly absorptive ground, but the ground does not need to be flat. Using the alternative method also requires an additional factor (D_{Ω}) be added to the modeled sound power level to account for reflections from the ground near the source. It is questionable weather or not this is needed when modeling wind turbines because of their relatively tall height.

ISO 9613-2 is only valid for moderate nighttime inversions with downwind conditions. The valid range of wind speeds is 1 to 5 m/s at 3 to 11 meters in height. For wind turbines it may be more accurate to consider adjustments such as those presented by CONCAWE.[3] These adjustments are to account for propagation at various wind speed, wind directions, and atmospheric stability. The CONCAWE meteorological adjustments are built into Cadna A.

B. Wind Farm Background

The wind farm in this study is situated on nearly eight square miles of flat farm land. There are a total of 67 wind turbines which are capable of producing about 100 megawatts of electricity. Each turbine hub is 80 meters tall, and the rotation path of the three blades is 80 meters in diameter. The turbines are roughly 1,000 feet apart, but there is a wide variation for individual pairs. An image of the terrain and some of the turbines is provided in Figure 1.

Figure 1: Rural 100 MW wind farm used to study ground attenuation and meteorological modeling factors

3. DATA COLLECTION AND METHODOLOGY

A. Sound Monitoring

Two sound level meters were set up at 120 meters and 610 meters from the northern edge of the wind farm. Each sound level meter was an IEC Type I Cesva SC310 fitted with windscreens. The sound level meter at 120 meters was placed flat on a 1 m square ground board, while the meter at 610 meters was mounted on a stake at approximately 1 m off the ground.

The measurement period was at night from approximately 10 pm to 10 am. Each meter logged 1-minute equivalent average sound levels in 1/3 octave bands. In addition, recordings of wav files were made at certain points.

At the same time, spot measurements of wind speed and direction at hub height, blade rotational frequency, and energy output for each wind turbine were made at 10-minute intervals.

Since we could not obtain background sound levels, we made an assumption that much of the localized wind noise would be at and above 2,000 Hz. Therefore, to isolate the wind turbine sound, we created a virtual low pass filter eliminating sound at frequencies above 2 kHz. In addition, assuming that the wind turbines operated within a narrow range of sound power over any one ten minute period, we used the 90th percentile 1-minute equivalent average sound level for each 10-minute period for comparison to modeled results.

B. Sound Propagation Modeling

The Cadna A sound propagation model, made by Datakustik GMBH, was used to model sound levels from the wind farm. Cadna A can utilize several standards of modeling, including ISO 9613 with or without CONCAWE meteorological adjustments.

A model run was conducted for every 10-minute period of turbine operation during the monitoring period. This was done by running Cadna A for the following scenarios:

- Standard meteorology with spectral ground attenuation, assuming G=1
- The same as above, but with non-spectral ground attenuation
- CONCAWE adjustments for D/E stability with winds from the south at greater than 3 m/s and spectral ground attenuation, assuming G=1.
- The same as above, but with non-spectral ground attenuation

For each scenario, a “protocol” was run which listed the ISO 9613-2 attenuation and propagation factors by frequency between each turbine and receivers at 120 m and 610 meters from the northern end of the wind farm. That is, the receivers which were represented by the sound monitoring locations. These attenuation factors were then put into a spreadsheet model which looked up the manufacturer sound power level for each turbine for each 10-minute period based on the actual measured wind speeds at each turbine. The spreadsheet model then calculated the sound level from each turbine by subtracting the attenuation factors from the sound power levels, and then combining each turbine to get an overall sound pressure level at the 610 m receiver.

4. RESULTS

A comparison of the modeled results to monitored sound levels over time is shown in Figure 2. As shown, the monitored sound levels ranged from about 34 dBA to 43 dBA. Except for the period between 2:00 am and 3:00 am, the sound levels were highly correlated with wind speed.

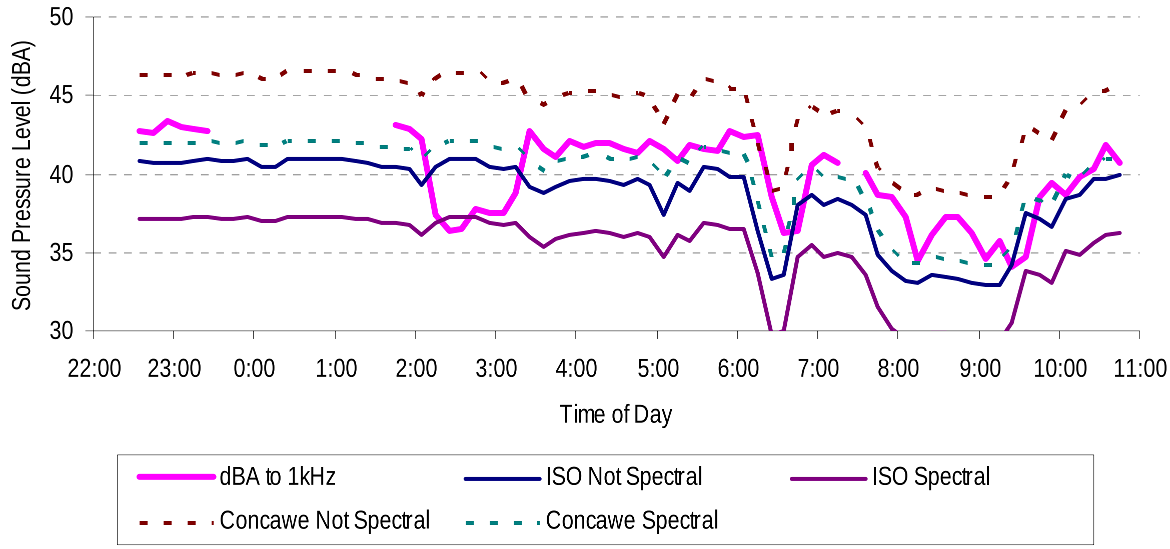

Figure 2: A comparison of monitored sound levels over time at 610 meters (shown in pink) with modeled sound levels under standard ISO 9613-2 meteorology, CONCAWE adjusted meteorology, spectral, and non-spectral ground attenuation.

We conducted further regression analyses to determine which method achieved the best fit to the modeled data. The results, shown are shown in Figure 3. Moving clockwise in the figure, we found that the ISO meteorology with non-spectral ground attenuation yielded a good fit. The coefficient of 0.957 indicates that average modeled levels underestimated monitored levels by about 4%. The CONCAWE meteorology along with the non-spectral ground attenuation consistently overestmated monitored sound levels. The CONCAWE meteorology combined with spectral ground attenuation had the coefficient closest to 1.0, and on average, underestimated sound levels by only 1%. On the opposite end of the scale, the ISO meteorology along with spectral ground attenuation significantly underestimated modeled sound levels by, on average, 13%. All trendlines were statistically significant with probabilities greater than 99%.

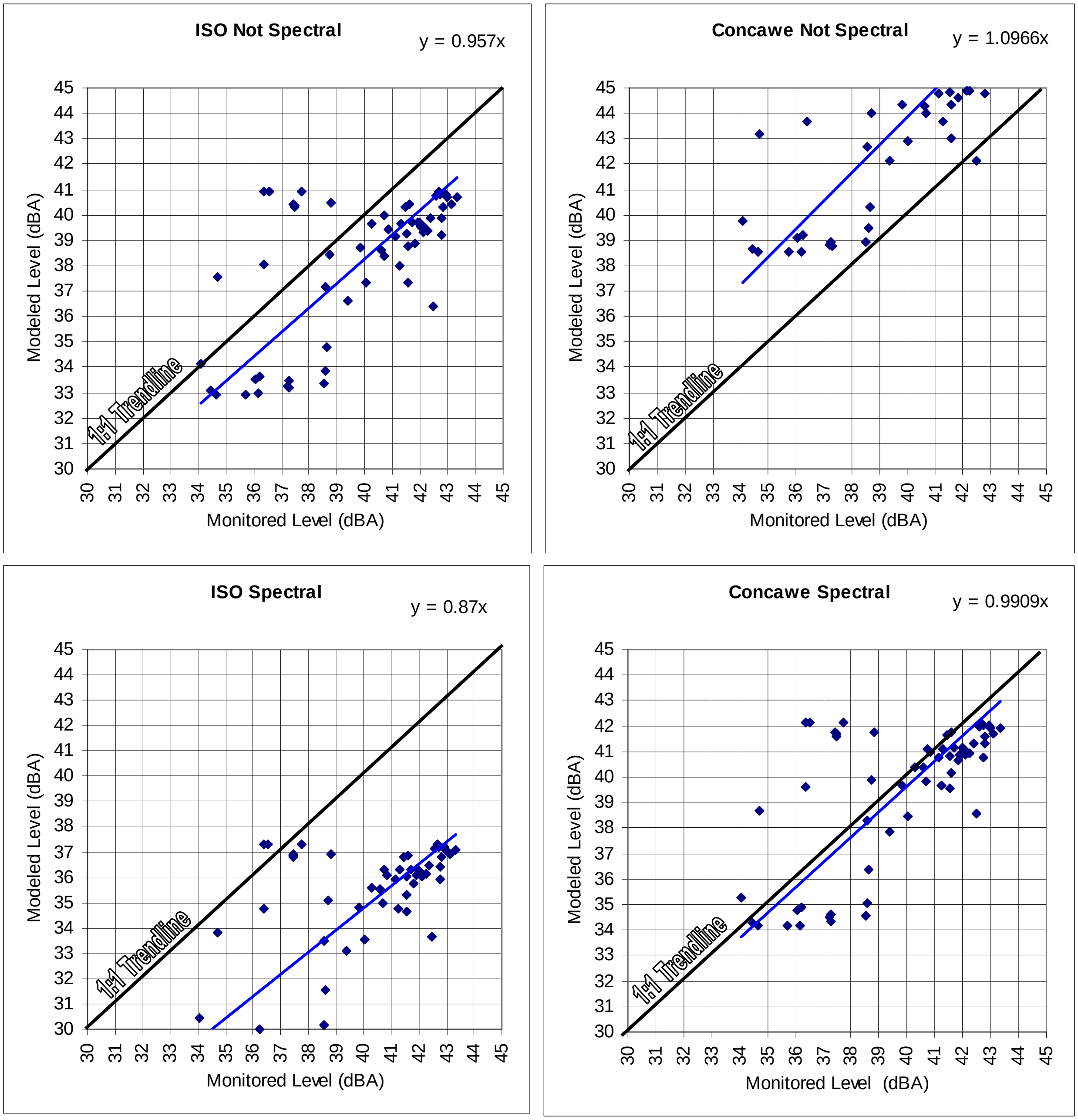

Figure 3: Comparison of modeled and monitored sound levels for four meteorological and ground attenuation combinations. Regression coefficients are shown in the upper right hand corner. The regression trendline is shown in blue and the 1:1 trendline, which would indicate a match between monitored and modeled sound levels, is shown in black. N = 60.

5. DISCUSSION AND CONCLUSIONS

The results of the study indicate the modeling of wind turbines in flat and relatively porous terrain may yield results that underestimate actual sound levels when using the standard ISO 9613-2 algorithms with spectral ground attenuation. We found that the best fit between modeled and monitored sound levels would occur when using CONCAWE adjustments for wind direction and wind speed along with spectral ground attenuation. The second best model fit was with the standard ISO 9613-2 meteorology with non-spectral ground attenuation.

While the ISO 9613-2 methodology specifically recommends spectral ground attenuation for flat or constant slope terrain, in this case, it underestimated the sound levels. This may be due to the height of the hub (80m) as compared with typical noise sources. That is, the sound waves may not significantly interact with the ground over that distance. It may also be due to the fact that sound from wind turbines comes not from a single point – we assumed a single point at hub height – but is more likely to be similar to a circular area source. Finally, wind turbines often operate with wind speeds that are higher than the ISO 9613-2 methodology recommends. The combination of higher wind speeds and a high noise source may result in greater downward refraction.

To be more representative, a larger dataset should be obtained. Some improvements to the methodology would include:

- Improved accounting for background sound levels
- Measurements of ground impedance so that the ISO 9613-2 "G" factor can be better estimated.
- Monitoring over a larger range of wind speeds
- Using ground-boards for the measurement microphone
- Measuring at distances greater than 610 meters
- Applying the methodology to other ground types and terrain

Care should taken in applying this methodology in other projects that are not similar.

ACKNOWLEDGEMENTS

We acknowledge gratefully the project sponsor, Iberdola, their project manager, Krista Jo Gorden, and the windfarm operator, enXco, for funding and cooperation.

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Improving predictions of wind turbine noise using PE modeling

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The modeling of wind turbine noise is most commonly conducted in the U.S. using the method of ISO 9613-2. This method is fast, allows one to estimate levels over a large surface area, and is commercially available in a number of software packages. Its predictions coincide to near-surface downwind propagation or, equivalently, a moderate nighttime inversion. Questions have been raised as to the ISO model's accuracy in estimating wind turbine sound levels under a variety of meteorological and complex topographic conditions. These issues can be addressed through the use of parabolic equation (PE) modeling, which is highly accurate assuming one can characterize in detail the vertical sound speed profile, ground impedance, turbulence, and other factors. This paper explores the use of PE models to estimate wind turbine noise. Strengths and weaknesses are explored, and recommendations are made for how PE models can be applied to wind turbines in special situations where the ISO model may not be appropriate or where adjustments to the ISO model should be devised. Comparisons are made between PE and ISO model output for simple, flat terrain under various sound speed profiles.

1 INTRODUCTION

In this paper, we discuss two sound propagation modeling techniques for wind turbine noise: ISO 9613-2 and parabolic equation modeling.

The former is used as an engineering method and is widely implemented worldwide in studies evaluating the noise impacts of wind turbines. It is designed to estimate sound levels characteristic of moderate, downwind conditions, "or equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occur at night."[1)][4],

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[1)] Wilson 2004 points out the daytime downwind and nighttime inversions are not necessarily equivalent.

The method allows for meteorological adjustments, but has no specific recommendations for combinations of atmospheric stability and wind speed.

At the same time, parabolic equation modeling (PE) is a full-wave numerical method that takes into account specific ground and layered atmosphere characteristics in calculating its solution. While extremely accurate, PE modeling has not been used in wind farm impact studies, as it is very slow, especially for higher frequencies, and involves a large amount of detail on the terrain and meteorological conditions being considered, much of which may not be available.

While this is the case, PE models have been used to create generalized meteorological adjustments for engineering methods, such as in the European NORD2000 and Harmonoise models. In that regard, we believe that PE modeling can be used to create adjustments to the ISO 9613-2 under specific conditions that have not been previously calibrated, or for underlying support of engineering methods. This generalized approach was recommended by Wilson where he writes, "Although there is an argument to be made against putting too much flexibility into a standard, it must be recognized that prediction of atmospheric effects on noise is rapidly evolving at present and that advances in numerical propagation modeling have a high potential improving the accuracy of noise predictions. One possibility would be to specify in the standard a "base" calculation that can be handled without advanced numerical models, but then provide an explicit but flexible alternative mechanism for incorporating the numerical models into more exact calculations."[14].

2 BACKGROUND

2.1 ISO 9613-2

In the U.S., the most common standard used for calculation of sound propagation from wind power projects is ISO 9613-2, *Acoustics - Attenuation of sound during propagation outdoors*[4]. This standard's application to wind turbines has been calibrated in several studies.

Kaliski and Duncan made field calibrations of wind turbine noise over 60 ten-minute periods over flat farmland[7]. They found that the use of a ground factor of 1.0, which represents porous ground in the ISO standard, underestimates monitored sound levels. Better accuracy of modeling is dependent on the assumption of a harder ground surface or adjustments for meteorological conditions. For example, by using a ground factor of 0.0 or by using non-spectral ground attenuation over flat terrain, ISO 9613-2 was found to be more accurate. Meteorological adjustments for downwind conditions using the CONCAWE method also helped improve model accuracy but tended to overestimate actual levels[8].

Bullmore et al. made comparisons between monitored sound levels and predicted sound levels of three different wind projects which were located in relatively flat rural areas with more than 20 turbines[1]. Their analysis found that by using spectral ground attenuation with a ground factor of 0.0 or 0.5 (i.e. hard and mixed ground) depending on site conditions and the manufacturer's mean sound power level, ISO 9613-2 yielded accurate yet conservative results for downwind conditions. These results were achieved without consideration of the turbine manufacturer's sound power uncertainty level, and in fact, Bullmore states that considering these uncertainty factors will result in "significant design conservatism."[2]

The use of ISO 9613-2 for predicting noise from wind turbines is not beyond criticism, though. Kalapinski and others have pointed out some of the method's limitations, including that it does not account for atmospheric variation over long distances and source heights greater than 30 meters, are not included in ISO 9613-2s stated confidence intervals[6]. They also point out that wind turbines are often modeled as point sources, at least in the U.S., which can cause underprediction at short distances. As they discuss, though, these limitations can be compensated for with adjustments to the standard calculations.

In Europe, the Harmonoise model is being developed as a new engineering sound prediction model. It departs from ISO 9613 in that it can take into account both wind speed and stability categories. In part, the model is based on a reference method developed through the results of boundary element and parabolic equation modeling. The NORD2000 model, which shares some algorithms with Harmonoise and is similarly based on numerical modeling, was calibrated to wind turbines using elevated speakers by Plovsing and Sondergaard[11]. They found that NORD2000 agreed very well in downwind conditions under both complex and simple terrain. The authors also compared the ISO 9613-2 method to measured values, and found that under porous ground assumptions and no adjustments to sound power, the ISO model underestimated downwind sound levels at a distance of 500 meters. Their findings are consistent with those discussed above.

2.2 PE Modeling

The PE method has been widely used in both underwater and outdoor sound propagation modeling as a method to solve the wave equation over long distances. It can take into account the complex ground impedance over the source-receiver range, vertical and horizontal sound speed profiles, turbulence, and irregular terrain.

A few authors have used PE methods in evaluating wind turbine noise. Duconsson compared measured sound levels over flat terrain with PE models[3]. Overall, she found that the PE model underpredicted sound levels. However, the study did not measure the sound power level of the source, and thus it is difficult to determine whether the underprediction was due to the propagation path modeling or specification of the sound emissions of the turbines themselves.

Kampanis and Ekaterinaris developed a method of modeling wind turbines over irregular terrain using PE models[8].

The PE approximation is inaccurate for propagation at elevations angles outside roughly ±15 deg from the horizontal. As a result, it cannot be used to model sound levels at locations above or below the source. This is generally not a concern for wind turbine modeling, as sensitive receivers are usually relatively far from individual turbines (>300 meters).

3 MODEL COMPARISON

Model comparisons can be made under a virtually infinite set of ground, source, and meteorological conditions. For this study, we limit our analysis to the following:

1) Source specification – 1/1 octave bands from 31.5 to 1,000 Hz, adding to 105 dBA.
2) Porous ground – For the ISO model, we specify spectral ground attenuation and a ground factor of 0.0. For the PE model, we estimate the ground impedance for tall grass, using the Wilson relaxation theory.
3) Flat terrain – For the ISO model, we calculate under porous, mixed, and hard ground over flat terrain. The PE model assumes flat terrain with a ground impedance characteristic of tall grass.
4) Various atmospheric conditions – For the ISO model, the meteorological adjustment, Cmet, is set to zero. For the PE model, we use actual data from the CASES '99 experiments near Leon, Kansas, east of Wichita.0 The examples consist of early evening (nearly neutral) and

early morning (deep, strong temperature inversion) scenarios. The resulting vertical profiles are shown in Figs. 1 and 2.

5) An 80 meter source height – For both ISO and PE, we assume a monopole point source at 80 meters.

One issue with modeling wind turbine noise that differs from near-ground sources is that atmospheric conditions above 100 meters play a greater role. That is, with a hub height of 80 meters and a 100-meter rotor diameter, as an example, the blade tip reaches to 130 meters above ground. The Monin-Obukhov Similarity Theory (MOST) works well to predict the vertical profiles of temperature and wind speed below 100 meters under a variety of stability conditions. However, MOST does not correctly capture the nonlinear increasing wind speed with height, and formation of a near-ground "jet", which often occurs over the lowermost couple hundred meters of the atmosphere at night in certain regions of the country[6], which may be very important in modeling turbine noise. MOST is also tenuous when the atmosphere is in a state of transition between the daytime and nighttime states, around sunset and sunrise. That is the primary reason why tethersonde data are used for the comparisons in this paper.

3.1 Modeling– ISO 9613-2

Modeling was conducted using the ISO 9613-2 algorithm as implemented in Datakustik's Cadna/A computer program. Model runs were done using Ground factors of 1, 0.5, and 0, representing soft, mixed, and hard ground, respectively. A separate model run was done using non-spectral ground attenuation, which assumes a mostly porous ground.

3.2 Modeling– PE

A Crank-Nicholson PE was run using neutral and very stable meteorology, as noted above. The results of the modeling, assuming a fixed 105 dB sound power for each octave band, are shown in Figs. 3 and 4. Height-range cross sections of the A-weighted sound levels are shown in Fig. 5.

3.3 Modeling – Harmonoise

The Cadna/A implementation of Harmonoise was run for stability S3 (neutral) with winds of 5 m/s, and stability S5 with winds of 2 m/s. This closely resembles the meteorological conditions collected in the CASES tethersonde data described above. Soft ground was assumed.

3.4 Comparison of Modeled Results

A comparison of modeled sound levels for upwind to downwind conditions under the neutral atmosphere is shown in Fig. 6. The PE model is shown as a black line, while the ISO and Harmonoise models are lighter lines. The Harmonoise model is specific to neutral stability (S3), but the ISO model has no adjustment for stability. In this case, the Harmonoise and ISO hard ground model overestimimate sound levels in downwind conditions. The ISO mixed ground and non-spectral do best in this case. Under upwind conditions, the Harmonoise and all ISO models overestimate as compared to the PE solution.

Under very stable conditions, sound levels predicted by the PE model were highest close to the source and dropped off rapidly in both upwind and downwind directions. This is likely due to absorption by the ground under multiple reflections, and much of the sound from the wind turbine being carried in upward refraction near the transition from the inversion condition to a negative temperature gradient. Otherwise, the ISO model with soft ground consistently underpredicted sound levels, except upwind at and beyond 1 km. At close ranges, the ISO model with hard ground, and Harmonoise under neutral and stable conditions were within a few dB of the PE model. These ISO and Harmonoise scenarios also followed each other very closely within 1 km of the source.

4 SUGGESTIONS FOR FURTHER RESEARCH

The model comparisons described in this paper meant to show how specific parameters describing the ground and atmospheric conditions at a site can be used to supplement model results from ISO 9613-2. Additional detail can be added in terms of the following:

4.1 Source Specification

A wind turbine is more than a simple point source. The wind turbine rotor can extend 100 meters or more. Over the course of the rotor plane, the sound power changes as sound emissions are largely a function of blade segment speed and surface area. Since sound emissions result largely from random processes along the blade (inflow turbulence and trailing edge separation), with the exception of sound related to blade/tower interactions, these discrete emission point in the rotor plane can be considered incoherent. As a result, the rotor can be represented as a series of point sources with random phases along a vertical axis. If we add up the sound energy in vertical slices along the rotor plane, we find the distribution of sound power shown in Fig. 7.

In addition to the height-dependent sound emission, a wind turbine has directionality similar to a propeller, that is, a dipole. Simplifying the results of NASA studies[13] of directionally from wind turbines (Fig. 8), we derive the following directional source strength as a function of angle around the axis of the tower:

$$f(\varphi) = 0.25(\cos 2\varphi + 1) + 0.5. \quad (1)$$

Directionality would be most important for receivers that are *not* directly downwind or upwind from the turbine.

4.2 Complex Terrain

Complex terrain is of special interest for wind turbines, since many are sited along ridgelines. On the one hand, ridgelines may enhance downwind propagation due to the potentially higher wind shear above the ridge. On the other hand, downwind propagation may be lessened by the breakup of wind shear by rough terrain and shear-related turbulence on the downwind side.

Several methods have been put forth to adapt PE modeling to complex terrain. These include, but are not limited to, conformal mapping and “generalized terrain PE” (GTPE)[12]. While these computational methods exist, it is also important to recognize that terrain affects atmospheric conditions, including turbulence, and vertical profiles of wind and temperature. As a result, modeling wind turbines in complex terrain is quite challenging. Microscale meteorological models are needed to create good downwind profiles over complex terrain.

4.3 3D modeling

Up to this point, we have concerned ourselves with modeling a single turbine in the upwind and downwind directions. This is primarily due to the long computational times of the PE. However, since the Green's Function PE is faster than the traditional Crank-Nicholson PE, three-dimensional PE calculations may be practical in some circumstances. A 3D PE would involve more complexity, as the ground and meteorological fields have to be specified over a much larger area. In additional, the source strength has to be adjusted since wind turbines are not axially symmetric. Again, this may also require microscale meteorological models to accompany the PE methods.

5 CONCLUSIONS

The ISO 9613-2 modeling methodology includes a factor for meteorological adjustments, Cmet, but no clear guidance on how it may be implemented. In this paper, we suggest that adjustment factors can be created by using PE modeling for particular meteorological and terrain conditions. These factors would then be applied as calculated adjustments to the faster engineering approach of the ISO 9613-2 method.

In the case study described above, where tethersonde data were collected on a relatively flat site subject to strong nocturnal low-level jets, we found that a very stable lower atmosphere did not behave in an easily predictable manner. While one could predict that a stronger inversion would increase downwind sound levels, this only occurred within a few hundred meters of the wind turbine. This was likely because some of the sound gets trapped above the nocturnal jet, and sound going below was subject to multiple absorptive ground reflections as the wave propagated. In this case, both the ISO and Harmonoise models overestimated the levels beyond about 750 meters.

Proceeding beyond this, it may be enough to say that the strong inversions do not make wind turbine noise worse, in this example. Or, adjustment factors for overall A-weighting or by 1/1 or 1/3 octave bands can be calculated and applied to ISO calculations for the multiple wind turbines over a large wind farm. Adjustments for other meteorological scenarios can also be calculated and applied to determine noise exposure over time, rather than simply some maximum theoretical noise level.

It should be noted that the detailed atmospheric observations collected for the CASES-99 study may not be practical to collect for many wind farms. This is especially true in complex terrain, where data should be collected or modeled outside of just the ridges where the met towers are typically located. However, new technologies, such as portable LIDAR, may become more commonly used in these instances. In addition, fluid modeling of the atmosphere may also be applied where data is not available.

Overall, there is still more research and development to be done before PE modeling becomes more prevalent in noise impact studies for wind farms. This R&D will likely be in the fields of atmospheric modeling, terrain representations, data collection, and development of user-friendly interfaces.

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Exhibit E

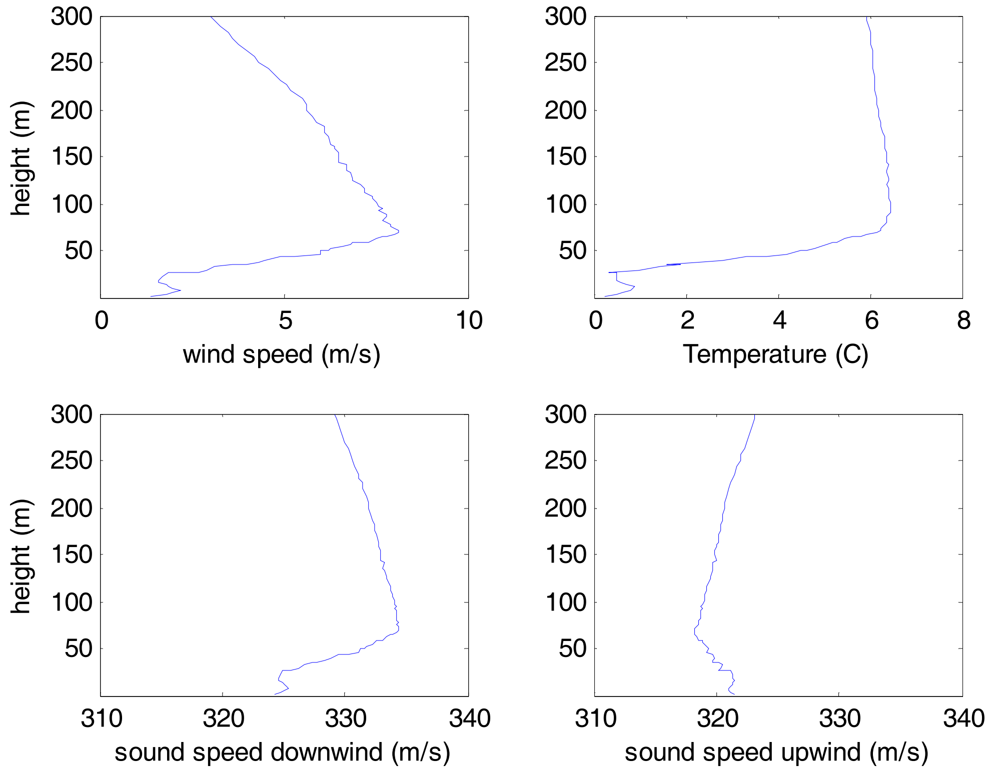

Fig. 1 - (top row) Vertical profiles of wind speed and temperature under a strong inversion observed during the CASES '99 experiment. Ttethersonde data recorded on 18 Oct 1999 at 1228 UTC (0628 local standard time) are shown. (bottom row) Vertical sound speed profiles for those same conditions under downwind and upwind scenarios. Note the deep temperature inversion layer, extending up to 70 m, and topped by low-altitude jet (wind-speed maximum).

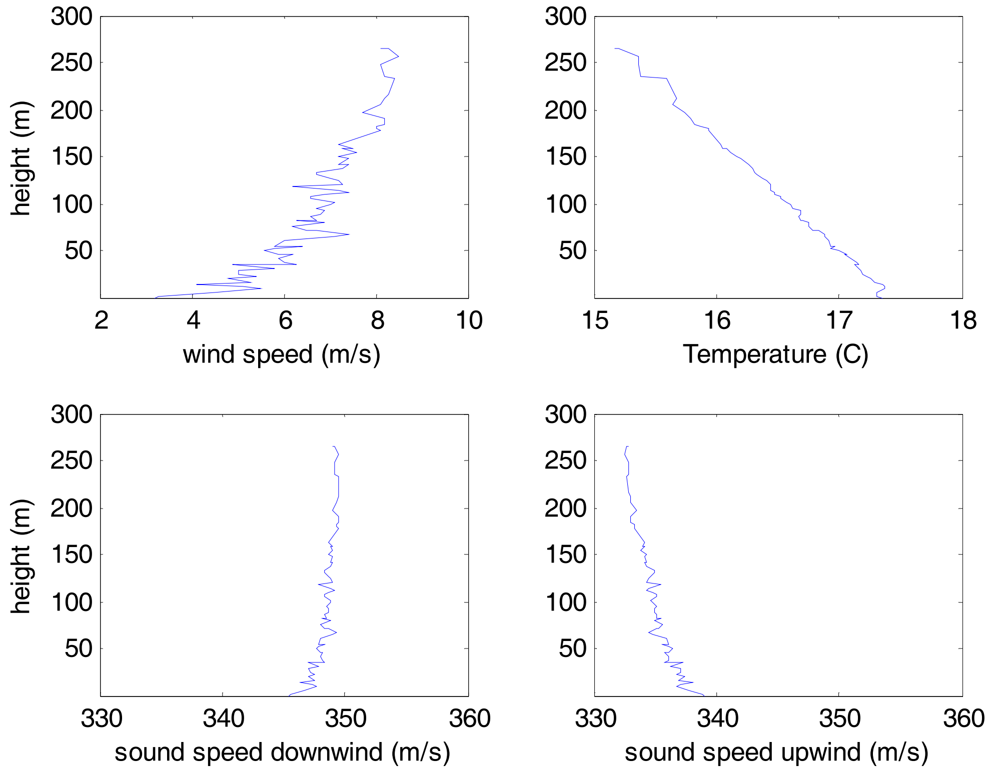

Fig. 2 - Similar to Figure 1, but for tethersonde data on 13 Oct 1999 at 2257 UTC (1657 local standard time). A very shallow temperature inversion, extending up to approximately 15-m height, has formed. Above the shallow inversion conditions are essentially neutral.

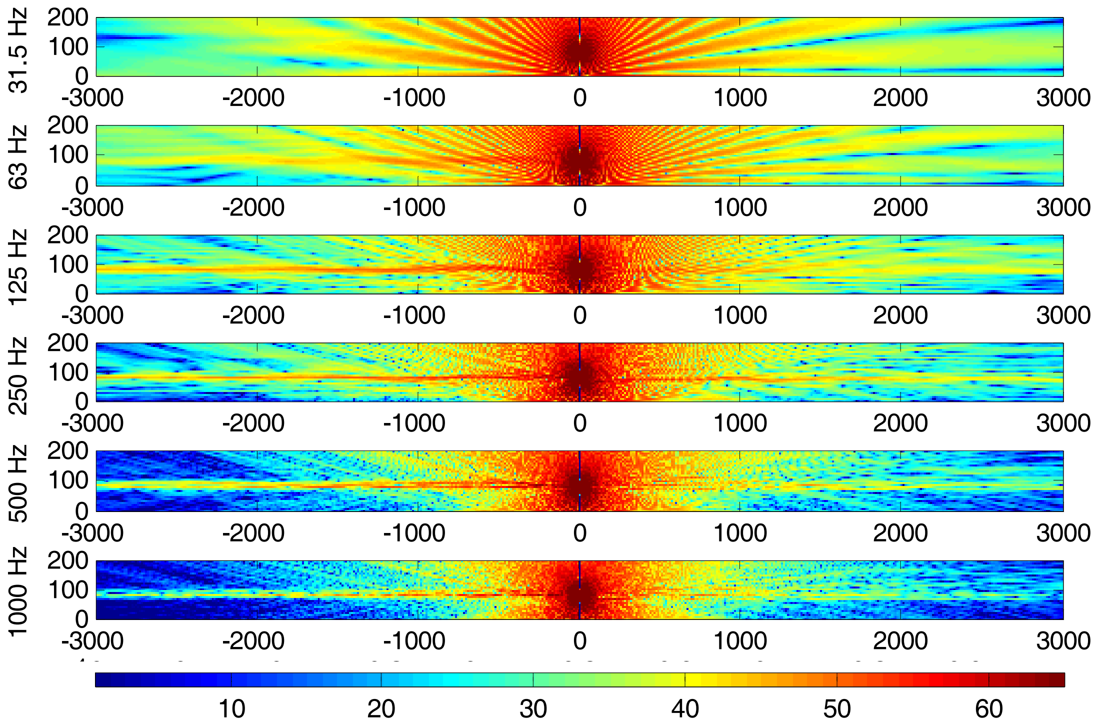

Fig. 3 - Results of PE modeling under early evening (nearly neutral) conditions at each full octave band center frequency to 1 kHz. Wind direction is from left to right. Height is on vertical axis and range in on horizontal axis (in meters), with the wind turbine centered.

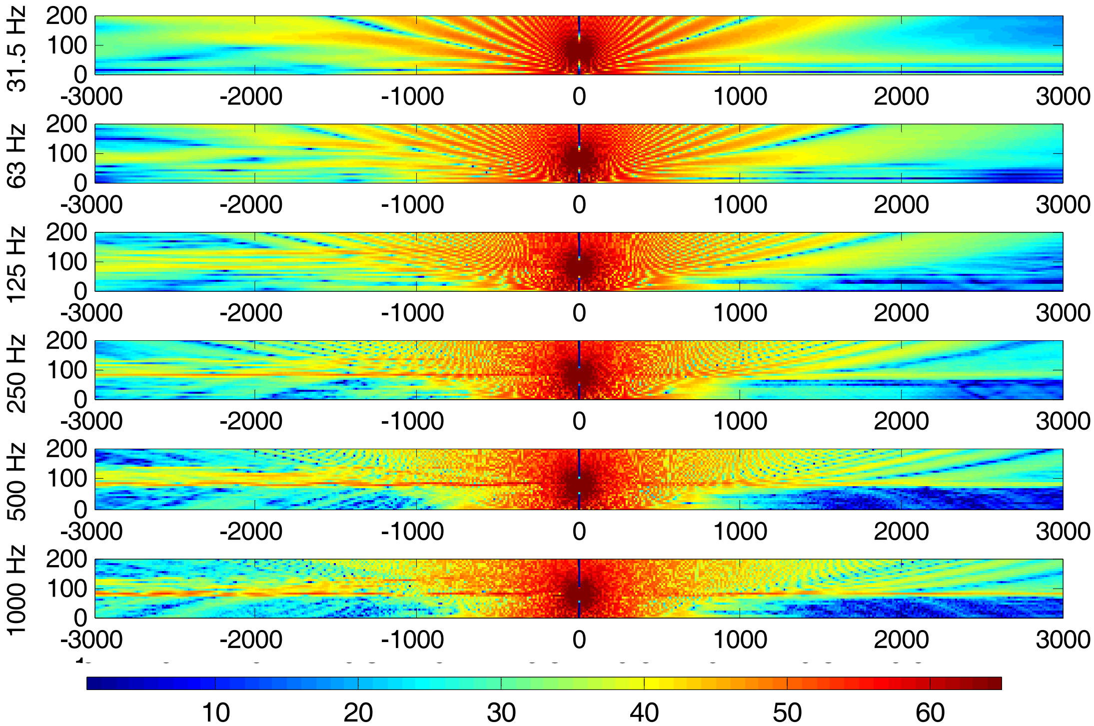

Fig. 4 - *Results of PE modeling under early morning (strongly stable) conditions at each full octave band to 1 kHz. Wind direction is from left to right. Height is on vertical axis and range in on horizontal axis (in meters), with the wind turbine centered.*

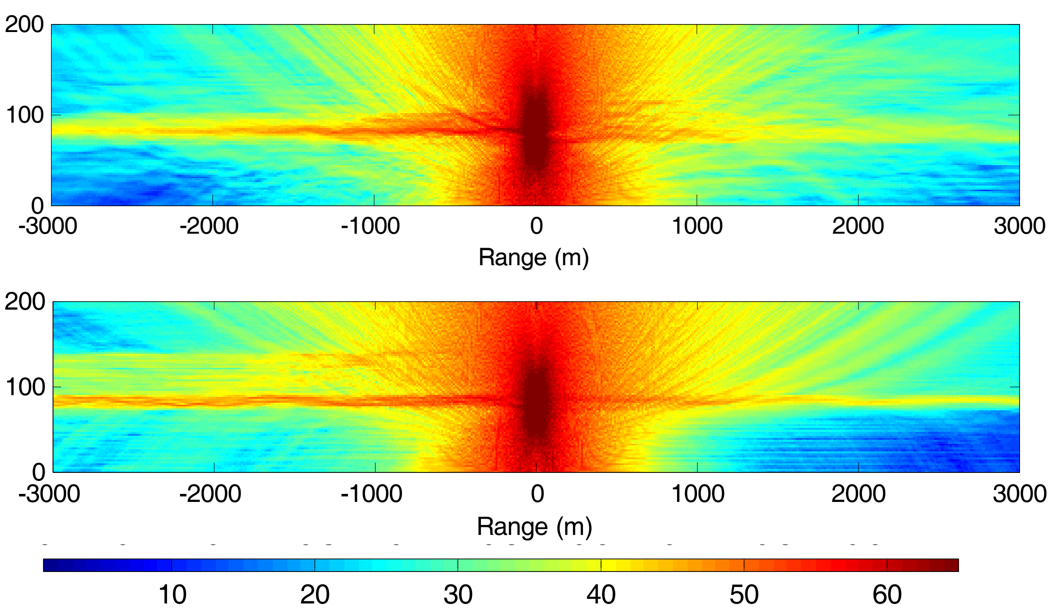

Fig. 5 - *A-weighted sound levels from PE modeling under neutral (top) and stable (bottom) conditions. Wind direction is from left to right.*

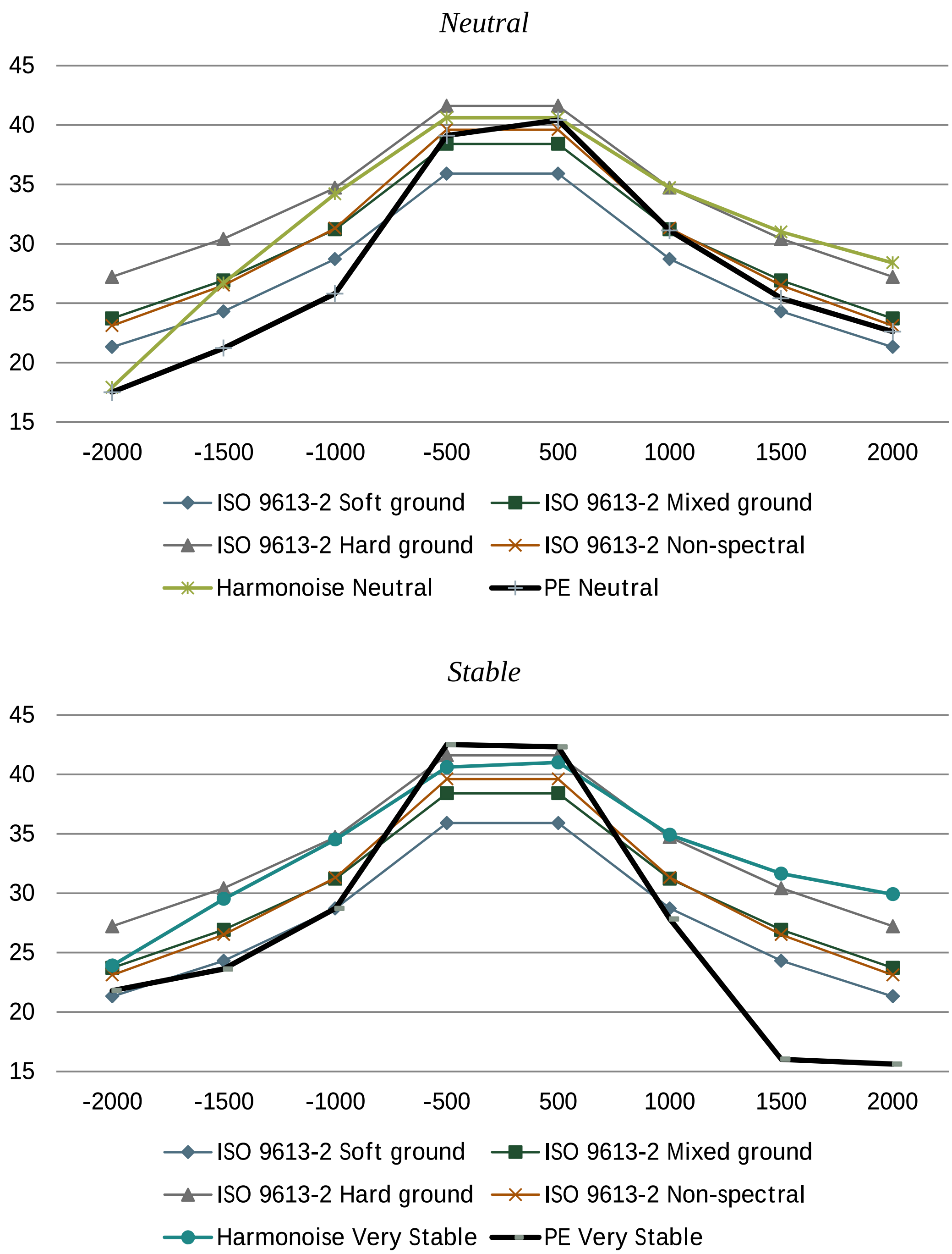

Fig. 6 - Comparison of modeling results for a wind turbine modeled as a point source at 80 meters. Wind direction is left to right, with the turbine a 0 meters, centered. A-weighted sound pressure levels is along the vertical axis. Top graph is neutral stability and bottom is stable, as described in the text. Note: the ISO 9613-2 results are the same for neutral and stable.

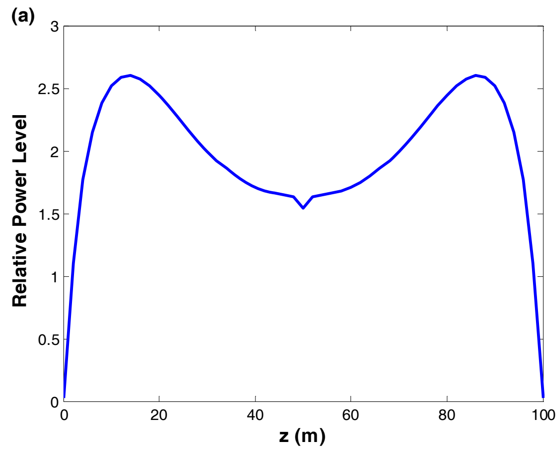

Fig. 7 - Relative sound power along horizontal slices of the rotor plane.This takes into account segment velocity, surface area, and blade rotation.

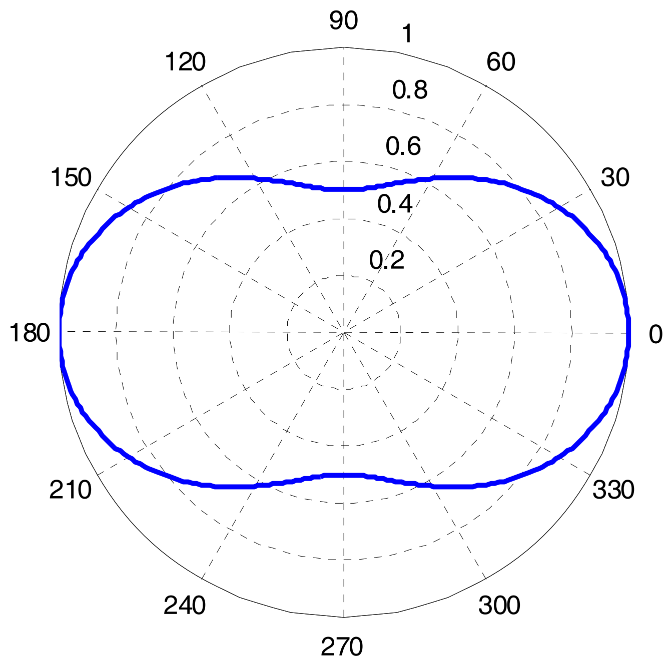

Fig. 8 - Directionality of a wind turbine, looking down from above. This is a simplification from Shepherd, et al. 1998[13].

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Recent developments in assessment guidelines for sound from wind power projects in Ontario, Canada, with a comparison to acoustic audit results

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ABSTRACT

The guidelines of the Ontario Ministry of the Environment (MOE) for the assessment of sound from wind power projects are the most sophisticated in Canada, relying on internationally recognized standards (ISO 9613 & IEC 61400-11) and allowing for a variation in both wind turbine sound power and background sound as a function of wind speed. The MOE completed a technical review of their procedures and published an updated guideline document in October of 2008. The revisions did not change the criteria (essentially 40 dBA at residences in rural areas under moderate wind speeds), but did address the need to consider several factors, such as the wind profile and ground attenuation, with greater specificity. While the revisions help improve the consistency between assessors, there remain some individuals that are critical of the approval process, and in practice there remains a fair degree of variability between the predicted sound levels and those levels occurring under operating conditions. This paper reviews the effect of these improvements, looks at the overall degree of precision versus the variability in sound levels as measured during several acoustic audits of wind power projects recently undertaken by HGC Engineering, and discusses the status of pending legislation that has the potential to modify the assessment process further.

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1. INTRODUCTION

The first commercial wind plant opened in the province Ontario in 2002 with 5 wind turbine generators. As of April 1, 2009, eight contractually separate major wind plants were operating in the province of Ontario, with a combined installed capacity of 887 MW [1]. One more, with a capacity of 198 MW is anticipated to go online this year [2]. Numerous other large scale plants are now under development, and the total installed capacity of all current and planned projects is about 1,600 MW by 2012 [2]. To put this into context, the total installed capacity for all types of power plants in Ontario is currently about 27,000 MW.

In Ontario, the environmental noise generated by industrial noise sources is regulated by the provincial Ministry of Environment (MOE). Generally, industrial noise is assessed by the MOE against background sound levels, or certain overriding minimum criteria. As wind turbine generators tend to emit the greatest sound power levels during conditions of higher wind speeds when background sound levels are elevated, the MOE recognized a special case and produced a guideline document in 2004 [3] pertaining to environmental noise from wind power projects.

That guideline defined a prediction method for use in assessing environmental noise from wind turbine generators, identifying ISO 9613 [4] as the model to be used in calculations for sound propagation, and required that source sound power data to be used in the calculations be established using IEC 61400-11 [5]. Specific sound level criteria were also provided. Thus, predictive engineering calculations were established as the basis for environmental noise prediction for wind turbine generators, and for determining setback requirements.

Following adoption of the guideline, areas for improvement were identified in the guideline by a variety of sources. Following a lengthy review and consultation process, the guideline was revised and reissued in 2008 [6]. The new version changed neither the criteria nor the required standards for sound power measurement and environmental noise prediction, but did specify certain analysis assumptions such as the degree of ground absorption, and perhaps most importantly, indicated that site-specific wind shear (wind profile) effects needed to be considered.

At the present time there is a concerted political effort in Ontario to encourage more renewable energy projects. Proposed provincial legislation in the form of a Green Energy Act, 2009 [7] will provide future regulations designed to establish new guaranteed prices for future wind power projects and potentially to exempt wind power projects from various municipal regulations and by-laws, including zoning and development related regulations, in order to streamline the approval process.

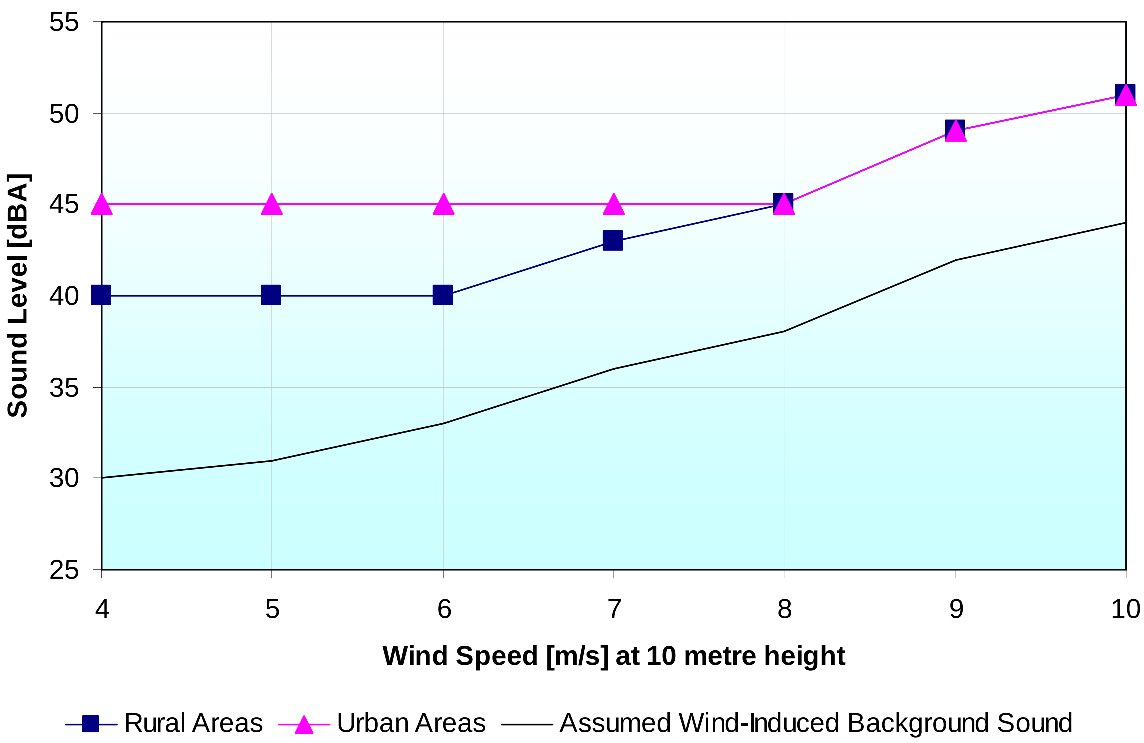
As part of the Green Energy Act, the guidelines of the MOE with respect wind power projects are once again open to input from a variety of stakeholder groups. There have been complaints related to noise and the impact on health from Ontario residents living near operating and proposed wind power projects, leading to pressure on the government to implement minimum setback distances between wind turbines and residential dwellings as part of the revised guidelines or as regulations made under the Act. This would be a departure from the current MOE guidelines wherein the setback distance is a function of the acoustic predictions and established criteria.

2. NOISE GUIDELINES FOR ENVIRONMENTAL NOISE, WIND POWER PROJECTS

In Canada, environmental regulations for industrial noise sources are under provincial jurisdiction. In Ontario, the applicable regulations for industrial sources pertain to sound level limits at sensitive noise receptors, such as residences, and are based on ambient sound levels at those receptors due to natural sources and road traffic. The guidelines for general industrial sources are based on the minimum ambient sound levels in any given hour which would be expected to occur under windless conditions. As wind turbine generators tend to emit the greatest sound power levels during conditions of higher wind speeds when background sound levels are elevated, the MOE produced a guideline document in 2004 pertaining explicitly to environmental noise from wind turbine projects.

That guideline defined a prediction method for use in assessing environmental noise from wind turbine generators, identifying ISO 9613 as the model to be used in calculations for sound propagation, and required that source sound power data to be used in the calculations be established using IEC 61400-11. Specific sound level criteria, defined in terms of the hourly energy-equivalent average (L_{EQ}) sound level were also provided based on an assumed relationship between wind-induced background sound and 10 metre height wind speeds. These criteria depend on whether the area is defined as acoustically urban or rural, and are summarized in Figure 1.

Figure 1: Summary of Provincial Sound Level Limits



The guideline required predictive engineering calculations using the standards described in the guideline, and thus detailed sound level calculations and definable sound power estimation techniques were established as an important factor in determining minimum setbacks from residencies, and wind plant layout.

However, in practice, the guideline document lead to a great deal of variation in assumptions between different assessors, and therefore to variability in the resulting typical setbacks from residential receptors.

One of the most dramatic variables is related to wind shear (wind profile), and the reference roughness length of IEC 61400-11. As required by IEC 61400-11, most manufacturers list the sound power output of their turbines as a range, correlated with 10 metre height wind speeds under the reference wind profile condition. Because the 2004 MOE guideline did not discuss variation in wind shear, some assessors used the sound power data derived under IEC at face value, and others were taking into consideration site-specific wind shear data.

In practice, then, where the wind shear exponent might vary from 0.05 to 0.45 through a given day, the sound power output from the turbine might vary over the entire published range (which could be 5 to 10 dBA), even while the speed at the reference height remains constant. This can lead to large variation in the calculated setback requirements between one assessor and another.

To address such discrepancies, the MOE published a new document in 2008 replacing the earlier guideline. The 2008 guideline did not alter the numeric criterion values, but did amongst other changes add a requirement that wind profile effects be considered. Specifically, the sound power data should be "adjusted for the average summer night time wind speed profile, representative of the site". Other assumptions to be used in the analysis, such as the effective acoustic absorption of the ground surface or "ground factor", and factors affecting atmospheric absorption were also specified for the first time.

Issues related to the quality of the sound produced by the wind turbines are also addressed by the 2008 guideline by explicitly describing a 5 dB penalty to be added in the event that the manufacture's data indicates that the sound is tonal in nature. While tonal noise is penalized if present, the guideline indicates that tonal characteristics are generally associated with maintenance issues. The amplitude modulation related to the characteristic aerodynamic "swoosh" is not penalized.

The 2008 guideline also addressed in greater detail some practical considerations. These included the cumulative effect of neighbouring wind power projects, the need to consider the transformers as ancillary sound sources, and the need to consider vacant lots that would allow a future residence as a sensitive receptor.

2. CURRENT ASSESSMENT EXPERIENCE

The 2008 version of the guideline contains a number of considerable improvements over the previous version. However, despite the increased specificity of the current guideline, there remain differences between the practice of different assessors, and more importantly, there remains considerable variation between predictions made using ISO 9613 with IEC 61400-11 and long term sound level measurements made after start-up.

HGC Engineering's recent experience in Ontario, measuring noise under different conditions around operational wind plants, indicates that while the typical minimum setbacks have increased over time (setbacks of 450 to 600 metres appear to be typical at present), there is considerable variation between actual sound levels at receptors and the impact predicted during the design of the wind plant. In practice, this fact makes validation of the acoustic performance of a wind plant vis-à-vis the MOE criteria quite difficult.

Figure 2 illustrates the results of a typical sound level monitoring period.

Figure 2: Comparison of Sound Levels Measured at a Residence and Sound Levels Measured Approximately 100m From Nearby Turbine. There is one generator located within 1 km from this residence.

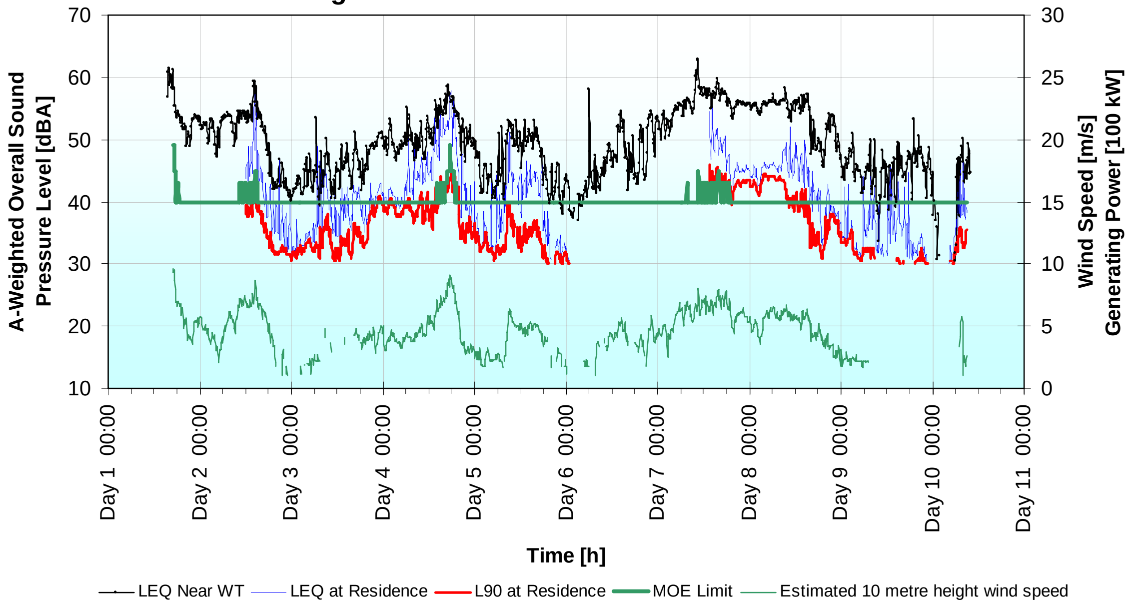


Figure 2 indicates considerable variation in both the energy-equivalent average (L_{EQ}) sound level and the "background" sound level (the L_{90} sound level, or the level exceeded 90% of the time) measured at a residence. Setting aside the strongest peaks in the L_{EQ} sound level, particularly those occurring during daytime hours when man-made sounds would be expected near a residence, there is still a large degree of variation, even for similar 10 metre height wind speeds. This is not unexpected, given the typical diurnal variation in the wind shear exponent, and the fact that the wind direction changes over time.

Figure 3 illustrates the variation another way. The L_{90} sound level measured at the residence is plotted against the wind speed recorded at the nacelle anemometer of the closest wind turbine generators. Considerable variation, on the order of 10 dBA is shown. For comparative purposes, the L_{90} sound level measured close (about 100 metres) from the nearest turbine, at a location where the noise from the turbine is the dominant sound source most of the time is shown in Figure 4. A similar pattern is evident.

Figure 3: L_{90} Sound Level at Residence vs Nacell Wind Speed
All Wind Directions Included

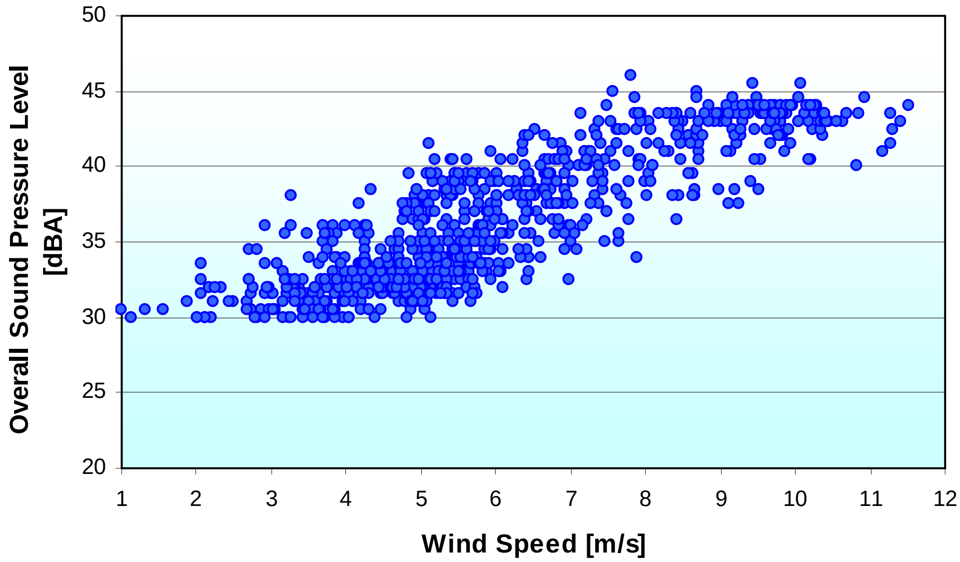
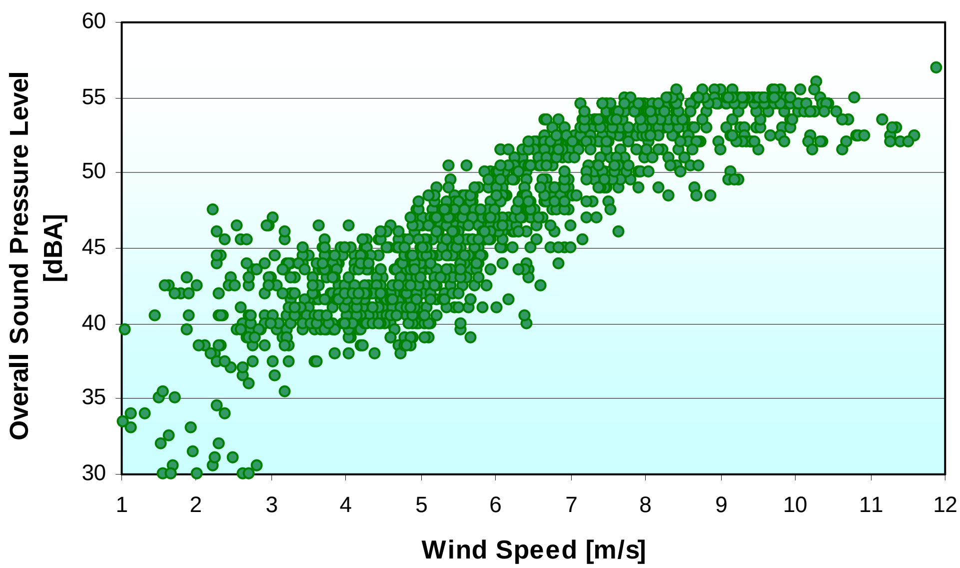


Figure 4: L_{90} Sound Level at WT vs Nacell Wind Speed
All Wind Directions Included



Given the magnitude of the variation, and given that the MOE standard when properly applied will result in a single number prediction for a given 10 metre high wind speed, it should be expected that there will be considerable variation in practice, both above and below the predicted sound level. This has certainly been the experience of HGC Engineering in conducting noise measurements around wind plants. Notice that the L_{90} sound level shown in Figure 1 exceeds the MOE criterion curve by 3 to 4 dBA for period centred around midnight on Day 8, while during periods on Days 2 and 4 with similar 10 metre wind speeds, the L_{90} sound level is effectively at the criterion curve.

The annoyance associated with the audibility of the sound, or with a given sound level impact is a subjective factor. The annoyance issue is complicated by the ability of the ear to become attuned to a particular sound. In one particular case where a homeowner had been complaining about noise from nearby wind turbine generators (there are 5 within a distance of about 1000 metres to this home). The complaints had grown fairly strident. In this case, the wind plant operators had been experimenting with different means to minimize the noise impact, while still allowing turbines in the area to operate. One such test involved a prolonged shutdown of the 5 turbines nearest to the home. The nearest operating turbines were then located at a considerable distance. In this case there were 7 operating turbines between 1000 and 2000 metres from the home. Complaints at this distance would normally be expected to be rare, however, while this operational condition presumably reduced the noise impact for the duration of the test, the homeowner still found the sound of the closest operating wind turbine generators to be objectionable. This highlights the need for prompt attention to any circumstance which may result in temporary increases in the sound levels near a turbine, or changes resulting in a more identifiable or potentially irritating sound such as mechanical wear or damage to blades.

3. PUBLIC PERCEPTION AND FUTURE ASSESSMENT POSSIBILITIES

In Ontario, there has been considerable media attention in recent months given to noise-related complaints from people living near to wind turbine generators (notably in range of 400 to 600 metres), and there has been public discussion around the suitability of the MOE guideline limits. At the same time, there is a renewed political impetus to encourage further wind plant development.

Proposed legislation presently in process, the Green Energy Act, 2009, may alter the noise assessment process in Ontario. Historically, wind power projects have required both municipal approval, in terms of zoning and site plan agreements, and provincial approval for sound. This often resulted in conflicting requirements for setback distances and, as both approval processes could be appealed, lengthy approval timelines extending out two or three years have been common. Amongst other things, the legislation proposes alterations to portions of the planning and environmental assessment acts, exempting wind power projects from certain municipal approval processes in order to expedite the development of wind power projects. It remains uncertain what effect the potential loss of these planning tools may have on the noise assessment process.

Interestingly, there has been considerable public discussion surrounding creating regulations under the act that would establish minimum setbacks between wind turbine generators and residences. Such setbacks may well end up being be a fixed limit, not based on an engineering assessment of site-specific factors such as wind profile, the sound power of the turbines, and the number and spacing of the turbines. There is pressure from some in the public, citing health concerns in addition to audibility and annoyance factors, that the setback distance be set at 1.5 km or more, citing recommendations of the French *Académie nationale de médecine* [8] and others.

Mandating a sufficiently large minimum distance would simplify the approval process and reduce the potential annoyance for nearby residents, but would have serious ramifications for the government's goal of increasing green power in the province. From a technical perspective, there are also a number of drawbacks to this approach. A fixed distance, particularly if it is selected to be on the order of 500 m, may not serve the interests of the nearby residents. Depending on the cumulative impact of multiple turbines near or around a given receptor and the sound power of the selected turbines, the noise impact could actually be greater than under the current regime. On the other hand, for projects with only a few smaller wind turbine generators, the distance chosen may be overly conservative, leading to overall inefficiencies in terms of land use and cost. Also, with a fixed setback, the incentive for power developers to select turbines based on sound emission or to consider a cost premium for low noise models would be removed. Future models may well be larger and generate greater sound levels, but with a fixed distance, there would be little pressure to combat increasing acoustic emissions.

4. CONCLUSIONS

Ontario has been on the forefront of noise assessment for wind power projects in Canada, having produced guidelines for the methodology and criteria in 2004, and updating these in 2008. The guidelines rely on internationally recognized standards, and the updated version has now considered and clarified factors such as the wind profile, penalties for the quality of the sound, and ground attenuation factors. These improvements have increased the consistency between assessments, although there remains in practice variations of at least +/- 5 dB between the predicted impacts and sound levels measured in the field. Despite the relatively robust approval process that is currently in place, complaints related to noise and health effects still occur and there is pressure from a segment of the public to increase the setback distance between wind turbine generators and residential dwellings. This concern is currently of great interest and discussion in Ontario as the province is introducing a Green Energy Act aiming to encourage wind energy projects and to streamline the approval process.

REFERENCES

[1] Independent Electrical System Operator website: http://www.ieso.ca/imoweb/marketdata/windpower_projects.asp

[2] Ontario Power Authority website: http://www.powerauthority.on.ca/Page.asp?PageID=924&SiteNodeID=234

[3] Ontario Ministry of Environment, (2004). Interpretation for applying MOE NPC technical publications to wind turbine generators. MOE PIBS 4709e v1.0.

[4] ISO (1996). Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation. ISO 9613-2, First edition.

[5] IEC (2002). Wind turbine generator systems – Part 11: Acoustic noise measurement techniques. IEC 61400-11, Second edition.

[6] Ontario Ministry of Environment (2008). Noise guidelines for wind farms. Interpretation for applying MOE NPC publications to wind power generation facilities.

[7] Legislative Assembly of Ontario (2009). An Act to enact the Green Energy Act, 2009 and to build a green economy, to repeal the Energy Conservation Leadership Act, 2006 and the Energy Efficiency Act and to amend other statutes.

[8] *Académie nationale de médecine* (2006). Human Health Repercussions of Windmill Operation

From: Tomlinson, Gary (ENE)
Sent: June 29, 2009 9:17 AM
To: Low, Victor (ENE)
Cc: Bardswick, Bill (ENE); Glassco, Jane (ENE)
Subject: RE: Multiple Wind Turbine noise level measurement

Victor:

I will be addressing the issues that GDO has\is experiencing with the Canadian Hydro Developers operation in Dufferin County in the order of your questions to Jane Glassco.

In short, the most pressing and immediate issue is that Certificates of Approval (Air) have been issued for wind turbines with noise emission compliance limits specified in the approval. MOE currently has no approved methodology for field measurement of the noise emissions from multiple noise sources. As such there is no way for MOE Field Staff, (and I would submit anyone else), to confirm compliance or lack thereof with the noise limits set in the approvals.

GDO Staff are scheduled to meet with Township of Amaranth staff during the week of 10 August, 2009 to discuss this matter, as well as meet with Amaranth Council on 19 August, 2009 to discuss CHD's compliance with it's approval(s) specifically as they relate to noise emissions from the transformer station and most importantly the multiple wind turbines located in the Township. I would be hard pressed to believe that the issue of ability to measure noise emissions from multiple sources to determine compliance will not come up as one of the items of discussion at that time.

A slightly more in depth response to your questions follows:

Step up Transformer Station Issues

The first set of complaints relate to the operation of the step up transformer substation located to the south and something like 6 km away from the main part of the wind farm. These complaints are also divided into two main types.

The first subset of transformer complains run as follows:

The complainants state, and GDO Staff have confirmed, that the noise emissions from the transformers, (primarily at night), are considerably above the normal nighttime ambient noise levels previously encountered in that area. (GDO Staff measurements utilizing the NPC-103 methodology, confirm that when the transformers are not operating, the normal nighttime background ambient noise level varies between 27 and 29 dBA. When the step up transformers are operating, the noise levels in the area vary between 37 and 39 dBA, [i.e. 32 dBA + 5 dBA tonal penalty to 34 dBA + 5 dBA tonal penalty], which is effectively a 10 dB increase over the usual nighttime levels that area residents have been conditioned to prior to March of 2006).

The second subset of transformer complaints run as follows:

The complainants state, and consultants retained by CHD, as well as observations made by GDO Staff, confirm that there is a strong tonal component to the noise emissions from the operation of the step up transformers, (an audible tone at 300 Hz, and another one at 360 Hz that run between 35 dB and 40 dB), which the complainants have identified as being particularly annoying and is probably the primary causative agent for the sleep deprivation that the three closest families are complaining of.

In both of the cases above, (or for that matter both of the above in combination), the noise emissions from the step up transformers are in compliance with NPC-232. The weighting against tones that occur below 500 Hz by the A scale system cancels out the audible tones occurring at 300 Hz and 360 Hz when viewed in conjunction with the remainder of the noise emissions from the transformer. As such the noise emissions from the transformers are in compliance with the CofA(Air) for the transformers, (40 dBA), and as MOE policy is to evaluate material discomfort\loss of use of property issues against the standards in NPC-232 and NPC-205, (in this case this is a Class 3 area as per NPC-232), and as there is no exceedance of the standards set out in those documents, there is considered to be no EPA S. 14(1) contraventions.

Understandably the complainants in this particular circumstance are not particularly receptive to our comments that the noise emissions from the transformer station are in compliance with the CofA(Air) requirements, and that MOE has no grounds to proceed with any abatement\enforcement action. Two of the three closest complainants to the transformer substation have moved out of their homes, (along with their families), and one of those families also have bought civil action against Canadian Hydro Developers, (for nuisance).

Exhibit G

Wind Turbine Issues

The second set of complaints relate to the operation of the 133 Canadian Hydro Developers wind turbines located in the Townships of Amaranth and Melancthon in Dufferin County. The 1.5 MW turbines, (total nameplate capacity of 199.5 MW), are spread out over an area of something like 180 km^2. These complaints can be divided into three main types.

The first subset of wind turbine complaints run as follows:

Complainants state, and consultants retained by CHD, as well as observations made by GDO Staff have confirmed, that some of the wind turbines, when operating, are generating an audible low frequency tonal hum that is generally inaudible outside of structures, but is audible, again under certain conditions, inside the structures, (such as homes). Work done by the consultants has documented that certain of the wind turbines, (apparently all of those built in the second phase of construction), (88 turbines), emit an audible tone, (a 35 dB "hum" at the complainants residence when measured utilizing the NPC-103 methodology), at 160 Hz. The "hum" is indeed generally inaudible outside of homes etc. but is audible inside homes etc. and is quite annoying to the occupants. It appears that the audibility inside the homes is dependent on the proximity of the turbine(s) to the homes, as well as the susceptibility of the home(s) to sympathetic vibration due to the low frequency "hum". The complainants have identified the "hum" as being particularly annoying and is probably the primary causative agent for the sleep deprivation that the most vocal family was complaining of.

CHD has indicated that they have identified the source of the 160 Hz "hum" as being in the gear train of the turbines. CHD has also indicted that they have devised a remedy for this issue, however the remedy for this problem has yet to be demonstrated as effective.

The second subset of wind turbine complaints run as follows:

The complainants state, and observations made by GDO Staff confirm that, at some locations that the cumulative noise emissions from the operation of a number of wind turbines, (blade whoosh), are exceeding the requirements set out in the CofA(Air), (in this case the CofA(Air) references the limits set in the "Interpretation For Applying MOE NPC Technical Publications To Wind Turbine Generators"). In the cases where GDO Staff have identified exceedances of the CofA, (noise levels measured between 44 dBA and 45 dBA utilizing NPC-103 methodology with wind speeds of less than 6 m/s), there are between 37 and 52 wind turbines observable inside of a 3 km radius from the points of measurement.

The third subset of wind turbine complains run as follows:

The complainants state, and GDO Staff have confirmed, that the noise emissions from the multiple wind turbines, (primarily at night), are considerably above the normal nighttime ambient noise levels previously encountered in that area. GDO Staff measurements utilizing the NPC-103 methodology, confirm that when the turbines are not operating, the normal nighttime background ambient noise level varies between 27 and 29 dBA. When the step up turbines are operating, (excluding locations identified in the last subset), the noise levels in the area vary between 35 dBA and 37 dBA, which is effectively an 8 to 10 dB increase over the usual nighttime levels that they had been conditioned to prior to March of 2006\October 2008.

In the first and third cases above, (or for that matter both of the above in combination), the noise emissions, (measured utilizing NPC-103 methodology), from the operation of the wind turbines appear to be in compliance with the document **Interpretation For Applying MOE NPC Technical Publications To Wind Turbine Generators**. The weighting against tones that occur below 500 Hz by the A scale system cancels out the audible tones occurring at 160 Hz when viewed in conjunction with the remainder of the noise emissions from the wind turbines. As such in these cases the noise emissions from the wind turbines are in compliance with the CofA(Air) for the wind turbines, and as MOE policy is to evaluate material discomfort\loss of use of property issues against the standards in NPC-232 and NPC-205, (as interpreted by the **Interpretation For Applying MOE NPC Technical Publications To Wind Turbine Generators** document**Noise Guidelines For Wind Farms**), and as there is no exceedance of the standards set out in those documents there is considered to be no EPA S. 14(1) contraventions.

Understandably the complainants in this particular circumstance are again not particularly receptive to our comments that the noise emissions from the wind turbines are in compliance with the CofA(Air) requirements, and that MOE has no grounds to proceed with any abatement\enforcement action. In this case two of the complainants have moved out of their homes, (along with their families), and have made financial settlements with CHD, with CHD buying the homes\properties from the complainants.

In the case of the second set of complaints, (measured exceedance of the CofA(Air) standards utilizing NPC-103 methodology), GDO staff have been informed by EAAB Staff, yourself among them, that NPC-103 methodology is not applicable to measuring noise emissions from multiple sources, (such as 37 wind turbines located inside a 3 km radius).

In all of the three cases above, District Office Staff are unable to confirm compliance, or identify non-compliance, utilizing the NPC-103 measurement methodology, with the applicable standard, and subsequently take appropriate action. EAAB has knowingly issued a series of Certificates of Approval (Air) that are unenforceable.

Objective

In the short term, in terms of addressing at least the three wind turbine issues noted above, the most immediate objective of the GDO is to obtain a methodology by which multiple noise sources impacting a sensitive receptor can be measured to identify compliance or the lack thereof with the applicable standard\limit. In other words, Field Staff need an addendum to NPC-103, (or for that matter a new NPC), that sets out a methodology to measure noise emissions form multiple sources impacting on a sensitive receptor. This is essential not only for these "non-GEA" wind energy approvals, and also for identifying compliance with future GEA wind energy approvals.

In the long term, in terms of addressing the two transformer complaints, and the first wind turbine issue, the objective are to:
(1)
Address the circumstances where a new noise source has been placed into a very quiet location beyond the circumstances identified and contemplated by the NPC-232 Class 3 area, and:
(2)
Address the circumstances whereby audible annoying\disruptive low frequency and near low frequency tones are present in the noise emissions from wind turbines and\or transformers, but are weighted against by the configuration of the A scale.

Feel free to give me a call directly if you require any clarification of these issues.

G.W. Tomlinson

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Spills Action Centre 1 800 268 6060

From: Glassco, Jane (ENE)
Sent: June 26, 2009 4:50 PM
To: Tomlinson, Gary (ENE)
Cc: Bardswick, Bill (ENE)
Subject: Fw: Multiple Wind Turbine noise level measurement

Exhibit G

Gary could you please email an update to Victor on Monday am. Thanks Jane
Jane (blackberry)

From: Low, Victor (ENE)
To: Glassco, Jane (ENE)
Sent: Fri Jun 26 16:43:24 2009
Subject: Multiple Wind Turbine noise level measurement
Jane,
As per my voice message today, we continue to work on developing a short term approach on how to inspect wind farms. This will be challenging, given the state of current science as outlined in Gary's email.

In order to help you out, I would like to better understand the precise issue which you are facing. Also, in terms of addressing the issue, what would your objective be?

Please also note that Doris has a meeting with Canadian Hydro Developers on Tuesday and would like to have an update on the latest issues with regard to CHD's project in your area, prior to Tuesday June 30.

Thanks,
Victor

From: Glassco, Jane (ENE)
Sent: June 12, 2009 1:38 PM
To: Greason, Ian (ENE); Low, Victor (ENE); Tomlinson, Gary (ENE)
Subject: Fw: Multiple Wind Turbine noise level measurement

Any word on a teleconference to discuss the turbine noise issue? (See below).......Jane Glassco

Jane (blackberry)

From: Tomlinson, Gary (ENE)
To: Glassco, Jane (ENE)
Sent: Fri Jun 12 11:13:09 2009
Subject: Multiple Wind Turbine noise level measurement
Jane:

This is further to our telephone conversation this morning:

The issue around the measurement and interpretation of obtained measurement(s) from multiple wind turbine noise sources seems to have become fairly confused, (apparently depending on how many times the issue has been retold and to whom). In short the issue is not one of is there a standard that is to be met? (To which the answerer is yes.) The issue is however does MOE have a methodology for obtaining noise measurements from multiple wind turbine sources such that MOE field, (Abatement), staff can determine spot compliance, (or lack thereof), via noise level measurement in the field? (To which the answer appears to be No.)

A quick explanation follows:

The current noise levels, (on the A Scale), that the wind turbines are required to meet, (typically as a requirement on their Certificate of Approval Air), are currently concisely identified in the October 2008 document titled "***Noise Guidelines for Wind Farms***", which superseded an earlier, (July 2004), document titled "***Interpretation For Applying NPC Technical Publications To Wind Turbine Generators***", (see attached), (PIBS # 4709e).

The problem arises in that the document, (NPC-103), (see above), that identifies the methodology by which the various measurement procedures to be used in connection with the various MOE NPC documents and other associated documents, (such as "***Noise Guidelines for Wind Farms***", and "***Interpretation For Applying NPC Technical Publications To Wind Turbine Generators***"), does not contain a methodology for the measurement of multiple dispersed sources, (such as 37 wind turbines inside a 3 km radius of a point of reception). This has been confirmed to myself by John Kowalewski of EAAB, and apparently by Victor Low, also of EAAB to you. Also, (confirmed by Kowalewski and Low at different times), there is no alternate document identifying methodology for measurements of this type, and the development of a methodology is not ongoing or even apparently under consideration at this time.

In short, MOE field staff have no approved methodology to determine compliance with the noise levels identified in the Guideline(s)\Certificates of Approval Air for noise emissions from dispersed multiple wind turbine sources, (or any other dispersed multiple noise sources).

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Effects of the wind profile at night on wind turbine sound

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Received 22 January 2003; accepted 22 September 2003

Abstract

Since the start of the operation of a 30 MW, 17 turbine wind park, residents living 500 m and more from the park have reacted strongly to the noise; residents up to 1900 m distance expressed annoyance. To assess actual sound immission, long term measurements (a total of over 400 night hours in 4 months) have been performed at 400 and 1500 m from the park. In the original sound assessment a fixed relation between wind speed at reference height (10 m) and hub height (98 m) had been used. However, measurements show that the wind speed at hub height at night is up to 2.6 times higher than expected, causing a higher rotational speed of the wind turbines and consequentially up to 15 dB higher sound levels, relative to the same reference wind speed in daytime. Moreover, especially at high rotational speeds the turbines produce a 'thumping', impulsive sound, increasing annoyance further. It is concluded that prediction of noise immission at night from (tall) wind turbines is underestimated when measurement data are used (implicitly) assuming a wind profile valid in daytime.

1. Introduction

In Germany several wind turbine parks have been and are being established in sparsely populated areas near the Dutch border. One of these is the Rhede Wind Park in northwestern Germany with seventeen 1.8 MW turbines of 98 m hub height and with 3-blade propellers of 35 m wing length. The turbines have a variable speed increasing with wind speed, starting with 10 r.p.m. (revolutions per minute) at a wind speed of 2.5 m/s at hub height up to 22 r.p.m. at wind speeds of 12 m/s and over.

At the Dutch side of the border is a residential area along the Oude Laan and Veendijk (see Fig. 1) in De Lethe: countryside dwellings surrounded by trees and agricultural fields. The dwelling nearest to the wind park is some 500 m west of the nearest wind turbine (W 16).

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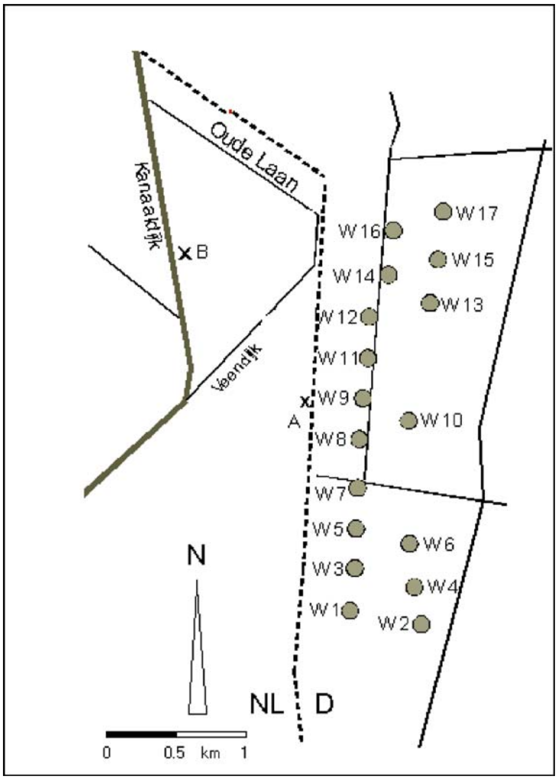

Fig. 1. Location of wind turbines (W_{nn}) and immission measurements (A and B) near the Dutch/German (NL/D) border.

According to a German noise assessment study a maximum immission level of 43 dB(A) was expected, 2 dB below the applied German noise limit. According to a Dutch consultancy immission levels would comply with Dutch (wind speed dependent) noise limits.

After the park was put into operation residents made complaints about the noise, especially at (late) evening and night-time. The residents, united in a neighbourhood group, could not persuade the German operator to put in place mitigation measures or to carry out an investigation of the noise problem and brought the case to court. The Science Shop for Physics had just released a report explaining a possible discrepancy between the calculated and the actual sound immission levels of the wind turbines because of changes in wind profile, and was asked to investigate the consequences of this discrepancy by sound measurements. Although at first the operator agreed to supply measurement data from the wind turbines (such as power output, rotation speed, axle direction), this was withdrawn after the measurements had started. All relevant data therefore had to be supplied or deduced from the author's own measurements.

2. Noise impact assessment

In the Netherlands and Germany noise impact on dwellings near a wind turbine or wind turbine park is calculated with a sound propagation model. Wind turbine sound power levels L_W are used as input for the model, based on measured or estimated data. In Germany a single 'maximum' sound power level (at 95% of maximum electric power) is used to assess sound impact. In the Netherlands sound power levels related to wind speeds at 10 m height are used; the resulting sound immission levels are compared to wind speed-dependent noise limits. Implicitly this assessment is based on measurements in daytime and does not take into account atmospheric conditions affecting the wind profile, especially at night.

In the Netherlands a national calculation model is used [1] to assess noise impact, as is the case in Germany [2]. According to Kerkers [3] there are, at least in the case of these wind turbines, no significant differences between both models.

In both sound propagation models the sound immission level L_{imm} at a specific observation point is a summation over j sound power octave band levels L_{Wj} of k sources (turbines), reduced with attenuation factors $D_{j,k}$:

$$L_{imm} = 10 \log \left[\sum_j \sum_k 10^{(L_{Wj} - D_{j,k})/10} \right], \tag{1}$$

where L_{Wj}, assumed to be identical for all k turbines, is a function of rotational speed. $D_{j,k}$ is the attenuation due to geometrical spreading (D_{geo}), air absorption (D_{air}) and ground absorption (D_{ground}): $D_{j,k} = D_{geo} + D_{air} + D_{ground}$.

Eq. (1) is valid for a downwind situation. For long-term assessment purposes a meteorological correction factor is applied to (1) to account for an 'average atmosphere'. When comparing calculated and measured sound immission levels in this study no such meteo-correction is applied.

3. Wind turbines noise perception

There is a distinct audible difference between the night and daytime wind turbine sound at some distance from the turbines. On a summer's day in a moderate or even strong wind the turbines may only be heard within a few hundred metres and one might wonder why residents should complain of the sound produced by the wind park. However, on quiet nights the wind park can be heard at distances of up to several kilometres when the turbines rotate at high speed. On these nights, certainly at distances between 500 and 1000 m from the wind park, one can hear a low pitched thumping sound with a repetition rate of about once a second (coinciding with the frequency of blades passing a turbine mast), not unlike distant pile driving, superimposed on a constant broadband 'noisy' sound. A resident living at 1.5 km from the wind park describes the sound as 'an endless train'. In daytime these pulses are not clearly audible and the sound is less intrusive or even inaudible (especially in strong winds because of the then high ambient sound level).

In the wind park the turbines are audible for most of the (day and night) time, but the thumping is not evident, although a 'swishing' sound—a regular variation in sound level caused by the pressure variation when a blade passes a turbine mast—is readily discernible. Sometimes a rumbling sound can be heard, but it is difficult to assign it, by ear, to a specific turbine or to assess its direction.

4. Stability-dependent wind profiles

Usually a fixed relation is assumed between the wind speed v_h at height h and the wind speed v_{ref} at a reference height h_{ref} (usually 10 m), which is the widely used logarithmic wind profile with surface roughness z as the only parameter. See for example the international recommendations for wind turbine noise emission measurements [4,5]. For height h the wind speed v_h is calculated as follows:

$$v_h = v_{ref} \log(h/z)/\log(h_{ref}/z). \quad (2)$$

This equation is an approximation of the wind profile in the turbulent boundary layer of a neutral atmosphere, when the air is mixed by turbulence resulting from friction with the surface of the earth. During daytime thermal turbulence is added, especially when the heating of the earth surface by the sun is significant. At night-time a neutral atmosphere, characterized by the adiabatic temperature gradient, occurs under heavy cloud and/or at relatively high wind speeds. When there is some clear sky and in the absence of strong winds the atmosphere becomes stable because of radiative cooling of the surface: the wind profile changes and can no longer be adequately described by Eq. (2). The effect of the change to a stable atmosphere is that, relative to a given wind speed at 10 m height in daytime, at night there is a higher wind speed at hub height and thus a higher turbine sound power level; also there is a lower wind speed below 10 m and thus less wind-induced sound in vegetation. According to measurements by Holtslag [6] in a non-neutral atmosphere (either stable or unstable) a correction must be added to the logarithmic terms in the wind profile according to Eq. (2):

$$v_h = v_{ref}[\log(h/z) - \Psi_m]/[\log(h_{ref}/z) - \Psi_m], \quad (3)$$

where $\Psi_m = \Psi_m(h/L)$ is a rather elaborate function of height h and Monin–Obukhov length L. L is a stability measure and is positive for a stable, negative for an unstable atmosphere; for a neutral atmosphere L is a large number, either positive or negative. For calculations of sound propagation in the atmosphere Kühner [7] proposes a simple equation used in the German Air Quality Guideline "TA-Luft" [8]:

$$v_h = v_{ref}(h/h_{ref})^m, \quad (4)$$

where m is a number that depends on stability.

Stability can be categorized in Pasquill classes that depend on observations of wind speed and cloud cover (see, e.g. Ref. [9]). They are usually referred to as classes A (very unstable) through F (very stable). In "TA-Luft" a closely related classification is given (again closely related, according to Kühner [7], to the international Turner classification). An overview of stability classes with the appropriate value of m is given in Table 1. In Fig. 2 wind profiles are given as measured by Holtslag [6], as well as wind profiles according to Eqs. (2) and (4).

According to long-term data from Eelde and Leeuwarden [10], two meteorological measurement sites of the KNMI (Royal Dutch Meteorological Institute) in the northern part of the Netherlands, a stable atmosphere (Pasquill classes E and F) at night occurs for a considerable proportion of night-time: 34% and 32%, respectively.

According to Eq. (2) the ratio of wind speed at hub height (98 m) to wind speed at reference height, over land with low vegetation ($z = 3$ cm), would be $f_{log} = v_{98}/v_{10} = 1.4$. According to

Table 1
Stability classes and factor m

Pasquill class	Name	Comparable stability class "TA-Luft" [8]	m
A	Very unstable	V	0.09
B	Moderately unstable	IV	0.20
C	Neutral	III2	0.22
D	Slightly stable	III1	0.28
E	Moderately stable	II	0.37
F	(Very) stable	I	0.41

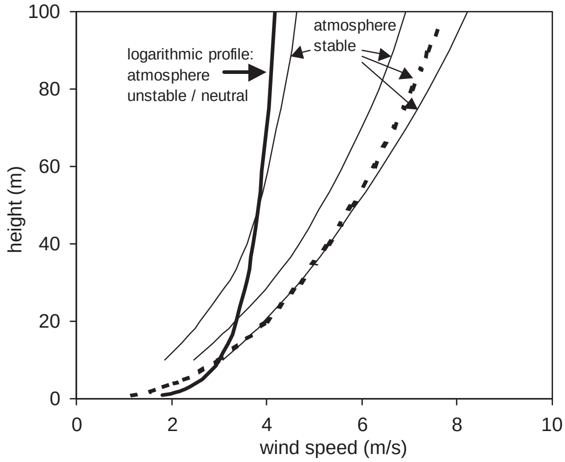

Fig. 2. Measured wind profiles (thin lines, [6]) and wind profile according to TA Luft (dotted line, [8]) in a stable atmosphere, and wind profile according to logarithmic model of formula 2 with $z = 3$ cm (bold line).

Eq. (4) and Table 1 this ratio would be 1.2 in a very unstable atmosphere and $f_{stable} = 2.5 = 1.8f_{log}$ in a (very) stable atmosphere.

The fact that wind speeds at 10 m height may not be a good, unique predictor for hub height wind speeds has been put forward by Rudolphi [11]. He concluded from measurements that wind speed at 10 m height is not a good measure for wind turbine sound power: according to his measurements near a 58 m hub height wind turbine at night the turbine sound level was 5 dB higher than expected. This conclusion was not followed by a more thorough investigation.

The question addressed in this study is: what is the influence of the change in wind profile on the sound immission near (tall) wind turbines?

5. Measurement method

Sound immission measurements were made over 1435 hours, of which 417 hours were at night, within four months at two consecutive locations with an unmanned Sound and Weather

Measurement System (SWMS) consisting of a type 1 sound level meter with a microphone at 4.5 m height with a 9 cm diameter foam wind shield, and a wind meter at 10 m as well as at 2 m height. Every second, wind speed and wind direction (at 10 and 2 m height) and the A-weighted sound level were measured; the measured data are stored as statistical distributions over 5 min intervals. From these distributions all necessary wind data and sound levels can be calculated, such as average wind speed, median wind direction or equivalent sound level and any percentile (steps of 5%) wind speed, wind direction or sound level, in intervals of 5 min or multiples thereof.

Also complementary measurements were done with logging types 1 and 2 sound level meters and a type 1 spectrum analyzer to measure immission sound levels in the residential area over limited periods ([12], not reported here), and emission levels near the wind turbines. Emission levels were measured according to international standards [4,5], but for practical purposes the method could not be adhered to in detail; with respect to the recommended values a smaller reflecting board was used for the microphone ($30 \times 44\,cm^2$ instead of a 1 m diameter circular board) and a smaller distance to the turbine (equal to tower height instead of tower height + blade length); reasons for this are given in a separate paper [13]. Also it was not possible to carry out emission measurements with only one turbine in operation.

6. Results: sound emission

Emission levels L_{eq} measured very close to the centre of a horizontal, flat board at a distance R from a turbine hub can be converted to a turbine sound power level L_W [4,5]:

$$L_W = L_{eq} - 6 + 10\log(4\pi R^2). \quad (5)$$

From earlier measurements [3] a wind speed dependence of L_W was established as given in Table 2. As explained above, the wind speed at 10 m height is not considered a reliable single measure for the turbine sound power. Rotational speed is a better measure.

Emission levels have been measured, typically for 5 min per measurement, at nine turbines on seven different days with different wind conditions. The results are plotted in Fig. 3; the sound power level is plotted as a function of rotational speed N. N is proportional to wind speed at hub height and could be determined by counting, typically during 1 min, blades passing the turbine mast. This counting procedure is not very accurate (accuracy per measurement is $\leqslant 2$ counts, corresponding to 2/3 r.p.m.) and is probably the dominant reason for the spread in Fig. 3. The best logarithmic fit to the data points in Fig. 3 is

$$L_W = 67.1\log(N) + 15.4\,\text{dB(A)} \quad (6)$$

with a correlation coefficient of 0.98. The standard deviation of measurement values with respect to this fit is 1.0 dB.

Table 2
Sound power level of wind turbines [3]

Wind speed v_{10}	m/s	5	6	7	8	9	10
Sound power level L_W	dB(A)	94	96	98	101	102	103

At the specification extremes of 10 and 22 r.p.m. the (individual) wind turbine sound power level L_W is 82.8 and 105.7 dB(A), respectively.

In Table 3 earlier measurement results [3] are given for the octave band sound power spectrum. Also in Table 3 the results of this study are given: the logarithmic average of four different spectra at different rotational speeds. In all cases spectra are scaled, with Eq. (6), to the same sound power level of 103 dB(A).

To calculate sound immission levels at a specific rotational speed (or vice versa) the sound power level given in Eq. (6), and the spectral form in Table 3 ('this study') have been used.

7. Results: sound immission

The sound immission level has been measured with the unmanned SWMS on two locations. Between May 13 and June 22, 2002 it was placed amidst open fields with barren earth and later low vegetation 400 m west of the westernmost row of wind turbines (location A, see Fig. 1). This site was a few metres west of the Dutch–German border, visible as a ditch and a 1.5–2 m high dike. Between June 22 and September 13, 2002 the SWMS was placed on a lawn near a dwelling 1500 m

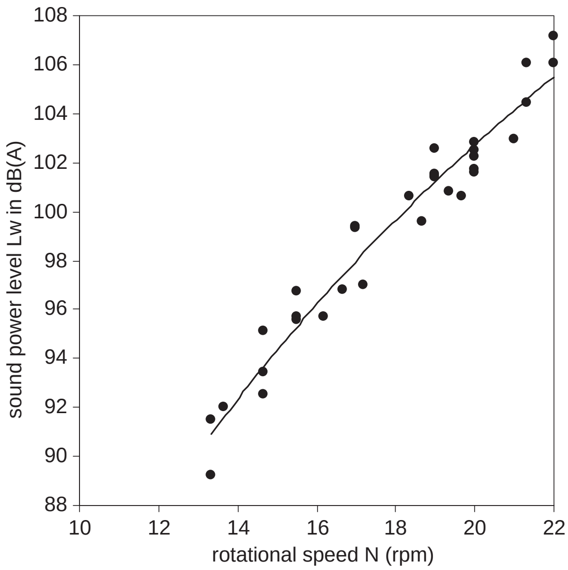

Fig. 3. Measured wind turbine sound power level L_W as a function of turbine rotational speed N.

Table 3
Octave band spectra of wind turbines at $L_W = 103$ dB(A)

Frequency	Hz	63	125	250	500	1000	2000	4000	L_W
This study	dB(A)	82	92	94	98	98	93	88	103
[3]	dB(A)	85	91	95	98	98	92	83	103

west of the westernmost row (location B), with both low and tall trees in the vicinity. On both locations there were no reflections of turbine sound towards the microphone, except via the ground, and no objects (such as trees) between the turbines and the microphone. Apart from possible wind induced sound in vegetation relevant sound sources are traffic on rather quiet roads, agricultural activities, and birds. As, because of the trees, the correct (potential) wind speed and direction could not be measured on location B, wind measurement data provided by the KNMI were used from their Nieuw Beerta site 10 km to the north. These data fitted well with the measurements on location A.

At times when the wind turbine sound is dominant, the sound level is relatively constant within 5 min intervals. In Fig. 4 this is demonstrated for two nights. Thus measurement intervals with dominant turbine sound could be selected with a criterion based on a low variation in sound level: $L_5 - L_{95} \leqslant 4$ dB, where L_5 and L_{95} are 5 and 95 percentile sound level. In a normal (Gaussian) distribution this would equal $\sigma \leqslant 1.2$ dB, with σ the standard deviation.

On location A, 400 m from the nearest turbine, the total measurement time was 371 h. For 25% of this time the wind turbine sound was dominant, predominantly at night (72% of all 105 nightly hours) and hardly during daytime (4% of 191 h) (see Table 4).

At location B, 1500 m from the nearest turbine, these percentages were almost halved, but the turbine sound remained dominant for over one-third of the time at night (38% of 312 h). The trend in percentages agrees with complaints mostly concerning noise in the (late) evening and at night and their being more strongly expressed by residents closer to the wind park.

In Fig. 5 the selected (i.e., with dominant wind turbine sound) 5 min equivalent immission sound levels $L_{eq,5\,\mathrm{min}}$ are plotted as a function of wind direction (left) and of wind speed (right) at 10 m height, for both location A (above) and B (below). It is not clear why the KNMI wind speed data (used for location B) cluster around integer values of the wind speed.

Also the wind speed at 10 and 2 m height at location A are plotted (in 5A and 5B, respectively), and the local wind speed (influenced by trees) at 10 m at location B (5C). The immission level data points are separated in two classes where the atmosphere was stable or neutral, according to

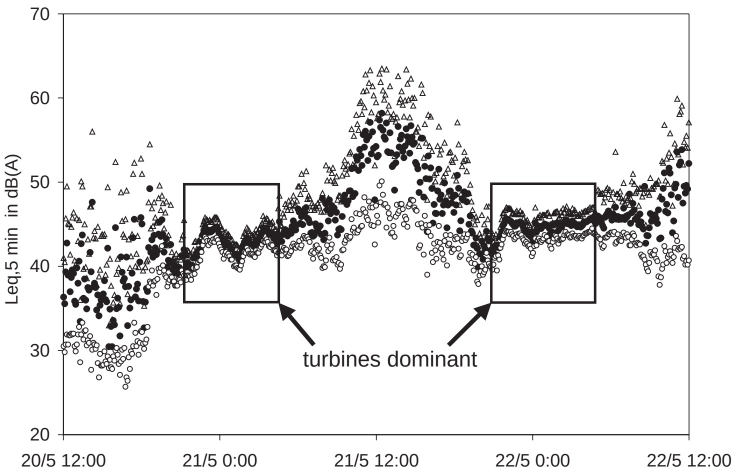

Fig. 4. 48 h registration of immission level ($L_5 = \triangle$; $L_{eq} = \bullet$; $L_{95} = \bigcirc$) per 5 min at location A; turbines are considered the dominant sound source if $L_5 - L_{95} \leqslant 4$ dB.

Table 4
Total measurement time in hours and selected time with dominant wind turbine sound

Location	Total time	Night 23:00–6:00	Evening 19:00–23:00	Day 6:00–19:00
A: Total	371	105	75	191
A: Selected	92	76	9	7
	25%	72%	12%	4%
B: Total	1064	312	183	569
B: Selected	136	119	13	4
	13%	38%	7%	0.7%

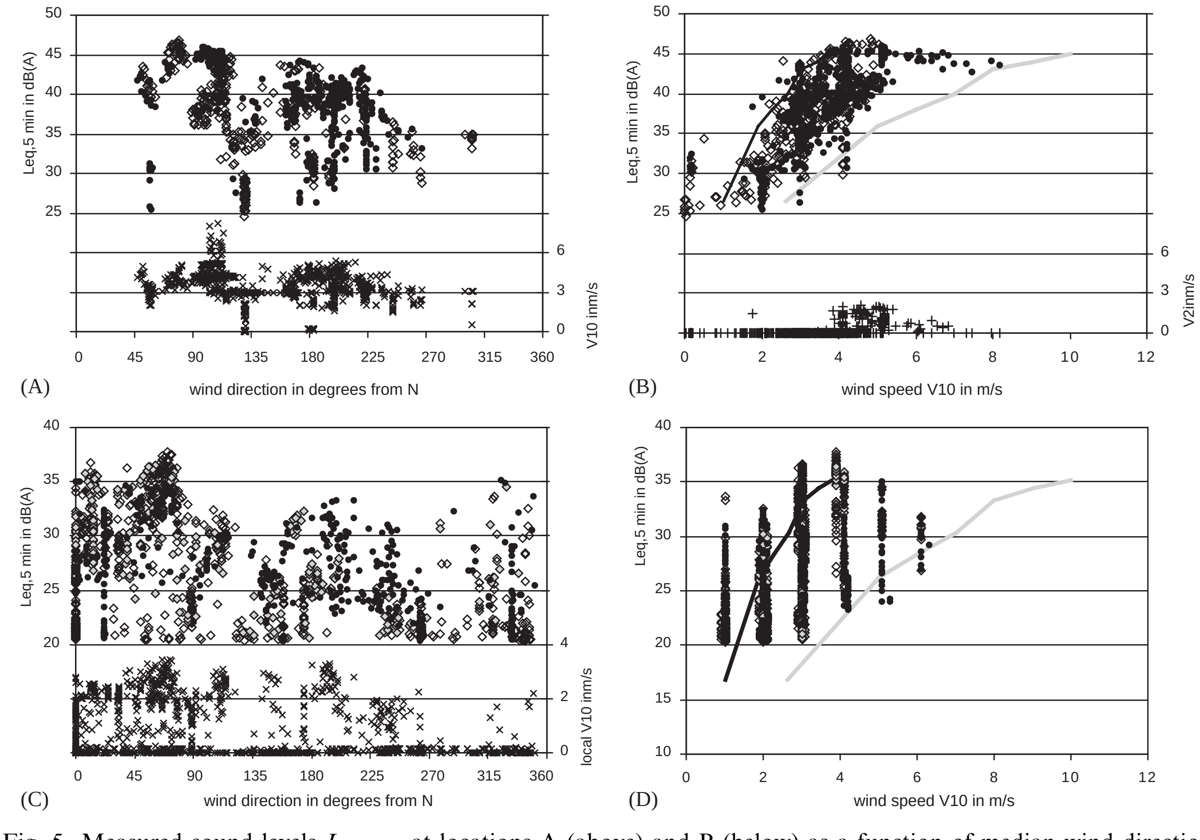

Fig. 5. Measured sound levels $L_{eq,5\,\mathrm{min}}$ at locations A (above) and B (below) as a function of median wind direction (left) and average wind speed (right) at reference height (10 m), separated in classes where the atmosphere at Eelde was observed as stable (◇) or neutral (●). Also plotted are expected sound levels according to logarithmic wind profile and wind speed at reference height (grey lines in B and D), and at a 2.6 higher wind speed (black lines in B and D). Figures A, B and C also contain the wind speed v_{10} (A), v_2 (B), and the local v_{10} (C) disturbed by trees, respectively.

observations of wind speed and cloud cover at Eelde. Eelde is the nearest KNMI site for these observations, but it is 40 km to the west, so not all observations will be valid for the area of the study.

In Fig. 5B a grey line is plotted connecting calculated sound levels with sound power levels according to Table 2 (the lowest value at 2.5 m/s is extrapolated [12]), implicitly assuming a fixed logarithmic wind profile according to Eq. (2). If this line is compressed in the direction of the abscissa with a factor 2.6, the result is a (black) line coinciding with the highest 1 h values ($L_{eq,1\,h}$) at each wind speed. Apparently, at these immission levels, the wind speed is 2.6 times higher than expected. In Fig. 6 this is given in more detail: all 5 min measurement periods that satisfied the L_5–L_{95}-criterion, with at least 4 periods per hour, were taken together in consecutive hourly periods and the resulting $L_{eq,T}$ ($T = 20$–60 min) was calculated. These 83 L_{eq}-values are plotted against the average wind speed v_{10} over the same time T. Also plotted in Fig. 6 are: the expected immission levels calculated from (1), implicitly assuming a logarithmic wind profile according to (2), so $f_{log} = 1.4$; the immission levels assuming a stable wind profile (4) with $m = 0.41$, so $f_{stable} = 2.5 = 1.8 \cdot f_{log}$; the maximum immission levels assuming $f_{max} = 3.7 = 2.6 \cdot f_{log}$, in agreement with a wind profile (4) with $m = 0.57$. The best fit of all data points ($L_{eq,T}$) in Fig. 6 with $1 < v_{10} < 5.5$ m/s is $L_{eq,T} = 32 \cdot \log(v_{10}) + 22$ dB (correlation coefficient 0.80); this fit agrees within 0.5 dB with the expected level according to the stable wind profile. The best fit of all 5 min data-points in Fig. 5B yields the same result.

Thus on location A the highest one hour averaged wind speeds at night are 2.6 times the expected values according to the logarithmic wind profile in Eq. (2). As a consequence, sound levels at (during night-time) frequently occurring wind speeds of 3 and 4 m/s are up to 15 dB higher than expected, 15 dB being the vertical distance between the expected and highest 1-h immission levels at 3–4 m/s (upper and lower lines in Figs. 5B and 6).

The same lines as in 5B, but valid for location B, are plotted in Fig. 5D; immission levels here exceed the calculated levels, even if calculated on the basis of a 2.6 higher wind speed at hub height. This is the result of shortcomings of the calculation model for long distances, at least for

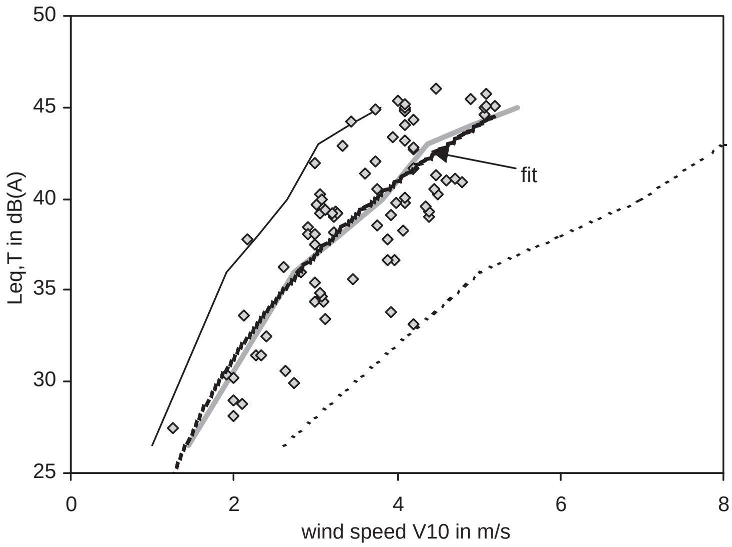

Fig. 6. Measured sound levels $L_{eq,T}$ ($T = 20$–60 min) at location A with best fit; and expected sound levels according to a logarithmic wind profile ($v_{98}/v_{10} = f_{log} = 1.4$; dotted line), a stable wind profile ($v_{98}/v_{10} = 1.8 \cdot f_{log}$; thick grey line) and maximum wind speed ratio ($v_{98}/v_{10} = 2.6 \cdot f_{log}$; thin line).

night-time conditions: from the long-term measurements at location B and short term (one night) at other locations ([12], not reproduced here) it follows that sound immission levels calculated according to the standard model used in the Netherlands [1], underestimate measured levels at night with ca. 1 dB at distances of 550–1000 m increasing to about 3 dB at distances up to 1900 m.

As is clear from the wind speed at 2 m height plotted in Fig. 5B, there is only a very light wind near the ground even when the turbines rotate at high power. This implies that in a quiet area with low vegetation the ambient sound level may be very low. The contrast between the turbine sound and the ambient sound is therefore higher at night than during the daytime.

Although at most times the wind turbine sound dominates the sound levels in Fig. 5, it is possible that at low sound levels, i.e., at low rotational speeds and low wind speeds, the L_5–L_{95}-criterion is met while the sound level is not entirely determined by the wind turbines. This is certainly the case at levels close to 20 dB(A), the sound level meter noise floor.

The long-term night-time ambient background level, expressed as the 95-percentile (L_{95}) of all measured night-time sound levels on location B, was 23 dB(A) at 3 m/s (v_{10}) and increasing with 3.3 dB/(m s^{-1}) up to $v_{10} = 8$ m/s [12]. Comparing this predominantly non-turbine background level with the sound levels in Figs. 5B and D, it is clear that the lowest sound levels may not be determined by the wind turbines, but by other ambient sounds (and instrument noise). This wind speed dependent, non-turbine background sound level L_{95} is, however, insignificant with respect to the highest measured levels. Thus, the high sound levels do not include a significant amount of ambient sound not coming from the wind turbines. This has also been verified on a number of evenings and nights by personal observation.

8. Comparison of emission and immission sound levels

From the 30 measurements of the equivalent sound level $L_{eq,T}$ (with T typically 5 min) measured at distance R from the turbine hub (R typically $100\sqrt{2}$ m), a relation between sound power level L_W and rotational speed N of a turbine could be determined: see Eq. (6).

This relation can be compared with the measured immission sound level $L_{i,T}$ ($T = 5$ min) at location A, 400 m from the wind park (closest turbine), in 22 cases where the rotational speed was known. These measurements were taken at different times to the emission measurements. The best logarithmic fit for the data points of the immission sound level L_{imm} as a function of rotational speed N is

$$L_{imm} = 57.6 \log(N) - 30.6 \text{ dB(A)} \tag{7}$$

with a correlation coefficient of 0.92 and a standard deviation of 1.5 dB. Both relations from Eqs. (6) and (7) and the data points are given in Fig. 7. The difference between both relations is $L_W - L_{imm} = 9.5 \log(N) + 46.0$ dB. For the range 14–20 r.p.m., where both series have data points, the average difference is 57.9 dB, the maximum deviation from this average is 0.8 dB (14 r.p.m.: 57.1 dB(A); 20 r.p.m.: 58.6 dB(A); see lower part of Fig. 7). It can be shown by calculation that about half of this deviation can be explained by the variation of sound power spectrum with increasing speed N.

The sound immission level can be calculated using Eq. (1). For location A, assuming all turbines have the same sound power L_W, this leads to $L_W - L_{imm} = 58.0$ dB. This is independent

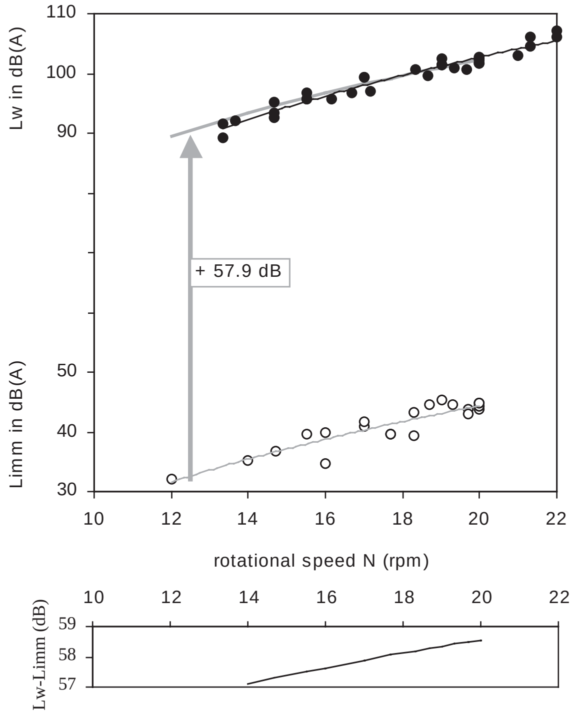

Fig. 7. Turbine sound power levels L_W measured near wind turbines (●) and immission levels L_{imm} measured at 400 m from wind park (○): averages differ 57.9 dB; (below) increase of difference L_W–L_{imm} with rotational speed.

of sound power level or rotational speed, as it is calculated with a constant spectrum averaged over several turbine conditions, i.e., speeds. The measured difference (57.9 dB) matches very closely the calculated difference (58.0 dB).

The variation in sound immission level at a specific wind speed v_{10} in Figs. 5B and D is thus seen to correspond to a variation in rotational speed N, which in turn is related to a variation in wind speed at hub height, not to a variation in v_{10}. At location A, N can be calculated from the measured immission level with the help of Eq. (7) or its inverse form $N = 3.4 \times 10^{L_{imm}/57.6}$.

9. Effect of atmospheric stability

In Fig. 5 measurement data have been separated into two sets according to atmospheric stability in Pasquill classes, supplied by KNMI from their measurement site Eelde, 40 km to the west of our measurement site. Although the degree of stability will not always be the same for Eelde and our measurement location, the locations will correlate to a high degree in view of the relatively small distance between them. For night-time conditions 'stable' refers to Pasquill classes E and F (lightly to very stable) and corresponds to $V_{10} \leqslant 5$ m/s and cloud coverage $C \leqslant 50\%$ or $V_{10} \leqslant 3.5$ m/s and $C \leqslant 75\%$, 'neutral' (class D) corresponding to all other situations. Although from Fig. 5 it is clear that the very highest sound levels at an easterly wind ($\approx 80°$) do indeed occur in stable conditions, it is also clear that in neutral conditions too the sound level is higher than expected for most of the time, the expected values corresponding to the grey lines in Figs. 5B and D, derived from daytime conditions. According to this study the sound production, and thus wind speed, at 100 m height is often higher than expected at night, in a stable, but also in a neutral atmosphere. On the other hand, even in stable conditions sound levels may be lower than expected (i.e., below the grey lines), although this rarely occurs. It may be concluded from these measurements that a logarithmic wind profile based only on surface roughness does not apply to the night-time atmosphere in our measurements, not in a stable atmosphere and not always in a neutral atmosphere.

10. Impulsive sound

At night the sound from the wind park contains repetitive pulses, unlike the sound in daytime. According to the long-term auditory observation of residents this pulse-like character or 'thumping', is more pronounced and more annoying at high turbine rotational speed. Fig. 8 shows a recording of the sound pressure level every 50 ms over a 180 s period, taken from a DAT-recording on a summer night (June 3, 0:40 h) on a terrace of a dwelling at 750 m west of the westernmost row of wind turbines (this sound includes the reflection on the façade at 2 m). There is a slow variation of the 'base line' (minimum levels) probably caused by variations in wind speed and atmospheric sound transmission. There is furthermore a variation in dynamic range: a small difference between subsequent maximum and minimum levels of less than 2 dB is alternated by larger differences. In the lower part of Fig. 8 part of the sequence is amplified and shows at first a somewhat irregular pattern of dynamic range 1–1.5 dB leading to a more regular pattern of a pulse every second with a pulse height of 3–4 or 5–6 dB. This pattern is compatible with a complex of three pulse trains with pulse height of about. 1 dB and slightly different repetition frequencies

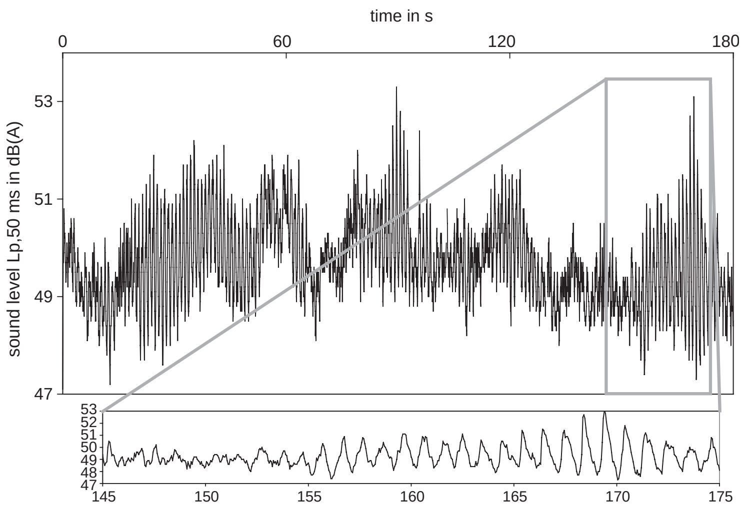

Fig. 8. Sound pressure level caused by wind turbines per 50 ms near dwelling at 750 m from nearest turbine (including reflection at façade at 2 m) over a 3 min period; part of the sequence is amplified below.

of about 1 Hz. When the pulses are out of phase (around 150 s in Fig. 8), there are only 1 dB variations. When 2 of them are in phase (around 160 s) pulse height is doubled (+3 dB), and tripled (+5 dB, 170 s) when all three are in phase. The rotational speed of the turbines at the time was 20 r.p.m., so the repetition rate of blades passing a mast was 1 Hz.

The low number of pulse trains, compared to 17 turbines, is compatible with the fact that only a few turbines dominate the sound immission at this location. The calculated immission level is predominantly caused by two wind turbines (numbers 11 and 12: see Fig. 1, contributing 35% of the A-weighted sound energy), less by two others (9 and 14; 21%), so only 4 turbines contribute more than half of the sound immission energy.

A pulse-like character was not expected; e.g., in a recent Dutch report [14] it was stated that wind turbines do not produce impulsive noise. However, when measurements are made at a single turbine, as is usual, no pulses will be audible according to the explanation given above.

11. Annoyance

The immission sound level at location A is for most of the time (at least 72% of night-time hours) higher than expected. At the most frequent night-time wind speeds (v_{10}) of 3 and 4 m/s the sound level is up to 15 dB more than expected. Also at location B, at a considerable distance (1500 m) from the wind park, the immission level is for a considerable amount of time (at least 38% of night-time hours) higher than expected. At location B and at wind speeds of 2–4 m/s the actual sound level is up to 18 dB higher than expected, of which 3 dB are due to limitations of the calculation model, and 15 dB to the underestimate of wind speed at hub height. With these higher sound levels and the impulsive character of the sound more annoyance than predicted is to be expected.

Pedersen et al. [15] have investigated the annoyance around wind turbines in the south of Sweden. Their paper gives preliminary results, and definitive results have yet to published [personal communication Pedersen]. They found highly annoyed residents at (calculated) sound levels as low as 32.5–35 dB(A). This study shows that tall wind turbines may in fact be up to 18 dB noisier than the calculated values suggest. A further increase in annoyance may be expected because of the pulse-like character of the wind turbine noise, especially at high rotational speeds.

12. Conclusions

Sound immission measurements have been made at 400 m (location A) and 1500 m (location B) from the wind park Rhede with 17 tall (98 m hub height), variable speed wind turbines. It is usual in wind turbine noise assessment to calculate immission sound levels assuming wind speeds based on wind speeds v_{10} at reference height (10 m) and a logarithmic wind profile. This study shows that the sound immission level may, at the same wind speed v_{10} at 10 m height, be significantly higher (up to 18 dB) during night-time than in the daytime. Another, 'stable' wind profile predicts a wind speed v_h at hub height 1.8 times higher than expected and agrees excellently with the average measured night-time sound immission levels. Wind speed at hub height may still be higher; at low wind speeds v_{10} up to 4 m/s, the wind speed v_h is at night is up to 2.6 times higher than expected.

Thus, the logarithmic wind profile, depending only on surface roughness and not on atmospheric stability, is not a good predictor for wind profiles at night. Especially for tall wind turbines, estimates of the wind regime at hub height based on the wind speed distribution at 10 m, will lead to an underestimate of the immission sound level at night: at low wind speeds ($v_{10} \leqslant 4$ m/s) the actual sound level will be higher than expected for a significant proportion of time. This is not only the case for a stable atmosphere, but also, to a lesser degree, for a neutral atmosphere.

The change in wind profile at night also results in lower ambient background levels then expected: at night the wind speed near the ground may be lower than expected from the speed at 10 m and a logarithmic wind profile, resulting in low levels of wind induced sound from vegetation. The contrast between wind turbine and ambient sound levels is therefore more pronounced at night.

Measured sound immission levels at 400 m from the nearest wind turbine almost perfectly match (average difference: 0.1 dB) sound levels calculated from measured emission levels near the turbines. From this it may be concluded that both the emission and immission levels could be determined accurately, even though the emission measurements were not quite in agreement with the recommended method. As both levels can be related through a propagation model, it may not be necessary to measure both; the immission measurements can be used to assess immission as well as emission sound levels.

There is, however, a growing discrepancy with distance; at distances of 1–2 km the calculated level may underestimate the measured level by 3 dB. This is most probably a consequence of the fact that the actual (night-time) atmospheric sound transmission is not adequately modelled in the sound transmission model.

At night the turbines cause a low pitched thumping sound superimposed on a broadband ‘noisy’ sound, the ‘thumps’ occurring at the rate at which blades pass a turbine tower. It appears that the characteristic, but usually small ‘swishing’ pulses that can be heard at the rate at which blades pass a turbine tower, coincide because turbines operate nearly synchronously. Two coinciding pulse trains thus give a 3 dB higher pulse level, three a 5 dB higher pulse level. The measured pulse levels and frequencies agree with values expected from nearly synchronous pulse trains generated by a small number of wind turbines.

The number and severity of noise complaints near the wind park are at least in part explained by the two main findings of this study; actual sound levels are considerably higher than predicted, and wind turbines can produce sound with an impulsive character.

The relatively high wind speeds at turbine hub height at night also have a distinct advantage; the electric power output is higher than predicted and benefits the operator of the wind turbine.

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Exhibit I

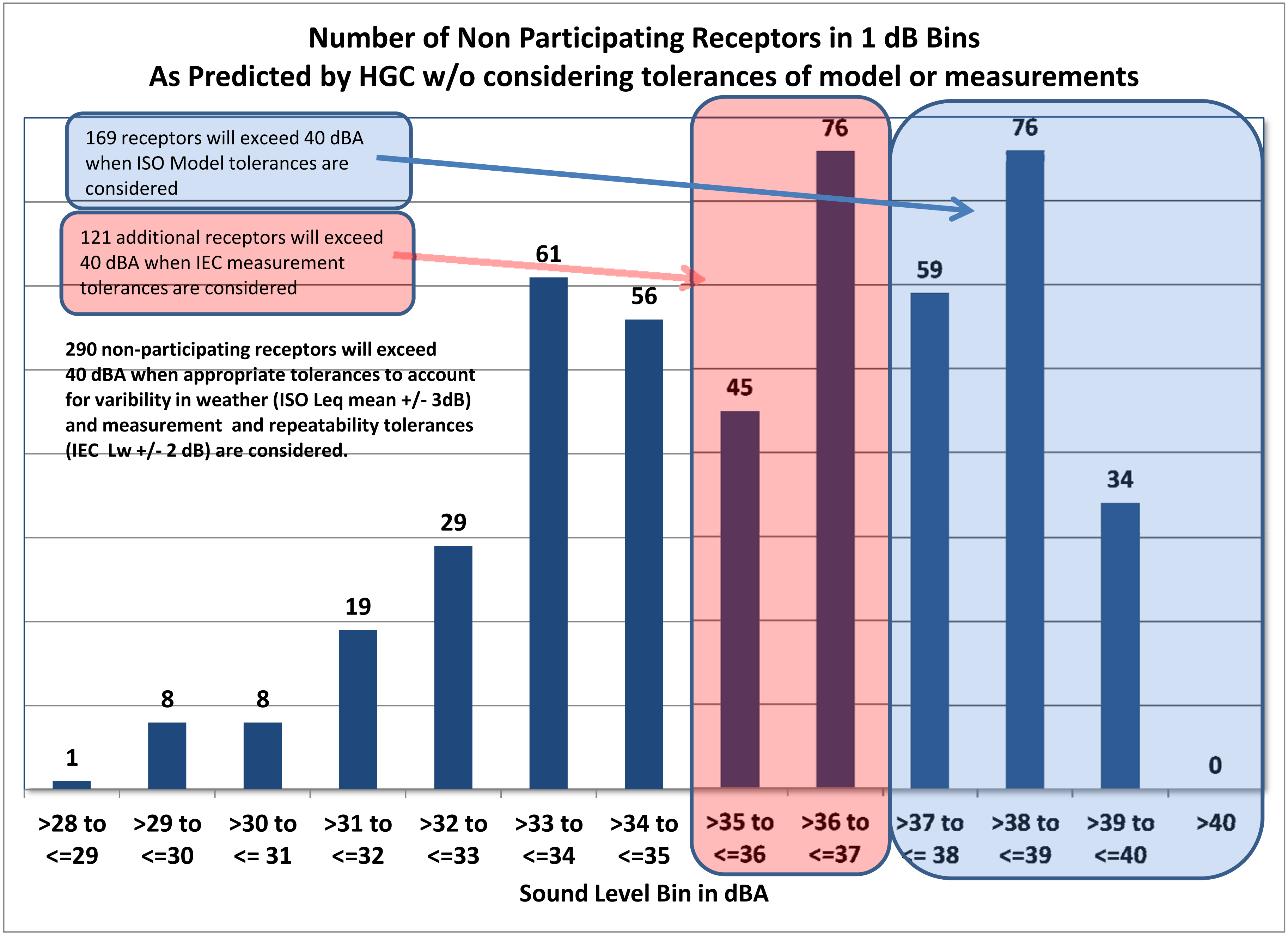
Number of Non Participating Receptors in 1 dB Bins
As Predicted by HGC w/o considering tolerances of model or measurements
169 receptors will exceed 40 dBA when ISO Model tolerances are considered
121 additional receptors will exceed 40 dBA when IEC measurement tolerances are considered
290 non-participating receptors will exceed 40 dBA when appropriate tolerances to account for varibility in weather (ISO Leq mean +/- 3dB) and measurement and repeatability tolerances (IEC Lw +/- 2 dB) are considered.
1
8
8
19
29
61
56
45
76
59
76
34
0
>28 to <=29
>29 to <=30
>30 to <= 31
>31 to <=32
>32 to <=33
>33 to <=34
>34 to <=35
>35 to <=36
>36 to <=37
>37 to <= 38
>38 to <=39
>39 to <=40
>40
Sound Level Bin in dBA

Exhibit H

The World Health Organization is one of the bodies which recognizes the special place of low frequency noise as an environmental problem. Its publications on Community Noise (Berglund et al., 1995 and 1999) makes a number of references to low frequency noise, some of which are as follows:

- *"It should be noted that low frequency noise, for example, can disturb rest and sleep even at low sound pressure levels" (1999)*
- *It should be noted that a large proportion of low frequency components in the noise may increase annoyance considerably.(1995)*
- *Where prominent low-frequency components are present, they should be assessed with appropriate octave or 1/3rd octave instruments. (1995)*
- *However, the difference between dBlin (or dBC) and dBA will give crude information about the contribution of low frequency sounds. If the difference is more than 20 dB, it is recommended to perform a frequency analysis of the noise. It should be noted that a large proportion of low frequency components in the noise may increase considerably the adverse effect. (1995)*
- *Health effects due to low-frequency components in noise are estimated to be more severe than for community noises in general (Berglund et al. 1996).*
- *"It is not enough to characterize the noise environment in terms of noise measures or indices based only on energy summation (e.g. LAeq), because different critical health effects require different descriptions. Therefore, it is important to display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. A separate characterization of noise exposures during night-time would be required. ….. If the noise includes a large proportion of low frequency components, still lower guideline values should be applied. (1999)*
- *The difference between dB(C) and dB(A) will give crude information about the presence of low-frequency components in noise, but if the difference is more than 10 dB, it is recommended that a frequency analysis of the noise be performed.(1999)*
- *Where noise is continuous, the equivalent sound pressure level should not exceed 30 dBA indoors, if negative effects on sleep are to be avoided. When the noise is composed of a large proportion of low-frequency sounds a still lower guideline value is recommended, because low frequency noise (e.g. from ventilation systems) can disturb rest and sleep even at low sound pressure levels(1999)*
- *Where prominent low frequency components are present, noise measures based on A-weighting are inappropriate" (1999)*
- *"Since A-weighting underestimates the sound pressure level of noise with low frequency components, a better assessment of health effects would be to use C-weighting"(1999)*
- *"It should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health"(1999)*

"***The evidence on low frequency noise is sufficiently strong to warrant immediate concern."***

(WHO 1999)