BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION OF
CROWNED RIDGE, LLC FOR A FACILITIES PERMIT TO
CONSTRUCTION 300 MEGAWATT WIND FACILITY

Docket No. EL19-003

REBUTTAL TESTIMONY AND EXHIBITS

OF CHRIS OLLSON

May 24, 2019

INTRODUCTION

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Chris Ollson. My business address is 37 Hepworth Crescent, Ancaster, Ontario, Canada.

Q. **BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?**

A. I am the sole proprietor of Ollson Environmental Health Management. This consultancy provides expertise on environmental health challenges related to siting of energy projects (e.g., oil and gas, pipelines, gas plants, wind turbines, solar, transmission lines, and energy-from-waste). Clients include a mix of private sector companies and governments at all levels.

Q. **WHAT ARE YOUR RESPONSIBILITIES?**

A. I am a consultant to Crowned Ridge Wind, LLC ("CRW") on the scientific literature related to sound and shadow/flicker and proper siting of wind turbines to ensure the protection of health of residents.

Q. **ARE YOU THE SAME CHRIS OLLSON WHO SUBMITTED SUPPLEMENTAL TESTIMONY ON APRIL 10, 2019?**

A. Yes.

Q. HAS THIS TESTIMONY BEEN PREPARED BY YOU OR UNDER YOUR DIRECT SUPERVISION?

A. Yes.

Q. PLEASE DESCRIBE THE PURPOSE OF YOUR REBUTTAL TESTIMONY.

A. The purpose of my testimony is to respond to the direct testimony of Staff witness David Hessler and Intervenors' proposed conditions as set forth in Staff witness Darren Kearney's Direct Testimony, Exhibit DK-8.

<u>Staff Witness Hessler's Testimony</u>

Q. STAFF WITNESS HESSLER (TESTIMONY AT PAGE 5, LINES 4-7) ASSERTS THAT ANYTIME WIND TURBINES SOUND LEVELS ARE HIGHER THAN 40 DBA, RESIDENTS WILL COMPLAIN, AND THE SEVERITY OF THE COMPLAINTS WILL INCREASE EXPONENTIALLY AS THE SOUND LEVEL APPROACHES 50 DBA. ALSO, INTERVENORS HAVE PROPOSED CONDITIONS 19, 20, 21 (KEARNEY EXHIBIT DK-8) THAT WOULD LIMIT SOUND AT 40 DBA AT THE PROPERTY LINE OF A NON-PARTICIPATING PROPERTY OWNER. DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT A 40 DBA SOUND LIMIT FOR NON-PARTICIPANTS?

A. No. The scientific literature published over the past decade from Europe and Canada showS that as wind turbine sound levels of sound increase over 40 dBA that there may be an increase in annoyance (not complaints) for some living around wind turbines. The level of annoyance certainly is higher for those non-participating homes at greater than 45 dBA.

To elaborate, noise-related annoyance from common sound sources is prevalent in many communities. For instance, results of national surveys in Canada and the U.K. by Michaud et al. (2005) and Grimwood et al. (2002) attached as Exhibit CO-R-1 and -2, respectively, suggested that annoyance from noise (predominantly traffic noise) might impact approximately 8% of the general population. Even in small communities in Canada (i.e., <5000 residents) where traffic is relatively light compared to traffic in urban centers, Michaud et al. (2005) reported that 11% of respondents were moderately to extremely annoyed by traffic noise. Importantly, annoyance is not a medical condition. It is not a recognized medical disease and it is not classified in the World Health Organization's International Statistical Classification of Disease and Related Health Problems 11th revision – ICD 11.

There have been a number of studies that have found that annoyance levels specific to wind turbine noise vary considerably upon whether one economically benefits. For example, Tables 3 and 4 from Bakker et al., 2012 (provided in my Supplemental Testimony as Exhibit CO-3) clearly indicate that the percentage of people that were rather/very annoyed of outdoor wind turbine noise (up to 54 dBA) that did not economically benefit was 12%, while it was only 3% for those who did economically benefit. In addition, no one who economically benefited from the wind project was rather/very annoyed with resulting indoor noise levels. This study, therefore, further supports that it is not the wind turbine noise itself that drives the annoyance state; rather, subjective factors such as visual cues and attitude are important.

Annoyance Levels in the Bakker et al., 2012 Study.

Table 3
Response to outdoor wind turbine sound among economically benefitting and non-benefitting respondents.

	Response											
	Do not notice		Notice, nor annoyed		Slightly annoyed		Rather annoyed		Very annoyed		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
No economical benefit	255	44	184	31	78	13	41	7	28	5	586	100
Economical benefit	15	15	68	69	13	13	2	2	1	1	99	100

Table 4
Response to indoor wind turbine sound among economically benefitting and non-benefitting respondents.

	Response											
	Do not notice		Notice, not annoyed		Slightly annoyed		Rather annoyed		Very annoyed		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
No economical benefit	394	68	98	17	46	8	21	4	20	4	579	100
Economical benefit	53	54	39	39	7	7	0	0	0	0	99	100

Furthermore, Michaud et al. (2018) (Exhibit CO-R-3) go on to state "Aggregate annoyance was effectively 0 (i.e., least squares mean − 0.11) among the 110 participants who reported to receive personal benefit from having wind turbines in the area, compared to an average of 1.93 among those who did not report such benefits." It is for these reasons I believe it is appropriate to set a 50 dBA limit for participating homes, because statistically landowners who economically benefit do not report annoyance from the wind turbines at levels over 50 dBA.

Further, a Canadian study (CO-Exhibit 11 in my Supplemental Testimony) concluded that:

> The results provide no evidence that self-reported or objectively measured stress reactions are significantly influenced by exposure to increasing levels of WTN up to 46 dB. There is an added level of confidence in the findings as this is the first study to date to investigate the potential stress impacts associated with WTN exposure using a combination of self-reported and objectively measured endpoints.

Therefore, at sound levels of 46 dBA wind turbine noise annoyance should not be considered a health impact and the level of annoyance falls within levels that we accept in our daily lives. Accordingly, Staff witness Hessler and the Intervenors advancement of a 40 dBA design standard is not supported by the weight of scientific evidence, because, regardless of the sound level being low in the Project area, it will result in some potential increase in annoyance in local populations. However, the annoyance level would be considered acceptable given:

- the annoyance level is similar to that of other forms of noise sources and approximately (e.g., road, rail, airplane);
- it is being influenced by other factors, including attitudes and visual cues with respect to the turbines themselves, and that it is not the noise itself that is driving this annoyance; and,
- that in the largest of its kind study by Health Canada (supported by past research) living with wind turbine noise <46 dBA was not associated with self-reported or physical measures of health or well-being.

Thus, the scientific literature does not support Intervenors' proposed conditions imposing a 40 dBA sound limit for non-participants nor Staff witness Hessler's position that the project should be viewed from the perspective of whether it is meeting 40 dBA for non-participants.

Q. EVEN IF WIND TURBINE ANNOYANCE DOES NOT LEAD TO HEALTH EFFECTS AT 45 dBA CAN IT ADVERSELY AFFECT QUALITY OF LIFE FOR THOSE LIVING NEAR WIND TURBINES?

A. The science shows that noise at 45 dBA poses no impact to quality of life. Determining if annoyance or any other perceived health effects for those living around wind projects has also been examined by determining if there has been a diminishment in their overall quality of life ("QOL"). This relates directly to whether annoyance leads to a deterioration of QOL.

Feder et al. (2015) conducted an assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines Journal of Environmental Research. (Health Canada) (Exhibit CO-R-4), a World Health Organization Quality of Life – BREF (WHOQOL-BREF) administered a questionnaire to 1238 participants that lived between 820 feet to 7 miles away from wind turbines. This questionnaire evaluates self-reported physical health, psychological, social relationships, and environment in relation to QOL. Regardless of sound level at people's homes wind turbine noise did not influence QOL. The authors stated:

> The present study findings do not support an association between exposure to WTN up to 46 dBA [820 ft] and any of the WHOQOL-BREF domains (Physical Health, Psychological, Social Relationships and Environment) or the two stand-alone questions pertaining to rated QOL and Satisfaction with Health. Participants who were exposed to higher WTN levels did not rate their QOL or Satisfaction with Health significantly worse than those who were exposed to lower WTN levels, nor did they report having significantly worse outcomes in terms of factors that comprise the 4 domains.

Overall, the recent work by Health Canada suggests that quality of life should not be diminished for non-participating residents around the CRW project.

Q. STAFF WITNESS HESSLER'S TESTIMONY AT PAGE 5 LINES 17 TO PAGE 6 LINE 5 CLAIMS THAT CRW SHOULD MOVE 16 PRIMARY TURBINE LOCATIONS TO ALTERNATIVE LOCATIONS TO REDUCE THE DBA FOR NON-PARTICIPANTS FROM A RANGE OF 43-45 DBA TO 41 OR 42 DBA.

DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT THE NEED TO REDUCE THE DBA AS HE PROPOSES?

A. There is no evidence in the scientific literature that a minor shift in noise levels from wind turbines from 43-45 to 41-42 dBA would change annoyance levels or complaint numbers. Such fine-tuning has not been reported in any of the literature. Knowing that the human ear can barely perceive a change in sound at 3 dBA it is unlikely that such a change would even be perceptible.

Most importantly, as stated above the bulk of the peer-reviewed scientific literature has demonstrated that the sound level itself does not contributing to the annoyance (or potentially complaints), rather it is visual cue and attitude that play a larger role. Therefore, such an arbitrary minor modification to sound levels is not supported by the scientific literature.

Intervenors' Proposed Conditions

Q. THE INTERVENORS' PROPOSED CONDITION 1 (KEARNEY EXHIBIT DK-8) WOULD REQUIRE THAT THERE BE A 2 MILE SETBACK FROM ALL NON-PARTICIPATING LANDOWNERS. IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. As previously described in my Supplemental Testimony the appropriate manner in which wind turbine setbacks should governed is by sound limits at the exterior of the homes. To achieve the 45 dBA limit at non-participating homes it effectively requires a minimum setback distance of approximately 2000 feet. There is no peer reviewed scientific literature that supports the need for a 2 mile set back.

Q. THE INTERVENORS' PROPOSED CONDITION 2 (KEARNEY EXHIBIT DK-8) REQUIRES THAT THERE BE A 2 MILE SETBACK FROM THE WAVERLY SCHOOL TO PROTECT CHILDREN FROM DISTURBANCES FROM THE PROJECT WHILE IN THEIR LEARNING ENVIRONMENT. IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. In 2008, Shield & Dockrell (Exhibit CO-R-5) published a paper in the Journal of the Acoustical Society of America (The effects of environmental and classroom noise on the academic attainments of primary school children.) In this paper, they describe the typical level of noise a child would experience in a primary school classroom:

> For much of the day in a primary school classroom, young children are exposed to the noise of other children producing "classroom babble" at levels typically of around 65 dBA LAeq, while the typical overall exposure level of a child at primary school has been estimated at around 72 dBA LAeq.

The modeled sound level at Waverly School was 39 dBA and the closest turbine is 6,207 feet away. At this setback distance, the sound level at the exterior of the school would be well below typical sound levels already experienced in the classroom. Given that the average sound level in a primary classroom (without external noise) is 65 dBA, and that the modeled sound level is 39.1 dBA at the exterior of the school the resulting sound would not be audible inside the classroom, even with windows open. Accordingly, there would be no additional benefit to setting wind turbines back two miles from the school.

Q. A NUMBER OF THE INTERVENORS' PROPOSED CONDITIONS (KEARNEY EXHIBIT DK-8) REQUIRE THE MEASUREMENT AND MONITORING OF INFRASOUND. ARE THESE CONDITIONS SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?

A. No. As previously described in my Supplemental Testimony, although infrasound is emitted from wind turbines it is at a level well below the perception threshold and the limited number of international general standards for infrasound (not specific to wind turbines). Although infrasound is not modeled for wind turbine projects the level of infrasound at varying distances from wind turbines can be predicted based on previous measurements in the scientific literature. These levels have been demonstrated to be well below any international infrasound standards at even 1000 feet from wind turbines. As stated by the Ministry for the Environment, Climate and Energy of the Federal State of Bade Wuerttemberg in Germany (Exhibit CO-R-6) "adverse effects relating to infrasound from wind turbines cannot be expected on the basis of the evidence at hand." Therefore, there would be no need to measure or monitor infrasound levels from the Crowned Ridge Wind project to ensure the protection of health.

Q. A NUMBER OF THE INTERVENORS' CONDITIONS (KEARNEY EXHIBIT DK-8) ARE PREMISED ON PEOPLE COMPLAINING ABOUT PHYSICAL CONDITIONS OR HEALTH ISSUES THEY BELIEVE ARE BROUGHT ON BY THE CRW WIND PROJECT. DOES THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS SUPPORT IMPOSING

CONDITIONS BECAUSE PEOPLE MAY ATTRIBUTE A PHYSICAL OR HEALTH ISSUE TO THE CRW WIND PROJECT?

A. As stated in my Supplemental Testimony an exterior sound limit of 45 dBA at non-participating homes is sufficient to ensure the protection of health of the residents. The scientific studies, including those published by Health Canada (the Michaud papers) indicate that both objective and subjective measures of health are not impacted by wind turbine sound at 45 dBA at the exterior of non-participating homes.

In addition, the phenomenon of complaints associated with those who previously opposed wind projects has been studied in Australia. In 2013, Chapman et al., published (Exhibit CO-R-7; <u>The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, 'Communicated Disease' Hypothesis</u>.) This paper demonstrated that the majority of wind projects generated no complaints from surrounding landowners. However, they reported:

> The large majority 116/129(90%) of complainants made their first complaint after 2009 when anti wind farm groups began to add health concerns to their wider opposition. In the preceding years, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

Professor Chapman and his colleagues concluded:

> The reported historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are "communicated diseases" with nocebo effects likely to play an important role in the aetiology of complaints.

In other words, those who opposed the wind farms prior to their construction and were concerned about health impacts are far more likely to file complaints and mistakenly attribute symptoms to the operation of the wind project.

Q. **THE INTERVENORS' PROPOSED CONDITION 19 (KEARNEY EXHIBIT DK-8) WOULD REQUIRETHAT "NO FLICKER SHALL BE ALLOWED TO CROSS NON-PARTICIPATING LANDOWNER'S PROPERTY LINE." IS SUCH A CONDITION SUPPORTED BY THE SCIENTIFIC PEER REVIEWED LITERATURE OR GOVERNMENT REPORTS?**

A. No. As previously described in my Supplemental Testimony shadow flicker does not impact health. Shadow flicker limits at homes have been developed to reduce any undue nuisance effect for residents. Shadows cast by wind turbines on open spaces or fields does not result in a "flicker effect", similar to that which can be experienced in enclosed rooms in a home. Instead it can be observed as an intermittent shadow on the ground (e.g., in a field) that does not cause annoyance. There have been no scientific reports that such shadows produce an annoyance for neighboring properties.

Q. DOES THIS CONCLUDE YOUR REBUTTAL TESTIMONY?

A. Yes, it does.

Noise Annoyance in Canada

D.S. Michaud[1], S.E. Keith[1] and D. McMurchy[2]

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The present paper provides the results from two nation-wide telephone surveys conducted in Canada on a representative sample of 5,232 individuals, 15 years of age and older. The goals of this study were to gauge Canadians' annoyance towards environmental noise, identify the source of noise that is viewed as most annoying and quantify annoyance toward this principal noise source according to internationally accepted specifications. The first survey revealed that nearly 8% of Canadians in this age group were either very or extremely bothered, disturbed or annoyed by noise in general and traffic noise was identified as being the most annoying source. A follow-up survey was conducted to further assess Canadians' annoyance towards traffic noise using both a five-item verbal scale and a ten-point numerical scale. It was shown that 6.7% of respondents indicated they were either very or extremely annoyed by traffic noise on the verbal scale. On the numerical scale, where 10 was equivalent to "extremely annoyed" and 0 was equivalent to "not at all annoyed", 5.0% and 9.1% of respondents rated traffic noise as 8 and above and 7 and above, respectively. The national margin of error for these findings is plus or minus 1.9 percentage points, 19 times out of 20. The results are consistent with an approximate value of 7% for the percentage of Canadians, in the age group studied, highly annoyed by road traffic noise (i.e. about 1.8 million people). We found that age, education level and community size had a statistically significant association with noise annoyance ratings in general and annoyance specifically attributed to traffic noise. The use of the International Organization for Standardization/Technical Specification (ISO/TS)-15666 questions for assessing noise annoyance makes it possible to compare our results to other national surveys that have used the same questions.
Keywords: telephone survey, annoyance, noise, traffic, Canada, ISO/TS-15666

Introduction

Noise can be defined as unwanted sound and is commonly associated with annoyance reactions. Environmental noise is ubiquitous and annoyance is one of the most widely studied adverse reactions to noise. According to the World Health Organization (WHO), health should be regarded as "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity" (World Health Organization 2001). Under this broad definition, noise-induced annoyance is an adverse health effect. As with any psychological reaction, annoyance has a wide range of individual variability, which is influenced by multiple personal and situational factors (Fields 1993, Broadbent 1972). On a community scale, however, annoyance is more uniform so that estimating community annoyance is possible through the use of established dose-response curves. The relationship between day-night sound level (Ldn) and the percentage of an exposed population highly annoyed by any transportation noise source was first given by Schultz as a single curve (Schultz 1978)[1]. The term "highly annoyed" refers to a response to a social survey question on noise annoyance with a response in the top 27 to 29% on an anchored numerical scale or in the top two categories on an adjectival, five point verbal scale (Schultz 1978). The Schultz curve has been updated

[1] *%Highly annoyed*$=0.8553Ldn - 0.0401Ldn^2 + 0.00047Ldn^3$

(Finegold and Finegold 2002)[2] (Fidell et al. 1991)[3] and separate relationships are also available for aircraft, road traffic and electric rail (Miedema and Oudshoorn 2001)[4] (ISO 2003)[5]. In the ISO standard for assessment procedures for environmental noise the percent highly annoyed is obtained from the rating level (RL) using equation:

$$\%\text{highly annoyed} = 100/[1+\exp(10.4-0.132*RL)]$$

where, RL is typically an adjusted Ldn[6], with adjustments made depending on the type of noise source. In the ISO standard, the relationship for road traffic noise is obtained when RL equals Ldn. The resulting curve nearly coincides with Schultz's original curve.

International estimates of exposure to road traffic noise have been made for Europe, Australia and the U.S. In 1996, it was estimated that, in Europe, 40% of the population was exposed to traffic sound levels between 45-65dBA (Ldn) and 20% (nearly 80 million people) were exposed to levels over 65dBA (Commission of the European Communities 1996). In Australia, approximately 8% of the population was exposed to outdoor road traffic noise levels greater than 65dBA during daytime hours (OECD 1991). In 1986, the Organization for Economic Co-operation and Development (OECD) estimated that 30% of the U.S. population was exposed to a 24 hr time-averaged (Leq24) traffic noise level between 55-65dBA and 7% was exposed to traffic levels above 65 dBA (Leq24) (OECD 1986). Eldred (1990) estimated that 138 million Americans were exposed to outdoor day-night sound levels above 55dBA, with more than 25 million U.S. citizens exposed to levels above 65dBA (Eldred 1990).

International estimates of road traffic noise annoyance from social surveys have also been made for several European countries. Estimations of road traffic noise annoyance from Austria and France (annoyed), Germany (severely affected) and the Netherlands (highly annoyed) range from 20% to 25% of the respective populations (Commission of the European Communities 1996, INRETS 1994). A recent national survey in the United Kingdom (UK) found that between 7-9% of the population was either very or extremely bothered, annoyed or disturbed by traffic noise (Department for Environment, Food and Rural Affairs 2002).

There has been a gap in our knowledge as to how Canada compares to international estimates of annoyance and noise exposure. Only by comparison to Australian data (OECD 1991) has it recently been estimated that about 2 million Canadians live in areas where road traffic noise exceeds Leq24 outdoor levels of 65 dBA (Health Canada 2001).

Comparing results from different surveys on annoyance is difficult because of differences in methodology, which include variability in reporting high annoyance (Finegold and Finegold 2002). As an attempt to circumvent this problem, the ISO/TS-15666 proposed that socio-acoustic surveys incorporate two standardized questions aimed at assessing annoyance (ISO 2001). Our objectives for the present study were to use these standardized questions in order to assess noise annoyance in Canada and characterize the source that was most annoying.

Methods

Subject sampling

The two surveys each entailed a probability

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[2] *%Highly annoyed=100/[1+exp(11.13 - 0.141Ldn)]*

[3] *%Highly annoyed= 78.9181 - 3.2645Ldn + 0.0360Ldn*^{2}

[4] *%Highly annoyed (aircraft) =* $-1.395*10^{-4}(Ldn-42)^3 + 4.081*10^{-2}(Ldn-42) + 0.342(Ldn-42)$

[5] *%Highly annoyed (road traffic) =* $9.994*10^{-4}(Ldn-42)^3 - 1.523*10^{-2}(Ldn-42)^2 + 0.538(Ldn-42)$

%Highly annoyed (rail) = $7.158*10^{-4}(Ldn-42)^3 - 7.774*10^{-3}(Ldn-42)^2 + 0.163(Ldn-42)$

%Highly annoyed= 100/[1 + exp(10.4 - 0.132Ldn)]

[6] *The number of daylight hours is 15, defined as the hours from 07:00-22:00 (ISO 2003)*

sample of approximately 2,600 Canadians 15 years and older, using the Waksberg-Mitofsky technique for random digit phone number selection. Most provinces were allocated a sample size reflecting a 5% margin of error and a 95% confidence interval; the Atlantic Provinces had smaller sample sizes and were grouped together for the purposes of analysis. For each region, the sample was then distributed among community strata according to their relative contributions to the overall provincial population. The five community strata used were as follows: i) less than 5,000; ii) 5,000-9,999; iii) 10,000-29,999; iv) 30,000-99,999; and v) 100,000-999,999. A sixth stratum was added for cities with a population over 1 million residents (Montreal, Toronto and Vancouver). Each respondent indicated the population of their community. Random digit dialing was used to generate potential telephone numbers and one subject within each household was selected using the Troldahl-Carter technique. This technique ensures that the sample accurately represents the eligible population according to its age and sex structures (Troldahl and Carter 1964). Once a potential respondent was chosen using this technique, no other person in the household could be substituted as a respondent. Upon completion of the survey, data were also weighted within provinces by age, sex and community size. Additionally, they were weighted nationally to reflect each province's relative contribution to the overall Canadian population. The national margin of error for this study is plus or minus 1.9 percentage points in 19 samples out of 20.

Telephone Survey #1

In the spring of 2002, PricewaterhouseCoopers Consulting™ performed a telephone survey for Health Canada wherein a randomized sample of 2,565 Canadians, age 15 and older, responded to a questionnaire on health, their experience with the health care system and health policy. The response rate to this survey was 33%. The questionnaire, that required 20-25 minutes to complete, contained the two following noise-related questions: *Over the past 12 months or so, when you are at home, how much are you bothered, disturbed, or annoyed by noise from outside your home?* Subjects were given the following response options: *Extremely, Very, Moderately, Slightly or Not at all.* The following open-ended question was asked to identify which source Canadians were most annoyed with: *What type of noise from outside your home bothers disturbs or annoys you the most?*

Telephone Survey #2

A follow-up telephone survey was conducted for Health Canada in December of 2002 by IBM Business Consulting Services™. This survey employed the same methodology as the first survey and the questionnaire was similar in content and length as the first and the response rate was 32%. However, the noise questions in this case specifically probed attitudes towards traffic noise, since this was the source identified as most annoying in the first survey. In accordance with the recommendations provided by ISO/TS-15666 the following two questions were asked to the randomized sample of 2,667 Canadians 15 years of age and older: *Thinking about the last 12 months or so, when you are at home, how much does noise from road traffic bother, disturb, or annoy you?* Again, subjects were asked to respond with one of the following options: *Extremely, Very, Moderately, Slightly or Not at all*. An important methodological shortcoming to the verbal scale is that the response categories do not necessarily engender the same meaning between individuals. As a way of checking this possibility the ISO/TS-15666 suggests that a second question with a numerical scale be used to validate the response obtained to the first question. Thus, in this survey the verbal question was followed by the following question: *Thinking about the last 12 months or so, what number from zero to ten best shows how much you are bothered, disturbed or annoyed by road traffic noise?* Prior to asking this question, the interviewer indicated to the respondent that *zero* is equivalent to "not at all bothered" and *ten* is equivalent to "extremely bothered".

Statistics

Univariate and bi-variate (cross-tabulations and t-tests) analyses were employed using statistical data management software, SPSS® version 11.5.

Table 1. Demographic characteristics of responses to the following question: Over the past 12 months or so, when you are at home, how much are you bothered, disturbed, or annoyed by noise from outside your home?

		Extremely (n)	Very (n)	Moderately (n)	Slightly (n)	Not at all (n)
Number of respondents (percentage of total N=2573)		108 (4.2)[7]	95 (3.7)	407 (15.8)	700 (27.3)	1257 (49.0)
Sex	male	52	30	192	364	662
	female	55	65	215	336	595
Age (years)	15-24	38	35	120	280	404
	25-44	38	38	155	234	362
	45-64	20	17	98	127	292
	65+	12	5	33	59	199
Gross salary (x1000/yr)	<20	22	24	94	153	229
	20-50	36	32	150	201	378
	>50	33	20	119	230	407
Education Level	<secondary	8	3	21	9	92
	secondary	57	25	151	335	565
	>secondary	41	67	230	355	594
Employment Status	not working	48	37	131	300	517
	working	59	59	275	399	739
Community Size (estimated by respondent)	<5,000	10	3	35	55	241
	5,000-99,999	6	8	91	125	249
	100,000+	92	84	281	520	768
Self-reported health status	poor-fair	25	11	66	118	176
	excellent-good	82	85	341	573	1080

7 Cells for each variable may not always add to the corresponding sample size because respondents could choose to not answer questions.

Results reported were statistically significant at the 0.05 level. Where multiple variables were significant and deemed relevant, logistic regression was employed to identify those factors most predictive of the various outcomes.

Results

Table 1 shows that about 8% of the sample indicated that they were either very or extremely bothered, disturbed or annoyed by noise outside their home, whereas nearly half of the respondents (49%) were not at all bothered. The major findings presented in Table 1 indicate that there was a statistically significant relationship between age, community size, education and sex with the level of annoyance. People 65 and over were the least likely to be annoyed by noise and the larger the respondent's community size, the more likely he or she was to be very or extremely disturbed by noise. Females were more likely to respond that they were slightly to extremely annoyed by noise compared to males. Finally, respondents with greater than secondary education were the least likely to respond that they were slightly or not at all annoyed by noise compared to those with a secondary or less then secondary education.

Table 2 shows the breakdown of the sources that respondents identified as being most annoying.

Table 2. The percentage of people annoyed the most by a particular type(s) of noise as a function of the extent to which they were bothered by noise in general.

Type of noise [8]	extremely (n=108)	very (n=95)	moderately (n=407)	slightly (n=700)	not at all (n=1257)
Road traffic	39.9	37.6	51.8	44.9	17.9
Animals outside	25.8	3.5	10.0	11.1	6.6
Other people outside	16.2	23.0	12.4	9.8	2.2
Off road traffic	7.0	13.2	4.2	7.6	2.5
Children outside	5.9	13.8	9.7	5.0	2.2
Trains	4.4	0.8	7.2	6.9	1.5
Neighbor's Music/TV (in/outside their home)	10.1	15.1	6.9	2.9	2.0
Construction work	7.3	11.0	3.5	4.1	2.6
Social events	6.6	9.3	5.0	5.3	0.7
People/animals from inside another dwelling	12.3	8.6	3.9	2.7	1.6
Aircraft	7.2	1.7	1.9	3.9	1.7
Snow removal	0.4	3.3	3.9	3.1	1.2
Alarms	1.9	3.9	2.3	0.6	2.7
Factories/machinery	5.6	0.2	2.5	3.4	0.8
Garden equipment	0.0	5.1	1.0	1.8	1.4
Farming machinery	8.9	0.1	0.3	0.0	0.3
Power tools	0.6	1.7	0.2	0.5	0.5
Subways	0.0	1.7	0.3	0.0	0.3
Other	7.7	17.1	5.9	5.8	12.0

[8] *Columns may not add to 100% because respondents were free to identify more than one source of noise.*

It is apparent that traffic noise is the most significant source of noise annoyance in Canada.

Results from the December survey were intended to further probe Canadians' annoyance towards traffic noise. The major findings were that, while nearly 7% of the respondents indicated that they were either very or extremely bothered by traffic noise, almost 63% were not at all bothered. Figure 1, panel A, shows the distribution of annoyance towards traffic noise. In this survey, respondents also had the opportunity to indicate how annoyed they were with traffic noise on a ten-point numerical scale, where zero represented "not at all annoyed" and ten represented "extremely annoyed". These results are presented in Figure 1, panel B. Panel C, in Figure 1 presents the results from the numerical scale collapsed according to the following breakpoints (0+1=not at all; 2+3=slightly; 4+5+6=moderately; 7+8=very and 9+10=extremely). Collapsing the numerical scale in this way yielded a correlation coefficient of 0.765 ($p<0.001$) between panel A and panel C.

Table 3 shows how annoyance ratings varied as a function of community size. Not surprisingly, annoyance towards traffic noise increased as function of community size so that almost 78% of the respondents from communities with less than 5,000 people were not at all annoyed by traffic noise, compared to only 58% of the respondents in communities with more than 100,000 residents. In communities with more

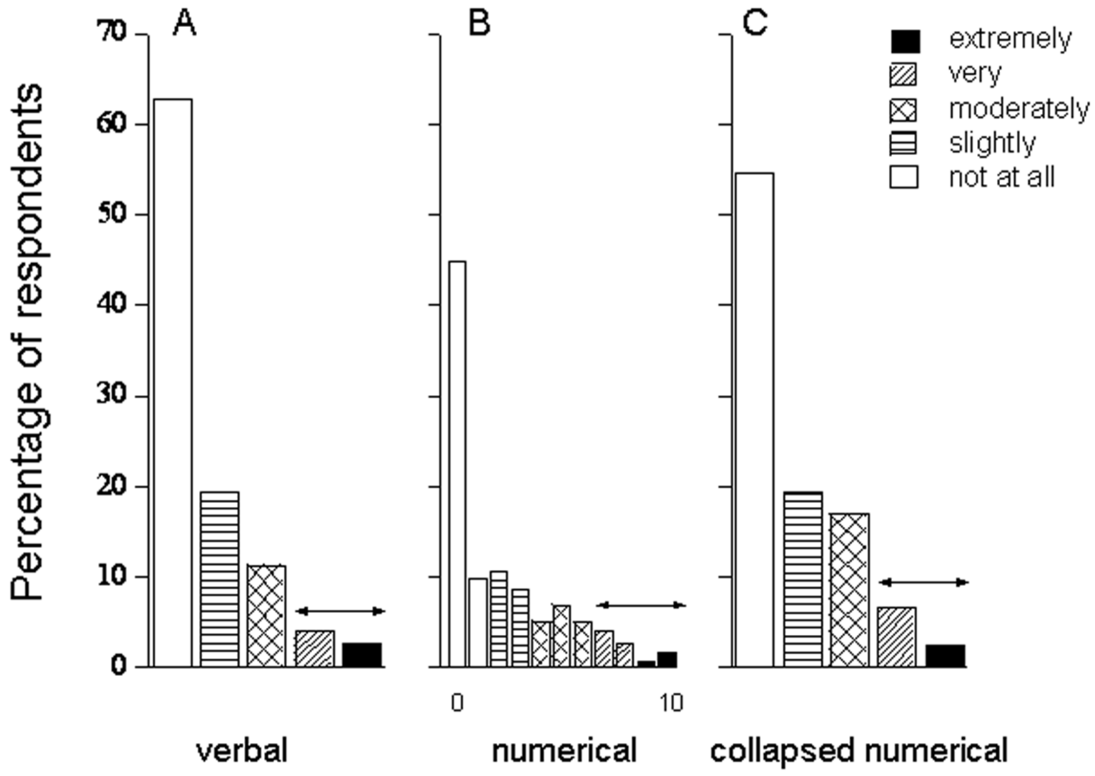

Figure 1. The distribution of self-reported annoyance towards traffic noise among respondents interviewed in the 2nd telephone survey using the ISO/TS 15666 recommended questions for assessing community annoyance. Panel A, shows the response on the verbal scale, Panel B shows the range of annoyance on the ten-point numerical scale and Panel C presents the results from the numerical scale collapsed according to the following breakpoints (0+1=not at all; 2+3=slightly; 4+5+6=moderately; 7+8=very and 9+10=extremely). Collapsing the numerical scale in this manner yielded a correlation coefficient of 0.765 (p<0.001) between panel A and panel C. Bars with arrowheads on each panel delineate the range of respondents considered "highly annoyed".

than 100,000 people, approximately 20% of respondents were moderately to extremely annoyed by traffic noise, compared to only 11% in communities with less than 5,000 residents.

Females were not only more annoyed by noise than males in general, but were 1.5 times more likely to be annoyed by traffic noise in particular. The average response from females on the numerical scale was 2.37 compared to 1.93 for males. Age and income had a statistically significant influence on respondent's annoyance ratings towards traffic noise. Individuals 65 and over were more likely to respond "not at all" annoyed and individuals between 25 and 44, were least likely to respond this way. Those in the middle-income bracket ($20,000-$49,999) were significantly more likely to be annoyed by traffic noise than respondents with incomes below and above this level. While almost three-quarters of those with less than a secondary education were not at all bothered by traffic

Table 3. The extent to which Canadians are bothered, annoyed or disturbed by road traffic noise as a function of community size.

		% Not at all	% Slightly	% Moderately	% Very	% Extremely
< 5,000	N=344	77.6	11.6	7.6	2.3	0.9
5,000-99,000	N=510	70.6	13.3	10.4	3.9	1.8
100,000+	N=1836	57.7	22.5	12.1	4.2	3.3

noise compared to 60% of those with a post-secondary education, no significant difference was found among education levels when those responding "slightly" and "not at all" were considered together. Another interesting observation was that individuals who rated their health as only fair or poor had a significantly higher mean rating on the numerical scale compared to those who said their health was good or excellent indicating that for traffic noise they had a greater level of annoyance (2.47 versus 2.09, respectively).

Discussion

There is no doubt that transportation noise can represent a significant source of annoyance. Efforts to reduce annoyance towards environmental noise should be greatly improved by an understanding of the pervasiveness of the annoyance. To our knowledge, the present study represents the first attempt to estimate noise annoyance in Canada using a national survey. Statistics Canada estimates that the Canadian population 15 years of age and over in 2003 was approximately 26 million (Statistics Canada 2004). Thus, our results suggest that nearly 2.1 million Canadians 15 years of age and over (+/- approximately 400,000) are either very or extremely annoyed by noise in general, and that 1.8 million Canadians 15 years of age and over (+/- 350,000) are similarly annoyed by traffic noise. It follows that the greatest reduction, nationally, in annoyance can be expected from efforts aimed towards reducing traffic noise in Canada. Our results are comparable to that obtained in the national survey conducted in the UK where it was found that 8% of the population was either very or extremely annoyed by traffic noise (BRE Environment 2002). This is an interesting comparison because the population of the UK in mid-2000 was about double that of Canada (Office for National Statistics 2003).

Our results indicate that traffic noise annoyance was greater among women and individuals with a higher income, and is lower among those 65 and over. In this study, education was no longer statistically associated with the level of traffic noise annoyance when the categories "slightly" and "not at all" were collapsed. However, these results were not entirely consistent with those of Fields (1993) in his review of the personal and situational factors contributing to noise annoyance. He found that education, income and age had no influence on annoyance ratings (Fields 1993). Our results are similar to a community study conducted in Canada 25 years ago that showed annoyance towards traffic noise was greater among residents classified as having a higher socioeconomic status (Bradley 1979). A higher socioeconomic status may be correlated with annoyance inasmuch as higher social status may be associated with a greater expectation of quiet, but this remains to be confirmed.

A recent study by (Ohrstrom 2004) showed the effectiveness of reducing annoyance by reducing traffic volume in a community in Sweden. In her longitudinal study, 58% of the exposed community was very annoyed by traffic noise caused by 25,000-30,000 vehicles per day (Leq-24hr = 67 dBA) and the average numerical rating on the 10-point annoyance scale was 8.9[9]. When traffic volume was reduced to 2,400 vehicles per day (Leq-24hr = 55dBA) the percentage highly annoyed dropped to 6.7% and the average numerical rating fell to 1.4. Not surprisingly, the reduction in traffic noise annoyance corresponded to an overall improvement in self-assessed general well-being. It is notable that it has been estimated that about 2 million Canadians are exposed to traffic noise levels in the range reported in Ohrstrom's study, before traffic volume was reduced (i.e. Leq24 > 65dBA). Based on the ISO curve (ISO 2003) though, it would not be expected that as many as 58% of these 2 million Canadians are very or extremely annoyed with traffic noise; non-acoustic variables likely contributed to annoyance in Ohrstrom's study sample (2001).

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9 *Using the dose-response curve recommended by ISO 1996-1: 2003, an Leq(24) of 67dBA would be associated with high annoyance in approximately 21% of the exposed community.*

Our findings provide a basis for establishing a full-scale national socio-acoustic survey similar to the UK study (BRE Environment 2002). This could further identify Canadian's concerns towards noise and, in turn, help devise strategies targeted at reducing annoyance. For instance, it was revealed in the UK survey that what specifically annoyed people the most about traffic was accelerating or speeding vehicles (BRE Environment 2002). In our initial survey we attempted to identify the sources which annoyed people the most, but among the 7.9% of respondents that were either very or extremely annoyed by noise in general, nearly 25% of them identified a type of source that was not one of the 18 sources listed in Table 2. More research could also help identify these unknown sources and target them to reduce annoyance among those highly annoyed.

Since acoustic variables may account for one third of the variance in annoyance, (Guski 1999) the present study would be improved if estimating respondent's noise exposure were possible. Future questions could specifically ask subjects how close they are to traffic and how often they are exposed. This would enable an estimate of the extent to which the noise levels correlate with annoyance scores.

The first survey was initiated as a pilot study to gauge Canadian's annoyance toward noise in general. It is of interest that among the 1257 respondents that indicated they were not at all annoyed by noise, 225 of them identified traffic as one of the sources that bothers, disturbs or annoys them the most. At first this finding seems paradoxical. It should be noted, however, that although everyone was asked both questions, most respondents that were not at all annoyed by noise in general did *not* provide a source that annoyed them the most. Thus, it is possible that one identifies traffic as the most annoying source of noise after indicating they are not at all annoyed by noise because 1) they have an expectation of the noise source that people would indicate as most annoying and they conform to this or 2) they find traffic so annoying that they effectively eliminate annoyance by avoiding the source that is most annoying.

Some caution should be made in comparing the results we obtained in the December survey to those conducted during warmer months since indoor noise exposure levels may be reduced in December with closed windows and people are more likely to be indoors during colder months. Although respondents are specifically instructed to respond based on their experience over the last 12 months or so, this may not fully account for seasonal effects. Seasonal effects on noise annoyance have been shown to account for as much as 10% of the variability in annoyance (Fields *et al.* 2000). Still, our results remain comparable to those obtained in the UK study since it was conducted in December/January.

For both surveys, the response rate was around 33%. Although this is common for public opinion research that utilizes random digit dialing (O'Rourke *et al.* 1998), we cannot rule out the possibility that selection bias may have had an impact on our results. It is important to note, though that a respondent's decision to participate or refuse to participate in the telephone survey was made without any knowledge that the survey would contain questions related to environmental noise. Furthermore, follow-up calls were made to individuals with soft refusals and numbers with no initial response.

The results of this study provide a basis for a more elaborate socio-acoustic survey that contains questions designed to estimate the respondent's level of noise exposure to transportation noise and to understand what non-auditory factors contribute to environmental noise annoyance. An ideal study would be supplemented with environmental noise mapping to better calculate how noise levels correlate with annoyance.

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References

Bradley J.S. (1979) The effects of site selected variables on human responses to traffic noise, Part 2: Road type by socio-economic status by traffic noise level. *J. Sound Vib*., 67: 395-407

Broadbent D.E. (1972) Individual differences in annoyance by noise. *Sound*, 6: 56-61

Commission of the European Communities (Brussels) (1996) Green Paper on Future Noise Policy.

Department for Environment, Food and Rural Affairs (2002) The 1999/2000 national survey of attitudes to environmental noise-Volume 3 United Kingdom results. 205217f

Eldred K.M. (1990) Noise at the year 2000. In: Proceedings of the 5th International Congress on Noise as a Public Health Problem: New Advances in Noise Research Part II, Berglund, B and Lindvall, T (eds) 5: 355-381

Fidell S., Barber D.S. and Schultz T. (1991) Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise. *J. Acoust. Soc. Am*., 89: 221-233

Fields J.M. (1993) Effect of personal and situational variables on noise annoyance in residential areas. *J. Acoust. Soc. Am*., 93: 2753-2763

Fields, J.M., Ehrlich, G.E. and Zador, P. (2000) Theory and design tools for studies of reactions to abrupt changes in noise exposure. NASA/CR-2000-210280, Langley Research Center, Hampton, Va.: NASA

Finegold L.S. and Finegold M.S. (2002) Development of exposure-response relationships between transportation noise and community annoyance. *J. Aviation. Environ. Res.*, 7: 11-22

Guski R. (1999) Personal and social variables as co-determinants of noise annoyance. *Noise Health*, 1: 45-56

Health Canada (Ottawa) (2001) Noise from civilian aircraft in the vicinity of airports-Implications for human health 1. Noise, stress and cardiovascular disease.

INRETS (Cedex, France) (1994) Study related to the preparation of a communication on a future EC noise policy. 9420

International Organization for Standardization (2001) Technical Specification ISO/TS 15666 "Acoustics-Assessment of noise annoyance by means of social and socio-acoustic surveys".

International Organization for Standardization (2003) Acoustics-Description, measurement and assessment of environmental noise-Part 1: Basic quantities and assessment procedures. ISO 1996-1:2003(E)

Miedema H.M. and Oudshoorn C.G. (2001) Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. *Environ. Health Perspect*., 109: 409-416

Office for National Statistics (2003) Population Estimates. Office for National Statistics, http://www.statistics.gov.uk/cci/nugget.asp?id=6 (accessed 09/03/2004)

Ohrstrom E. (2004) Longitudinal surveys on effects of changes in road traffic noise--anoyance, activity disturbances, and psycho-social well-being. *J. Acoust. Soc. Am.*, 115: 719-729

Organisation for Economic Co-operation and development (Paris) (1986) Fighting Noise: Strengthening noise abatement policies.

Organisation for Economic Co-operation and Development (Paris) (1991) Fighting noise in the 90s.

O'Rourke D., Chapa-Resendez G., Hamilton L., Lind K., Owens L. and Parker V. (1998) An Inquiry into declining RDD response rates. Part 1: Telephone survey practices. *Surv. Res*., 29: 1-14

Schultz T. (1978) Synthesis of social surveys on noise annoyance. *J Acoust. Soc Am*., 64: 377-405

Statistics Canada (2004) Estimates of population, by age group and sex, Canada, provinces and territories, annual (Persons unless otherwise noted) (4725 series). Statistics Canada

Troldahl V.C. and Carter R.E. (1964) Random selection of respondents with households in phone surveys. *J. Marketing Surveys*, 1: 71-76

World Health Organization (2001) Occupational and Community Noise. WHO-OMS, http://www.who.int.inf-fs/en/fact258.html (accessed on 10/01/2004)

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The UK National Noise Attitude Survey 1999/2000

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The UK National Noise Attitude Survey 1999/2000

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Summary

A survey of community response to environmental noise involving over 5,000 respondents has recently been completed and has established a year 2000 benchmark for community response to noise in the UK. This paper presents some of the key findings. The survey was undertaken for the Department for Environment, Food and Rural Affairs and the Devolved Administrations. The survey design involved two parallel population samples and two different noise attitude questionnaires. One of the questionnaires had been used previously in England and Wales during 1991, allowing us to investigate changes in attitudes to noise over the last 10 years.

The key findings from this research should be considered in the following context:

- 69% of respondents reported general satisfaction with their noise environment.
- 57% of respondents reported that noise did not at all spoil their home life.
- noise was ranked 9th in a list of 12 environmental problems.

Nevertheless:

- 21% of respondents reported that noise spoilt their home life to some extent, with 8% reporting that their home life was spoilt either '*quite a lot*' or '*totally*'.
- 84% of respondents heard road traffic noise and 40% were bothered, annoyed or disturbed to some extent.
- 28% of respondents reported that road traffic noise at their homes had got worse in the last five years; this should be considered alongside the trends in noise level and noise exposure found in the National Noise Incidence Study 00/01.
- 81% of respondents heard noise from neighbours and/or other people nearby and 37% were bothered, annoyed or disturbed to some extent.
- the proportion of respondents who reported being adversely affected by noise from neighbours has increased over the last 10 years, whilst for all other categories of environmental noise the proportion adversely affected has remained unchanged.
- only a small proportion of respondents who were bothered by noise from neighbours complained to the environmental health department of the local authority, which means that noise complaint statistics will greatly underestimate the extent of community dissatisfaction.

1 Introduction

The Department for Environment, Food and Rural Affairs commissioned BRE to carry out a research project with the following main objectives:

- to track changes in community attitude to environmental noise in England & Wales between 1991[1] and 1999.
- to obtain the best possible estimate of attitudes to environmental noise in the UK for 1999/2000.

- to investigate the importance of questionnaire design in noise attitude surveys.

Between November 1999 and February 2000, two sample groups, each approximately equivalent in size to that used in 1991, were interviewed in England and Wales; the first with the 1991 questionnaire, and the second with a new modular questionnaire. During October and November 2000, the survey using the new modular questionnaire was extended to include Scotland and Northern Ireland in order to estimate UK attitudes to environmental noise.

The sample used was a multi-stage clustered sample generated with probability of selection proportional to population at each stage, in order to obtain a sample representative of the national population. All respondents were adult householders, pre-selected from the electoral role, and all interviews were conducted face to face in their homes.

This paper presents some interesting findings from the National Noise Attitude Survey (NAS). Section 2 gives examples of the UK results using the new questionnaire. Section 3 gives examples of trends in community attitude to noise for England and Wales between 1991 and 2000. Further information on the studies is available in the full project reports, which are being made available on the web[2,3,4,5,6].

Throughout this paper, NAS91 refers to the 1991 questionnaire as used in 1991; NAS91_99 refers to the 1991 questionnaire being used in 1999 and NAS99 refers to use of the new 1999 modular questionnaire. Where appropriate, the survey results given in Annex A and B are shown with 95% confidence intervals.

2 Community attitude to noise in the UK

A new questionnaire, NAS99, was designed for the UK wide survey with a modular structure that is intended to allow the six supplementary sections dealing with various categories of environmental noise to be used independently of each other in the future. Numerous specific sources of environmental noise are embraced in the design through the use of showcards. Filter and ranking techniques are used to manage the overall length of interview and the size of subsamples. Supplementary sections on road traffic noise and neighbour noise were made mandatory for all respondents. A total of 2876 interviews were achieved, with an overall response rate of 63%. Some key findings from the UK survey are listed below.

- 18% of respondents reported noise as one of the top five from a list of environmental problems that personally affected them. Overall, noise was ranked ninth in this list of 12 environmental problems.
- 69% of respondents reported general satisfaction with their noise environment (i.e. liking the amount (or absence) of noise around them at home to some extent).
- 21% of respondents reported that noise spoilt their home life to some extent, with 8% reporting that their home life was spoilt either '*quite a lot*' or '*totally*'.
- 84% of respondents heard road traffic noise; 40% were bothered, annoyed or disturbed to some extent; 28% said it had got worse and 10% that it had got better over the past five years.

- 81% of respondents heard noise from neighbours and/or other people nearby; 37% were bothered, annoyed or disturbed to some extent; 14% said it had got worse and 15% that it had got better over the past five years.
- 71% of respondents heard noise from aircraft; 20% were bothered, annoyed or disturbed to some extent.
- 49% of respondents heard noise from building, construction, demolition, renovation or road works; 15% were bothered, annoyed or disturbed to some extent.
- the most commonly selected word (from a list of 21) used to describe the effects of noise was *irritated*; 30% of respondents selected this for road traffic noise and 25% for noise from neighbours.
- the evening (1900 – 2300) and night-time (2300 – 0700) periods are the times when the greatest proportion of respondents reported being particularly bothered, annoyed or disturbed by most types of noise from neighbours and/or other people nearby.
- only a small proportion of respondents who were bothered by the various specific sources of noise from neighbours complained to the environmental health department of the local authority. The most common action taken was to complain directly to the person responsible. In general, only a small proportion (usually less than 10%, although this depends on source) of respondents who were bothered contacted any department of the local authority. For all sources of noise from neighbours a greater proportion of respondents complained to the police rather than the environmental health department.

More details of these findings are illustrated in Annex A of this paper. The full reports should be consulted if further information, or a more detailed understanding, is required.

3 Trends in attitude to noise in England & Wales

The survey using the NAS91_99 questionnaire was designed to be as similar as possible to the survey first undertaken in England and Wales during 1991, hence enabling a direct assessment of changes in attitude to be made. The questionnaire used in 1999/2000 was identical to that previously used in 1991; the first part of the questionnaire gathered information on the noises heard whilst a second part asked further questions on up to 49 specific sources of environmental noise. The questionnaire design was intended to increase the likelihood of accurate response data for each specific noise source but has disadvantages in terms of the length of interview and the creation of small subsamples for certain noise sources. A total of 2534 interviews were achieved, with a response rate of 64%. Examples of the trends found for the most commonly heard sources of environmental noise are presented in the subsections below. Unless otherwise stated all trends are statistically significant at the 95% confidence level.

Respondents were asked if they heard a number of general categories and specific sources of environmental noise whilst at home. The main findings are:

- An increase in the proportion of respondents reporting hearing road traffic (from 48 to 54%).
- An increase in the number of respondents reporting hearing the following specific road traffic noise sources: *private cars/vans* (24 to 32%), *residential/estate roads* (10 to 14%), *police/other sirens* (10 to 14%), *vehicles starting/stopping/ticking over* (5 to 7%), *motorways* (1 to 6%).

- An increase in the proportions of respondents reporting hearing *neighbours* (19 to 25%) and *other people nearby* (15 to 21%).
- An increase in the number of respondents reporting hearing the following specific neighbour noise sources: *people's voices* (11 to 17%), *children* (9 to 16%), *radio/TV/hi-fi* (9 to 12%), *cars or motorcycles starting up/leaving/repairs* (6 to 10%), *doors banging* (5 to 7%) and *lawnmowers* (5 to 10%).
- No statistically significant change in the proportion of people reporting hearing aircraft (41 to 43%).
- An increase in the proportion of people reporting hearing the following specific aircraft noise source: *private / commercial helicopters* (10 to 16%).

Respondents were asked a number of questions about the various effects of noise. In this paper the term 'adversely affected' means that the respondent reported one or more effects from the list of six adverse effects in the question reproduced below.

Q13 NAS91 & NAS91_99 Section A

I would now like you to think about the noise that you hear from…. Please answer yes or no to the following:

A. Do you personally object to this noise?
B. Does the noise irritate you?
C. Does the noise sometimes disturb you?
D. Are you personally concerned about the noise?
E. Do you find the noise annoys or upsets you at times?
F. Do you consider the noise a nuisance to you personally?

The main findings are:

- No statistically significant change in the proportion of people reporting being adversely affected by noise from road traffic (29 to 30%).
- An increase in the proportion of people reporting being adversely affected by the following specific road traffic noise sources: *private cars/vans* (11 to 13%), *motorways* (1 to 3%).
- An increase in the proportion of people reporting being adversely affected by noise from neighbours and/or other people nearby (21 to 26%).
- An increase in the proportion of people reporting being adversely affected by the following specific sources of noise from neighbours and/or other people nearby: *people's voices* (7 to 11%), *children* (5 to 8%), *radio/TV/hi-fi* (6 to 9%), *lawnmowers* (1 to 3%).
- An increase in the proportion of people reporting the following activities being disturbed by noise from neighbours and/or other people nearby: *sleeping or resting* (12 to 16%), *listening to TV/radio/music* (11 to 14%), *reading or writing* (7 to 10%), *can't open windows* (6 to 8%), *telephone conversations* (5 to 9%), *use of garden* (4 to 6%).
- An increase in the proportion of people reporting the following reactions to noise from neighbours and/or other people nearby: *annoys me* (12 to 16%), *resent loss of peace and quiet* (11 to 14%), *makes me fed up* (6 to 8%), *makes me stressed* (3 to 5%), *makes me tired* (3 to 5 %), *makes me depressed* (2 to 7%).
- No statistically significant change in the proportion of people reporting being adversely affected by noise from aircraft (17 to 17%).
- An increase in the proportion of people reporting being adversely affected by the following specific aircraft noise sources: *private/commercial helicopters* (3 to 7%), *microlight aircraft/powered gliders* (0 to 1%).

More details of these findings are illustrated in Annex B of this paper. The full reports should be consulted if further information, or a more detailed understanding, is required.

4 The importance of questionnaire design

The sampling basis of the two studies was essentially identical and no statistically significant differences were found between the demographics of the two separate survey samples for England and Wales. Therefore this project affords a unique opportunity to compare the results obtained from two different noise attitude questionnaires (NAS91_99 and NAS99) applied to a similar population at a similar time. For the purpose of this paper we have simply chosen a question dealing with the general adverse effects of environmental noise and presented the corresponding results from the two questionnaires in Figures 1 and 2. The two questions being compared in Figures 1 and 2 are shown below.

Q13 NAS91_99 Section A

I would now like you to think about the noise that you hear from…. Please answer yes or no to the following:

A. Do you personally object to this noise?
B. Does the noise irritate you?
C. Does the noise sometimes disturb you?
D. Are you personally concerned about the noise?
E. Do you find the noise annoys or upsets you at times?
F. Do you consider the noise a nuisance to you personally?

NAS99 Main / NAS99 Road Traffic Noise / NAS99 Noise from Neighbours & Other People Nearby

When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from…?

Not at all – A little – Moderately – Very – Extremely – (Don't Hear)

Figure 1 shows the relationship between these two questions when using general categories of noise such as road traffic noise, aircraft noise, noise from neighbours and/or other people nearby. Figure 2 shows the relationship when using specific source descriptors of road traffic noise such as heavy lorries, motorbikes, motorways, and specific source descriptors of neighbour noise such as banging doors, footsteps, radio/TV/music.

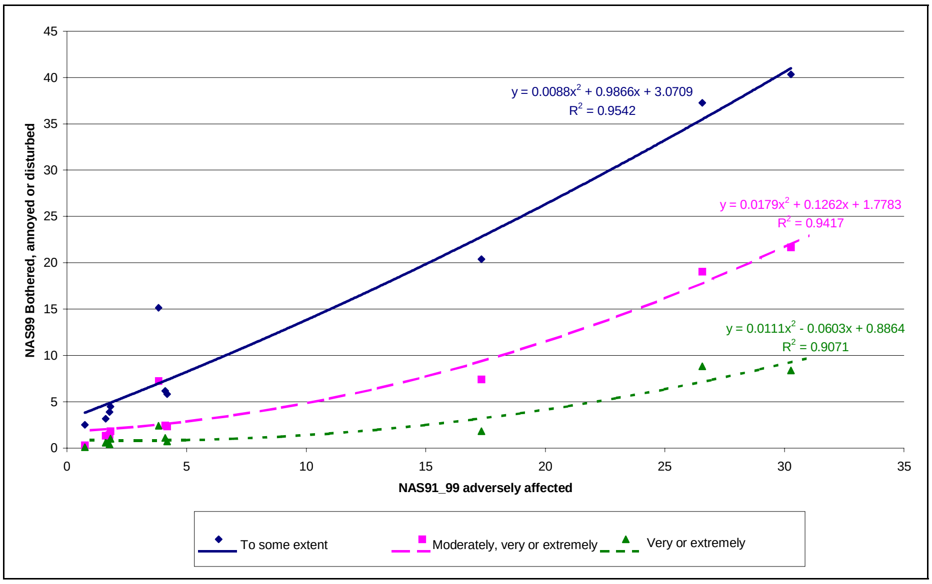

Figure 1. Proportion reporting annoyance from general categories of noise sources – relationship between two questionnaires

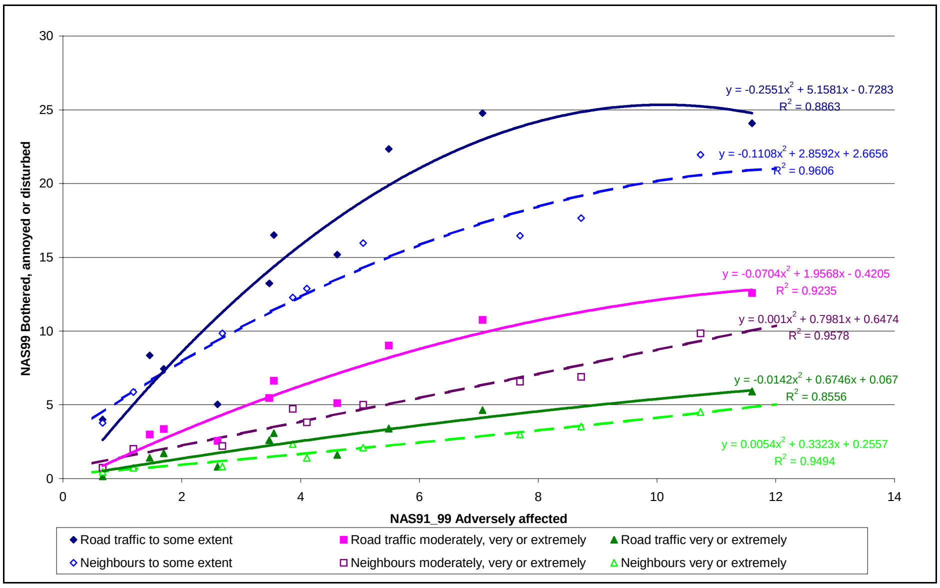

Figure 2. Proportion reporting annoyance from specific sources of road traffic noise and neighbour noise – relationship between two questionnaires

This is one example of a number of similar findings from the study[6] which demonstrate that great care must be taken when making comparisons between different noise attitude surveys using different questionnaires. Indeed, even where it appears that two questions are identical, the responses obtained may differ significantly owing to a variety of other factors within the questionnaire and its administration. A number of differences between the results obtained from the two questionnaire designs have been found in the study which can be attributed to a number of factors, including the following: (i) routing within the questionnaires and the use of filter questions, (ii) question wording and the options given for responses, (iii) interviewer coding instructions, (iv) use of showcards, (v) focus of questions on specific noise sources or general categories of noise, (vi) interviewers themselves, (vii) questionnaire structure and the order of questions within the questionnaires.

The direction of the effect of each of these factors may be relatively easily predicted but the overall result of the combination of several factors, and determining which will dominate in a given situation, is much less predictable and contributes to the observed lack of correspondence between the results obtained from the two different questionnaires.

However, as shown above in Figures 1 and 2, we have found that whilst there may be a lack of *correspondence* there is nevertheless a strong *correlation* between the results from the two questionnaires. This between-questionnaire correlation is particularly strong for the questions dealing with the adverse effects from general categories of noise. This, in turn, suggests that it may be possible to estimate the response to certain questions using the responses from another questionnaire but it seems to us that this relationship would need to be determined empirically for the particular studies under consideration. This finding has implications for those involved in the combined analysis of results from several different studies and for those making noise policy decisions on the basis of the results of social surveys.

5 Acknowledgements

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6 References

1. C. J. Grimwood, Effects of environmental noise on people at home, *BRE Information Paper IP22/93*, 1993.
2. M.K. Ling, C.J. Skinner, C.J. Grimwood, G.J. Raw, The 1999/2000 National Survey Of Attitudes to Environmental Noise: Volume 1 Methodology, *BRE Client Report No:* 205215f, 2002.
3. M.K. Ling, C.J. Skinner, C.J. Grimwood, G.J. Raw, The 1999/2000 National Survey Of Attitudes to Environmental Noise: Volume 2 Trends in England and Wales, *BRE Client Report No:* 205216f, 2002.
4. C.J. Skinner, M.K. Ling, C.J. Grimwood, G.J. Raw, The 1999/2000 National Survey Of Attitudes to Environmental Noise: Volume 3 United Kingdom results, *BRE Client Report No:* 205217f, 2002.
5. M.K. Ling, C.J. Skinner, C.J. Grimwood, G.J. Raw, The 1999/2000 National Survey Of Attitudes to Environmental Noise: Volume 4 Questionnaires, *BRE Client Report No:* 205218f, 2002.
6. C.J. Skinner, C.J. Grimwood, G.J. Raw, The 1999/2000 National Survey Of Attitudes to Environmental Noise: Volume 5 Questionnaire comparison and review, *BRE Client Report No:* 205219f, 2002.

Annex A – United Kingdom results (NAS99 questionnaire)

Environmental problems

Q21 NAS99 Main

Please look at this list of environmental problems. Which FIVE would you say you are personally most affected by?

- Chemicals put into the rivers and/or seas
- Sewage on beaches or in bathing water
- Loss of plant life and/or animal life
- Quality of drinking water
- Use of insecticides and/or fertilisers
- Losing green belt land
- Litter & rubbish
- Traffic exhaust fumes & urban smog
- Fouling by dogs
- Using up of natural resources
- Not enough recycling
- Noise

Environmental problems affecting respondents	Proportion ranking problem in top five (%) (n=2876)
Fouling by dogs	50 ± 3
Litter and rubbish	48 ± 3
Traffic exhaust fumes & urban smog	31 ± 4
Losing green belt land	27 ± 4
Quality of drinking water	26 ± 3
Chemicals put into the sea and/or rivers	24 ± 3
Sewage on beaches or in bathing water	24 ± 4
Not enough recycling	20 ± 3
Noise	18 ± 3
Use of insecticides and/or fertilisers	18 ± 3
Loss of plant life and/or animal life	16 ± 2
Using up of natural resources	9 ± 1

Attitudes to noise environment

Q22 NAS99 Main

In general, how do you feel about the amount of noise (or the absence of noise) around here?

	Proportion (%) (n=2876)
1 – Definitely like	32 ± 3
2	22 ± 2
3	15 ± 2
4	13 ± 1
5	7 ± 1
6	4 ± 1
7 – Definitely don't like	5 ± 1
Don't know	1 ± 0

Extent bothered, annoyed or disturbed by categories of environmental noise and specific sources of noise from neighbours and/or other people nearby

Q24 NAS99 Main
When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from …?

Not at all – A little – Moderately – Very – Extremely

Noise Category (n=2876)	Hear (%)	Bothered, annoyed or disturbed (%) To some extent	Moderately, very or extremely	Very or extremely
Road traffic	84 ± 3	40 ± 3	22 ± 2	8 ± 1
Neighbours (inside their homes)	58 ± 4	18 ± 2	9 ± 1	4 ± 1
Neighbours (outside their homes)	71 ± 4	22 ± 2	10 ± 1	4 ± 1
Other people nearby	68 ± 4	20 ± 3	8 ± 1	3 ± 1
Neighbours and/or other people nearby (combined category)	*81 ± 3*	*37 ± 3*	*19 ± 2*	*9 ± 1*
Aircraft/airports/airfields	71 ± 4	20 ± 4	7 ± 2	2 ± 1
Building, construction, demolition, renovation or road works	49 ± 5	15 ± 2	7 ± 2	2 ± 1
Trains or railway stations	36 ± 4	6 ± 1	2 ± 1	1 ± 0
Sports events	34 ± 4	4 ± 1	1 ± 0	0 ± 0
Other entertainment or leisure	31 ± 4	6 ± 1	2 ± 1	1 ± 0
Community buildings	30 ± 3	4 ± 1	1 ± 0	0 ± 0
Forestry, farming or agriculture	26 ± 4	3 ± 1	0 ± 0	0 ± 0
Factories or works	23 ± 3	4 ± 1	2 ± 0	1 ± 0
Other commercial premises	23 ± 4	3 ± 1	1 ± 0	1 ± 0
Sea, river or canal traffic	16 ± 3	0 ± 0	0 ± 0	0 ± 0
Any other noise[a]	15 ± 3	4 ± 1	3 ± 1	1 ± 0

[a] The additional specific sources of noise given by respondents under the category *any other noise* included: birds / pigeons, church bells, crackling of overhead power lines, electric substations, military establishments

NN1 NAS99 Neighbour Noise
When you are at home, to what extent are you personally bothered, annoyed or disturbed by noise from …?

Not at all – A little – Moderately – Very – Extremely

Specific source of noise from neighbours and/or other people nearby (n=2782)	Hear (%)	Bothered, annoyed or disturbed (%) To some extent	Moderately, very or extremely	Very or extremely
Teenagers' or adults' voices	70 ± 4	22 ± 3	10 ± 2	5 ± 1
Radio, TV, music	55 ± 4	18 ± 2	7 ± 1	4 ± 1
Dogs	65 ± 4	17 ± 2	7 ± 1	3 ± 1
Children	67 ± 4	16 ± 2	7 ± 1	3 ± 1
Cars/motorcycles starting up/leaving, repairs etc.	67 ± 4	15 ± 2	5 ± 1	2 ± 1
Burglar alarms	53 ± 4	15 ± 2	5 ± 1	2 ± 1
DIY (hammering, drilling, etc.)	62 ± 4	13 ± 2	4 ± 1	1 ± 0
Doors banging	46 ± 4	12 ± 2	5 ± 1	2 ± 1
Lawnmowers or other garden equipment	74 ± 4	10 ± 2	2 ± 1	1 ± 0
Parties (when held outdoors)	50 ± 4	8 ± 1	3 ± 1	1 ± 0
Parties (when held indoors)	44 ± 4	7 ± 1	3 ± 1	1 ± 0
Footsteps	41 ± 4	6 ± 1	2 ± 1	1 ± 0
Domestic equipment	36 ± 4	4 ± 1	1 ± 0	0 ± 0
Other animals	31 ± 4	3 ± 1	1 ± 1	1 ± 0
Electric Switches	20 ± 4	1 ± 0	0 ± 0	0 ± 0
Any other kind of noise[b]	24 ± 4	5 ± 1	3 ± 1	2 ± 0

[b] The additional specific sources of noise from neighbours given by respondents under the category *any other kind of noise* included: mobile phones, telephones, fireworks, toilets flushing and plumbing noises

Times when bothered by noise from neighbours and/or other people nearby

DNN1 NAS99 Detailed Neighbour Noise

Does the noise from … particularly bother, annoy or disturb you, at each of the times listed on the card…
a) during the week (Monday to Friday)?
b) during the weekend (Saturday and Sunday)?

- Day (0700-1900)
- Evening (1900-2300)
- Night(2300-0700)

Specific source of noise from neighbours and/or other people nearby	**n**	**Weekdays (%)**			**Weekends (%)**		
		Day	**Evening**	**Night**	**Day**	**Evening**	**Night**
Other animals	28	32	25	61	32	25	64
Footsteps	55	27	51	55	36	45	53
Parties (when held indoors)	81	1	35	54	6	57	79
Doors banging	141	33	55	46	41	49	45
Burglar alarms	150	19	27	35	19	23	36
Cars, motorcycles starting up/leaving, repairs etc.	137	41	42	34	45	41	33
Radio, TV, music	201	26	54	34	41	54	40
Teenagers' or adults' voices	295	24	64	33	34	62	43
Dogs	201	43	35	32	44	32	29
Parties (when held outdoors)	74	9	34	30	20	65	59
Electric switches	6	0	33	17	33	50	17
DIY (hammering, drilling etc)	110	32	50	15	65	47	17
Children	189	45	63	12	62	59	14
Domestic equipment (vacuum cleaners etc)	27	22	37	7	48	41	4
Lawnmowers and other garden equipment	64	44	20	2	73	23	2
Other noises	75	35	53	44	37	55	47

View on whether noise from road traffic and noise from neighbours is getting worse

NAS99 Road Traffic Noise RT7

Would you say the road traffic noise here, at your home, has been getting better or worse over the past five years?

	Proportion (%)				
	England (n=2356)	Wales (n=147)	Scotland (n=247)	Northern Ireland (n=99)	UK (n=2849)
1 - Definitely better	4	3	5	0	4
2	5	4	14	8	6
3	42	48	40	57	43
4	13	10	15	16	13
5 - Definitely worse	16	16	6	13	15
Have not liver here for 5 years	13	8	16	3	13

NAS99 Noise from Neighbours & Other People Nearby NN8

Would you say that the noise from neighbours and/or other people around here, at your home, has been getting better or worse over the part five years?

	Proportion (%)				
	England (n=2296)	Wales (n=140)	Scotland (n=247)	Northern Ireland (n=99)	UK (n=2782)
1- Definitely better	7	12	7	3	7
2	7	5	15	10	8
3	51	53	43	62	50
4	7	7	9	10	7
5 - Definitely worse	8	4	4	11	7
Have not lived here 5 years	16	9	17	3	15

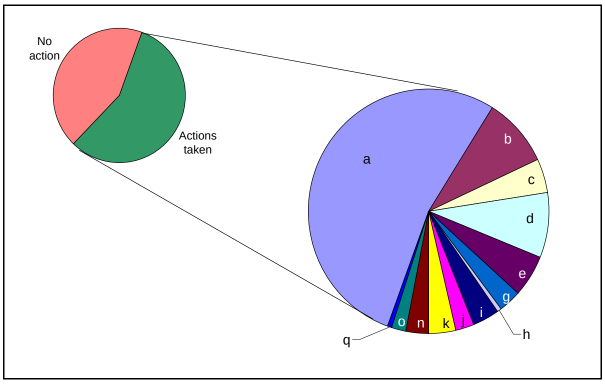
Actions taken in response to noise from neighbours and/or other people nearby

DNN5a NAS99 Detailed Neighbour Noise

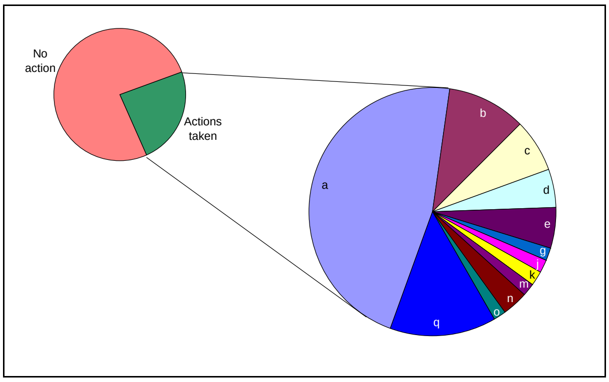
Have you ever done any of the things listed on the card to try to deal with the noise from … that you hear?

a) Complained to the person / people / organisation that is making the noise
b) Complained to the police
c) Complained to the Environmental Health Department
d) Complained to another Local Authority (Council) Department
e) Complained to the Landlord / Housing Department / Housing Association / Other landlord
f) Complained to a Government Department
g) Complained to an MP or councillor
h) Started / signed / joined a campaign or petition
i) Installed double glazing
j) Did something else to keep the noise out
k) Did something to help you sleep (e.g. earplugs, sleeping pills)
l) Talked to the Citizens Advice Bureau
m) Took legal advice / action
n) Did something else
o) Asked someone else to do one of the above
p) No action taken
q) Same action as for another neighbour noise type

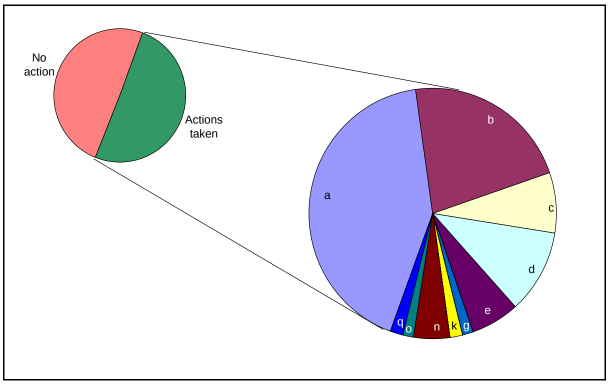
The results from this question are presented in the pie charts opposite for several specific types of noise from neighbours and/or other people nearby. The results are presented as proportions of the subsample that completed a Detailed Neighbour Noise (DNN) questionnaire for that noise type. It should be noted that the DNN questionnaire was only completed by respondents who reported being *moderately*, *very* or *extremely* bothered, annoyed or disturbed by noise from that source.



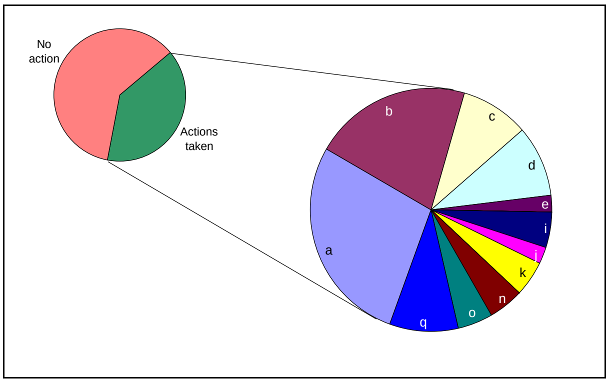
Actions taken for noise from radio, TV, music (n=201)



Actions taken for noise from dogs (n=162)



Actions taken for noise from parties (when held indoors (n=81)



Actions taken for noise from parties (when held outdoors) (n=74)

Annex B – England & Wales – changes from 1991 to 1999

Noise sources heard

Q6 Main NAS91 & NAS91_99

When you are at home do you, personally, hear any of the following noises? You may mention as many or as few as you like.

Category of environmental noise	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
Road traffic	48	54	Increase
Aircraft	41	43	-
Neighbours	19	25	Increase
Other people nearby	15	21	Increase
Neighbours and/or other people nearby (combined category)	*28*	*38*	*Increase*
Trains or railways	13	17	-
Building construction or road works	6	7	-
Sports events	6	7	-
Entertainment or leisure	5	6	-
Farming or agriculture	4	5	-
Factories or works	2	4	-
Commercial premises	2	3	-
None of these	22	17	Decrease

Q10 Main NAS91 & NAS91_99
Which of these kinds of road traffic noise do you hear while you are at home?

Specific noise source	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
Private cars/vans	24	32	Increase
Heavy lorries	20	20	-
Other main roads	19	22	-
Smaller lorries/buses	16	16	-
Motor bikes/scooters	13	13	-
Minor roads	12	12	-
Residential/estate roads	10	14	Increase
Police/other sirens	10	14	Increase
Brake squeal	7	6	-
Vehicles starting/stopping/ticking over (at traffic lights, crossings etc.)	5	7	Increase
Air brakes	3	3	-
Noise caused by irregularities in road surface	3	3	-
Milk floats	3	2	-
Motorways	1	6	Increase
None of these other special noise types	29	24	Decrease
None of these road types	12	6	Decrease
None of these vehicle types	9	7	-

Q11 Main NAS91 & NAS91_99

Which of these kinds of noise do you hear from neighbours or from other people nearby?

Specific noise source heard	1991 (%) (n=2373)	1999 (%) (n=2534)	Significant changes (95% confidence level)
People's voices	11	17	Increase
Children	9	16	Increase
Radio/TV/hi-fi	9	12	Increase
Barking dogs or other animals	9	12	-
Cars, motorcycles starting up/leaving, repairs etc.	6	10	Increase
DIY – drilling, hammering etc.	5	7	-
Doors banging	5	7	Increase
Lawnmowers	5	10	Increase
Vacuum cleaners, washing machines etc.	2	3	-
Footsteps	3	4	-
Other neighbour noises	1	2	-

Proportion adversely affected

The proportions of the whole sample who reported hearing and being adversely affected are presented for general categories of environmental noise and specific sources of noise from neighbours and/or other people nearby in the tables below.

A separate Section A supplementary questionnaire was completed for each specific noise source that respondents reported hearing in the Main Questionnaire. Question 13 from Section A has been used to assess the proportion of respondents who reported being adversely affected by each specific noise source.

Environmental noise categories

Category of environmental noise	**Proportion adversely affected**		**Significant changes (95% confidence level)**
	1991 (%) (n=2373)	**1999 (%) (n=2534)**	
Road Traffic (one or more specific sources)	29	30	-
Neighbours and/or other people nearby (one or more specific sources)	*21*	*26*	*Increase*
Aircraft (one or more specific sources)	17	17	-
Trains or railways (one or more specific sources)	4	4	-
Building construction or road works	3	4	-
Entertainment or leisure	3	4	-
Factories or works	2	2	-
Commercial premises	1	2	-
Sports events	1	2	-
Farming of agriculture	1	1	-

Specific sources of noise from neighbours and/or other people nearby

Specific source of noise from neighbours and/or other people nearby	**Proportion adversely affected**		**Significant changes (95% confidence level)**
	1991 (%) (n=2373)	**1999 (%) (n=2534)**	
People's voices	7	11	Increase
Children	5	8	Increase
Radio/TV/hi-fi	6	9	Increase
Barking dogs or other animals	6	7	-
Cars, motorcycles starting up/leaving, repairs etc.	4	5	-
DIY – drilling, hammering etc.	3	4	-
Doors banging	4	4	-
Lawnmowers	1	3	Increase
Footsteps	1	1	-
Vacuum cleaners, washing machines etc.	1	1	-

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QUANTITATIVE RESEARCH

The association between self-reported and objective measures of health and aggregate annoyance scores toward wind turbine installations

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Abstract

Objective An aggregate annoyance construct has been developed to account for annoyance that ranges from *not at all annoyed* to *extremely annoyed*, toward multiple wind turbine features. The practical value associated with aggregate annoyance would be strengthened if it was related to health. The objective of the current paper was to assess the association between aggregate annoyance and multiple measures of health.

Methods The analysis was based on data originally collected as part of Health Canada's Community Noise and Health Study (CNHS). One adult participant per dwelling (18–79 years), randomly selected from Ontario (ON) ($n = 1011$) and Prince Edward Island (PEI) ($n = 227$), completed an in-person questionnaire.

Results The average aggregate annoyance score for participants who indicated they had a health condition (e.g., chronic pain, Pittsburgh Sleep Quality Index (PSQI) > 5, tinnitus, migraines/headaches, dizziness, highly sensitive to noise, and reported a high sleep disturbance) ranged from 2.53 to 3.72; the mean score for those who did not report these same conditions ranged between 0.96 and 1.41. Household complaints about wind turbine noise had the highest average aggregate annoyance (8.02), compared to an average of 1.39 among those who did not complain.

Conclusion A mean aggregate annoyance score that could reliably distinguish participants who self-report health effects (or noise complaints) from those who do not could be one of several factors considered by jurisdictions responsible for decisions regarding wind turbine developments. However, the threshold value for acceptable changes and/or levels in aggregate annoyance has not yet been established and could be the focus of future research efforts.

Résumé

Objectif Un indice de gêne global, de *pas du tout gênant* à *extrêmement gênant*, a été élaboré pour tenir compte de la gêne causée par de nombreuses caractéristiques des éoliennes. La valeur pratique associée à la gêne globale serait renforcée si celle-ci était liée à la santé. L'objectif était d'évaluer l'association entre la gêne globale et divers indicateurs de santé.

Méthode Cette analyse est fondée sur des données recueillies à l'origine dans le cadre de l'Étude sur le bruit ambiant et la santé (ÉBAS) de Santé Canada. Des participants adultes (18 à 79 ans), un par ménage, sélectionnés au hasard en Ontario ($n = 1011$) et à l'Île-du-Prince-Édouard ($n = 227$), ont rempli un questionnaire en personne.

Résultats En moyenne, l'indice de gêne global des participants ayant fait état d'une affection de santé (p. ex. douleur chronique, indice de qualité du sommeil de Pittsburgh [PSQI] >5, acouphène, migraines/maux de tête, étourdissements, forte sensibilité au

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bruit et perturbation élevée du sommeil) se situait entre 2,53 et 3,72; l'indice moyen des participants n'ayant pas déclaré ces mêmes affections se situait entre 0,96 et 1,41. Les plaintes des ménages au sujet du bruit des éoliennes ont été associées en moyenne à l'indice de gêne global le plus élevé, soit 8,02, contre 1,39 en moyenne chez les participants qui ne se plaignaient pas du bruit des éoliennes.

Conclusion Un indice de gêne global moyen permettant de façon fiable de distinguer les participants qui font état d'effets sur leur santé (ou qui se plaignent du bruit) de ceux qui ne déclarent pas de tels effets pourrait être l'un de plusieurs facteurs à considérer par les administrations qui prennent des décisions sur le développement éolien. Toutefois, le seuil de gêne globale acceptable (son niveau et/ou son changement) reste à définir et pourrait faire l'objet d'études futures.

Keywords Noise · Principal component analysis · Community survey · Renewable energy · Canada

Mots-clés Bruit · Analyse en composantes principales · Enquête communautaire · Énergie renouvelable · Canada

Introduction

An aggregate annoyance construct has been developed to account for magnitudes of annoyance that range from *not at all annoyed* to *extremely annoyed* toward five wind turbine features (Michaud et al. 2018). These features included noise, shadow flickers, blinking lights, visual impacts, and vibrations. The construct was developed in recognition of the observation that wind turbine noise (WTN) was not the only, nor the most prevalent, wind turbine feature associated with community annoyance in the Community Noise and Health Study (CNHS). An aggregate annoyance score provides a more comprehensive assessment of annoyance than can be gleaned from any individual feature in isolation. The setback distance that corresponds with a statistically significant change in an aggregate annoyance score can inform jurisdictions that set policy. Although the point of departure from the curve is informative, there may be added value in knowing if there is, on average, an aggregate annoyance score that can reliably distinguish groups reporting health effects from those that do not.

As discussed elsewhere (Michaud et al. 2018), principal component analysis (PCA) weights each annoyance response in terms of how much it contributes to the aggregate annoyance construct. However, the authors acknowledge that the validity of the construct as one that has relevance to health or well-being is based on the tacit assumption that the valuation of significance placed on the items that constitute aggregate annoyance is reflected in the magnitude of rated annoyance assigned to each by study participants. The science base available to date does not refute this assumption; however, as outlined in the "Discussion" section, evaluating an untested assumption of equivalence could be a focus of future research in this area.

Previous research has demonstrated a statistical association between *high* noise annoyance and several measures of reported and measured health outcomes (Basner et al. 2014; WHO 2011; Niemann et al. 2006), including several objectively measured outcomes in Health Canada's CNHS (Michaud et al. 2016a). While statistical associations between high noise annoyance and some indicators of health are clearly insufficient to conclude a causal relation between annoyance and health, they may provide support for efforts that aim to mitigate long-term high noise annoyance. The same analysis has not yet been conducted for a measure that is based on several variables related to annoyance (i.e., aggregate annoyance).

Aggregate annoyance represents a novel approach to evaluating community annoyance. The adoption of this approach over conventional methods requires that there is a predictable change in aggregate annoyance as a function of proximity to wind turbines similar to that reported elsewhere (Michaud et al. 2018). Moreover, the pragmatic application of presenting an aggregate annoyance score as representing a community's magnitude of total annoyance toward wind turbines would be more defensible if the aggregate annoyance score was shown to be statistically related to measures of health and/or well-being. To this end, the primary purpose of the current analysis was to assess the mean aggregate annoyance scores among participants' health outcomes measured in the CNHS. The specific health measures assessed were based on their claimed attribution to WTN exposure (e.g., dizziness, tinnitus, migraines, sleep disturbance, depression) or the idea that they may be altered if annoyance represents or influences a stress response. Multiple measures of stress were reported and objectively measured in the CNHS, including but not limited to hair cortisol, blood pressure, heart rate, and perceived stress.(Michaud et al. 2016a)

Methods

Study characteristics

The current study is a secondary analysis of the data collected as part of Health Canada's CNHS. Any duplication of the methods already presented is intentional and considered the minimum necessary for the current analysis to stand on its own. The study characteristics have been described in another publication (Michaud et al. 2016b). Briefly, dwellings were identified from two Canadian provinces. The ON and PEI sampling regions included 315 and 84 wind turbines and 1011 and 227 dwellings, respectively. The wind turbine electrical power outputs ranged between 660 kW and 3 MW (average 2.0 ± 0.4 MW). Turbine hub heights were predominantly 80 m. To maximize sampling in areas where potential impacts from WTN exposure would be most likely to occur, a "take-all" sampling strategy was employed for all identified dwellings within approximately 600 m of a wind turbine. The remaining dwellings were selected randomly up to approximately 11 km. From each dwelling, one participant between the ages of 18 and 79 years was randomly chosen to participate. No substitution was permitted under any circumstances, and participants were not compensated for their participation.

Data collection

The full study questionnaire is available in the supplementary materials elsewhere (Michaud et al. 2016b). Statistics Canada-trained interviewers (16) conducted in-person home interviews between May 2013 and September 2013. In addition to basic demographic variables and previously validated content, the questionnaire's *perception module* included several questions on annoyance to multiple wind turbine features. In addition to noise, participants were also asked to indicate their magnitude of annoyance toward turbine blinking lights, shadows or flickers of light, visual impacts, and vibration or rattles noticed indoors which coincided with a participant's recollection of wind turbine operations. Annoyance response categories included *not at all*, *slightly*, *moderately*, *very*, and *extremely*. Pertinent to the current analysis, the questionnaire also included several health-related measures, including but not limited to, chronic pain, stress, blood pressure, tinnitus, migraines, dizziness, quality of life, and sleep disturbance. For brevity, methodological procedures for measured blood pressure, heart rate, and hair cortisol levels are presented elsewhere (Michaud et al. 2016c). In an attempt to mask the study's focus on wind turbines, potential participants were informed that the purpose of the survey was to investigate the potential impact on health from community noise.

Statistical methodology

Derivation of an aggregate annoyance construct

The method for deriving the aggregate annoyance construct has been reported elsewhere (Michaud et al. 2018). Briefly, a PCA was conducted in order to discover and summarize the pattern of intercorrelations among the five evaluated wind turbine features (i.e., "annoyance features"). The information derived from this preliminary investigation was then used to predict a single criterion variable for annoyance based on the five wind turbine features. Aggregate annoyance was based on all magnitudes of annoyance from not at all annoyed to extremely annoyed (0: not at all, 1: slightly annoyed, 2: moderately annoyed, 3: very annoyed, 4: extremely annoyed) and therefore reflects the combined annoyance toward multiple wind turbine features. The possible range in aggregate annoyance was 0 to 20. A score of 0 reflects no perception/annoyance toward any wind turbine feature and a score of 20 reflects extreme annoyance toward all 5 features.

Relationship between aggregate annoyance and health conditions

An ANOVA was performed based on the constructs derived from the PCA to compare aggregate annoyance levels with the presence or absence of self-reported health conditions. The variability due to distance and province were accounted for in the ANOVA models. The analysis was reanalyzed using A-weighted WTN categories in place of distance categories (see supplemental material). This was not repeated with C-weighted WTN levels as the results would essentially mirror A-weighted findings due to the high correlation between dBA and dBC values (i.e., Pearson's linear correlation coefficient $r > 0.8$) (Keith et al. 2016). The assumptions of the ANOVA were verified using the Anderson-Darling test for normality and Levene's test for equal variance of the residuals. When the assumptions were not satisfied, non-parametric methods were applied (i.e., the data were ranked, and the analysis was conducted on the ranks of the data). Self-reported variables of interest included chronic pain, high blood pressure, heart disease, quality of sleep, quality of life, satisfaction with one's health, tinnitus, migraines/headaches, dizziness, medication for anxiety/depression, noise sensitivity, sleep disturbance, lodging a complaint about wind turbines, and reporting to receive personal benefits from having wind turbines in the area. Quality of sleep was based on the Pittsburgh Sleep Quality Index (PSQI) where values greater than 5 are considered to indicate "poor" sleep (Buysse et al. 1989). Quality of life and satisfaction with one's health are based on the two stand-alone questions from the WHOQOL-BREF questionnaire (WHOQOL Group 1998). As reported elsewhere (Feder et al. 2015), participants were considered to have a poor quality of life if they responded either "poor" or "very poor" to *In the past month, how would you rate your quality of life?* All other responses ("neither poor nor good," "good," "very good") were considered to indicate participants have a good quality of life. Similarly, participants were considered to be "dissatisfied" with their health if they responded either "dissatisfied" or "very dissatisfied" to *In the past month, how satisfied were you with your health?* All other responses ("neither dissatisfied nor satisfied", "satisfied", very satisfied) were considered to indicate participants were satisfied with their health (Feder et al. 2015). ANOVA models relating self-reported health conditions and aggregate annoyance were further adjusted for age and sex, in addition to distance to the nearest turbine and province. Spearman correlation coefficient and linear regression models were used to investigate the relationship between the overall annoyance construct and the following continuous variables: systolic blood pressure, diastolic blood pressure, heart rate, hair cortisol levels, perceived stress scale (PSS), PSQI, and the four WHOQOL-BREF domains (physical health, psychological well-being, social relationships, and environmental factors). Again, these linear regression models were adjusted for distance to nearest turbine and province, and then refit adjusting for age and sex in addition to distance to nearest turbine and province.

The data analysis for this paper was generated using SAS/STAT software, version 9.2 of the SAS System for Windows 7. Unless otherwise indicated, a 5% significance level ($\alpha = 0.05$) was implemented throughout.

This study was approved by the Health Canada and Public Health Agency of Canada Review Ethics Board in accordance with the Tri-Council Policy Statement Ethical Conduct For Research Involving Humans (TCPS) (Protocol no. 2012-0065 and no. 2012-0072).

Results

Relationship between aggregate annoyance and health conditions

The association between aggregate annoyance (which reflects all levels of annoyance, from *not at all annoyed* to *extremely annoyed*) and self-reported health outcomes or other negative reactions to noise (e.g., complaints) was investigated. Table 1 presents the results when relating aggregate annoyance to various health conditions originally reported in Health Canada's CNHS (Michaud et al. 2016b). Self-reported variables of interest in the current analysis included chronic pain, high blood pressure, heart disease, quality of sleep, quality of life, satisfaction with one's health, tinnitus, migraines/headaches, dizziness, medication for anxiety/depression, noise sensitivity, and sleep disturbance. In addition, lodging a complaint about noise from wind turbines and reporting to receive personal benefit from having wind turbines in the area were assessed.

All health conditions were equally distributed between distance groups and dBA WTN groups (results not shown). Least squares means and confidence intervals were based on the mean of the total five annoyance features for each participant; p values of the models were based on non-parametric statistics of the first construct from PCA for the overall annoyance. A significant increase in average aggregate annoyance was observed among participants who self-reported to have chronic pain, scores on the PSQI above 5 (i.e., poor sleep), tinnitus, migraines/headaches, dizziness, reported very or extreme (i.e., high) sensitivity to noise, and reported very or extreme (i.e., high) sleep disturbance at home over the last year, for any reason.

An increase in average aggregate annoyance was also observed among those who lodged a complaint as well as among those who did not receive personal benefits. Age and sex were also related to aggregate annoyance; participants between the ages of 45 and 64 years had higher aggregate annoyance scores when compared to other age categories, as did males compared to females. Further adjusting the models for age and sex differences did not affect the results (see Table 1). For the self-reported health variables considered, the average aggregate annoyance score for those participants who indicated they had a health condition (e.g., chronic pain, PSQI > 5, tinnitus, migraines/headaches, dizziness, highly sensitive to noise, and reported a high sleep disturbance) ranged from 2.53 to 3.72; the mean aggregate annoyance for those who did not exhibit these same health conditions ranged between 0.96 and 1.41. Participants who reported that someone in their household lodged a formal complaint (34 participants) had the highest average aggregate annoyance (i.e., 8.02), compared to an average of 1.39 among those who did not lodge a formal complaint. Aggregate annoyance was effectively 0 (i.e., least squares mean − 0.11) among the 110 participants who reported to receive personal benefit from having wind turbines in the area, compared to an average of 1.93 among those who did not report such benefits.

Similar results were detected when the analysis was conducted with A-weighted WTN levels (see supplemental material). For example when A-weighted WTN levels were used in place of proximity to turbines, a significant increase in average aggregate annoyance was also observed among participants who self-reported to have chronic pain, scores on the PSQI above 5 (i.e., poor sleep), tinnitus, migraines/headaches, dizziness, reported very or extreme (i.e., high) sensitivity to noise, and reported very or extreme (i.e., high) sleep disturbance at home over the last year, for any reason. Again, the average aggregate annoyance score for those participants who reported these health effects ranged from 2.38–3.50; the mean aggregate annoyance for those who did not report these same health conditions ranged from 0.78 to 1.27.

Finally, linear regression models, after adjustments were made for age and sex, revealed that diastolic blood pressure, PSS, and PSQI scores were positively associated with increased values of aggregate annoyance (see Table 2). For example, for every unit increase in the log-transformed diastolic blood pressure (log mmHg), aggregate annoyance would increase by 2.28 (SE 0.86, $p = 0.0084$). Aggregate annoyance would increase by 0.07 (SE 0.02, $p < 0.0001$) for every unit increase in PSS and by 0.21 (SE 0.03, $p < 0.0001$) for every

Table 1 Aggregated annoyance related to specific outcome assessed

Variable	Number	ANOVA model adjusted for distance and province[a]		ANOVA model adjusted for distance, province, age, and sex[b]	
		Least squares means (95% CI)[c]	*p* value[d]	Least squares means (95% CI)[e]	*p* value[d]
Sex					
Male	600	1.89 (1.47, 2.31)	0.0345		
Female	626	1.46 (1.05, 1.87)			
Age group (years)					
≤24	72	0.63 (−0.29, 1.54)	0.0089		
25–44	327	1.65 (1.16, 2.14)			
45–64	543	1.94 (1.51, 2.37)			
65+	284	1.38 (0.85, 1.91)			
Chronic pain					
Yes	285	2.69 (2.16, 3.22)	0.0001	2.47 (1.89, 3.05)	0.0002
No	939	1.41 (1.04, 1.78)		1.20 (0.80, 1.61)	
High blood pressure					
Yes	368	1.52 (1.04, 2.01)	0.3909	1.20 (0.65, 1.76)	0.1962
No	854	1.72 (1.34, 2.10)		1.48 (1.06, 1.90)	
Heart disease					
Yes	94	1.45 (0.63, 2.26)	0.3341	1.15 (0.31, 2.00)	0.2533
No	1131	1.68 (1.32, 2.04)		1.42 (1.02, 1.83)	
Reported "poor" sleep					
PSQI > 5	549	2.53 (2.11, 2.96)	< 0.0001	2.31 (1.84, 2.77)	< 0.0001
PSQI ≤ 5	650	0.96 (0.54, 1.37)		0.75 (0.31, 1.19)	
Rated QOL, previous month[f]					
Poor	80	2.41 (1.54, 3.28)	0.1187	2.14 (1.25, 3.02)	0.1372
Good	1144	1.61 (1.25, 1.98)		1.36 (0.95, 1.76)	
Rated satisfaction with health, previous month[g]					
Dissatisfied	173	2.32 (1.69, 2.95)	0.1086	2.04 (1.38, 2.70)	0.1392
Satisfied	1053	1.56 (1.19, 1.93)		1.31 (0.91, 1.72)	
Tinnitus					
Yes	290	2.89 (2.38, 3.40)	< 0.0001	2.63 (2.09, 3.17)	< 0.0001
No	935	1.28 (0.91, 1.65)		1.02 (0.61, 1.43)	
Migraines[h]					
Yes	287	3.49 (2.98, 4.01)	< 0.0001	3.37 (2.83, 3.92)	< 0.0001
No	938	1.21 (0.85, 1.57)		0.90 (0.50, 1.29)	
Dizziness					
Yes	270	3.00 (2.48, 3.53)	< 0.0001	2.82 (2.26, 3.37)	< 0.0001
No	956	1.30 (0.94, 1.67)		1.04 (0.63, 1.45)	
Medication for anxiety or depression					
Yes	141	1.51 (0.83, 2.20)	0.2415	1.30 (0.59, 2.02)	0.3293
No	1085	1.68 (1.31, 2.05)		1.41 (1.01, 1.82)	
Noise sensitivity[i]					
High	171	3.72 (3.10, 4.34)	< 0.0001	3.52 (2.87, 4.18)	< 0.0001
Less than high	1051	1.36 (1.00, 1.72)		1.14 (0.74, 1.54)	
Long-term sleep disturbance[j]					
High	162	3.48 (2.84, 4.12)	< 0.0001	3.25 (2.58, 3.93)	< 0.0001
Less than high	1061	1.41 (1.05, 1.77)		1.19 (0.79, 1.59)	
Household complaint lodged regarding WTN					
Yes	34	8.02 (6.79, 9.24)	< 0.0001	7.73 (6.48, 8.97)	< 0.0001

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Table 1 (continued)

Variable	Number	ANOVA model adjusted for distance and province[a]		ANOVA model adjusted for distance, province, age, and sex[b]	
		Least squares means (95% CI)[c]	*p* value[d]	Least squares means (95% CI)[e]	*p* value[d]
No	1189	1.39 (1.04, 1.74)		1.18 (0.79, 1.56)	
Personal benefit[k]					
Yes	110	− 0.11 (− 0.88, 0.66)	< 0.0001	− 0.36 (− 1.15, 0.43)	< 0.0001
No	1064	1.93 (1.54, 2.31)		1.68 (1.25, 2.11)	

[a] Analysis of variance (ANOVA) model of aggregate annoyance related to variable, model adjusted for province and distance to turbines

[b] ANOVA model of aggregate annoyance related to variable, model adjusted for province, distance to turbines, age, and sex

[c] Least squares means of aggregate annoyance and corresponding 95% confidence interval (CI) after adjusting for province and distance to turbines

[d] *p* values are based on the ranks of the data (non-parametric statistics)

[e] Least squares means of aggregate annoyance and corresponding 95% confidence interval (CI) after adjusting for province, distance to turbines, age, and sex

[f] Poor includes ratings of "poor" and "very poor"; good includes ratings "neither poor nor good," "good," and "very good"

[g] Dissatisfied includes the ratings "dissatisfied" and "very dissatisfied"; satisfied includes the ratings "neither satisfied or dissatisfied," "satisfied," and "very satisfied"

[h] Frequent migraines or headaches (includes nausea, vomiting, sensitivity to light and sound)

[i] Noise sensitivity was defined as "high" for participants who reported to be very or extremely sensitive and "less than high" for participants who reported to be not at all, slightly, or moderately sensitive

[j] The magnitude of reported sleep disturbance over the previous year while at home for any reason was defined as "high" for participants who reported to be very or extremely sleep disturbed and "less than high" for participants who reported to be not at all, slightly or moderately sleep disturbed

[k] Includes benefit through rent, payments, or other indirect benefits such as a hall or community centre for having wind turbines in their area

unit increase in PSQI. From the WHOQOL-BREF, physical health, psychological well-being, and environmental factors domains were negatively associated with increased values of aggregate annoyance (see Table 2). Larger domain values indicate a healthier QOL for the respective domain. For example, as physical health domain increased, aggregate annoyance decreased by − 0.23 (SE 0.04, $p < 0.0001$); as the psychological well-being index increased, aggregate annoyance decreased by − 0.12 (SE 0.04, $p = 0.0085$); as the environmental factors index increased, aggregate annoyance decreased by − 0.25 (SE 0.05, $p < 0.0001$). All model-adjusted R^2 ranged between 7% and 12%. Results were similar when A-weighted WTN levels were used in the linear regression model (see supplemental material).

Discussion

The current analysis investigated the potential statistical association between aggregate annoyance and health outcomes that were either subjectively reported or objectively measured in the CNHS. Although the associations observed were not as widespread as they were when the analysis was limited to high WTN annoyance (Michaud et al. 2016a), higher aggregate annoyance scores were found to correlate with an increase in diastolic blood pressure, perceived stress (i.e., PSS), rated sleep quality over the previous 30 days (i.e., PSQI scores), physical health, psychological well-being, and environmental factors as measured by the WHOQOL-BREF domains. Annoyance was also higher among participants reporting chronic pain, tinnitus, migraines/headaches, dizziness, and high sleep disturbance at home for any reason over the previous year. When considered collectively, an aggregate annoyance level around 2.5 appeared to separate the group reporting these conditions from those that did not. Average aggregate annoyance dropped below 2.5 in the distance ranges (0.550–1) km in PEI and (1–2) km in ON, from wind turbines.(Michaud et al. 2018) Conditions not related to aggregate annoyance included hair cortisol concentrations, systolic blood pressure, and rated quality of life when assessed with the single standalone question. It should be underscored that the observed associations between aggregate annoyance and health outcomes should not be mistakenly interpreted to mean that annoyance causes adverse health effects (or vice

Table 2 Aggregated annoyance related to specific health condition, continuous variables

Variable (minimum, maximum)	Number	Spearman correlation coefficient (*p* value)	Adjusted R^2 of the linear regression model[a]	Linear regression of aggregate annoyance relative to the variable[a]		Adjusted R^2 of the linear regression model[c]	Linear regression of aggregate annoyance relative to the variable[c]	
				Slope (SE)[b]	*p* value		Slope(SE)[b]	*p* value
Systolic blood pressure (83, 186)	1066	0.06 (0.0580)	0.07	0.01 (0.01)	0.0911	0.07	0.01 (0.01)	0.1356
log(systolic blood pressure) (4.42, 5.23)	1066	0.06 (0.0580)	0.07	1.54 (0.84)	0.0682	0.07	1.48 (0.91)	0.1041
Diastolic blood pressure (50, 114)	1066	0.12 (0.0001)	0.08	0.03 (0.01)	0.0066	0.08	0.03 (0.01)	0.0118
log(diastolic blood pressure) (3.91, 4.74)	1066	0.12 (0.0001)	0.08	2.41 (0.85)	0.0047	0.08	2.28 (0.86)	0.0084
Heart rate (41, 125)	1066	0.02 (0.4222)	0.07	0.00 (0.01)	0.7764	0.07	0.00 (0.01)	0.8553
log(heart rate) (3.71, 4.83)	1066	0.02 (0.4222)	0.07	− 0.15 (0.70)	0.8301	0.07	− 0.07 (0.71)	0.9180
Cortisol (18.12, 7139.34)	670	0.03 (0.4021)	0.07	0.00 (0.00)	0.2896	0.07	0.00 (0.00)	0.3026
log(cortisol) (2.90, 8.87)	670	0.03 (0.4021)	0.08	0.25 (0.14)	0.0871	0.07	0.22 (0.15)	0.1274
PSS (0, 37)	1220	0.13 (< 0.0001)	0.08	0.06 (0.02)	< 0.0001	0.09	0.07 (0.02)	< 0.0001
PSQI (0, 21)	1199	0.19 (< 0.0001)	0.12	0.20 (0.03)	< 0.0001	0.12	0.21 (0.03)	< 0.0001
DOM1 (4–20)	1225	− 0.17 (<0.0001)	0.10	− 0.22 (0.03)	< 0.0001	0.10	− 0.23 (0.04)	< 0.0001
DOM2 (4–20)	1224	− 0.06 (0.0404)	0.08	− 0.11 (0.04)	0.0104	0.08	− 0.12 (0.04)	0.0085
DOM3 (4–20)	1222	− 0.04 (0.1689)	0.07	− 0.05 (0.04)	0.2342	0.07	− 0.04 (0.04)	0.2916
DOM4 (7–20)	1225	− 0.14 (<0.0001)	0.09	− 0.25 (0.05)	< 0.0001	0.09	− 0.25 (0.05)	< 0.0001

PSS perceived stress scale, *PSQI* Pittsburgh Sleep Quality Index, *DOM1* the physical health domain of the WHOQOL-BREF, *DOM2* the psychological well-being domain of the WHOQOL-BREF, *DOM3* the social relationships domain of the WHOQOL-BREF, *DOM4* the environmental factors domain of the WHOQOL-BREF

[a] Linear regression model is adjusted for distance and province

[b] The slope (SE) standard error corresponds to that of the variable listed in column 1 of the table

[c] Linear regression model is adjusted for distance, province, age, and sex

versa). These are statistical observations made from data collected at one point in time with no documented historical records for any of the evaluated outcomes or control for other factors that may impact annoyance or health.

Part of the widespread adoption of *high noise annoyance* as a targeted outcome for community noise in general is that the WHO has quantified the burden of disease associated with it (WHO 2011). No equivalent measure is available to calculate the impact associated with lower magnitudes of annoyance, or when annoyance is directed toward non-noise exposures. High noise annoyance has repeatedly been shown to have a statistical association with elevated long-term average sound levels and other health measures (Niemann et al. 2006; Michaud et al. 2016a). The relationship between elevated sound levels and high noise annoyance may be adequate for transportation noise sources and certain resource activities (e.g., mining) where high noise levels are the principal factor driving community annoyance. A change in high noise annoyance by an equivalent of 6.5% has been suggested as one of the potential measures of a significant noise impact in environmental assessments that are subject to Canadian federal government review (Michaud et al. 2008; Health Canada 2016). However, in situations where multiple variables are driving community annoyance, as appears to be the case with utility scale wind turbines, consideration of only high noise annoyance may undermine other emissions that contribute to overall community annoyance.

As data in this area accumulates, there is no reason why an alternative approach, based upon aggregate annoyance, could not eventually be adopted for situations where multiple source features are known to underscore community annoyance reactions. A mean aggregate annoyance score that could reliably distinguish participants who self-report health effects (or noise complaints) from those who do not could be one of several factors considered by jurisdictions responsible for decisions regarding wind turbine developments. Decisions would have even more support if aggregate annoyance scores could be reliably associated with objectively measured health outcomes. However, the threshold value for acceptable changes and/or levels in aggregate annoyance has not yet been established and some insight may be gained in this regard from future research. Additional research in this area could also assess the perceived valuation attributed to various wind turbine features. For example, aggregate annoyance as an

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outcome that has some relevance to land-use planning assumes that rated measures of annoyance toward noise, shadow flickers, blinking lights, vibrations, or overall visual impacts represent the attributed impact that people assign to each of these wind turbine features. The assumption is that instructing respondents to recall their exposure *over the previous year* before reporting their annoyance level balances differences between wind turbine features, be that in exposure and/or the level of effort one invests in coping with each.

It should also be underscored that in response to concerns raised during the external peer review of this paper, the association between the non-noise annoyance variables and self-reported and measured health outcomes was evaluated. With the exception of vibration annoyance, which could not be evaluated due to the small sample size, blinking lights, shadow flicker, and visual annoyance were found to be statistically associated with several measures of health, including, but not limited to, migraines, dizziness, tinnitus, chronic pain, sleep disturbance, perceived stress, quality of life measures, lodging a WTN-related complaint, and measured diastolic blood pressure. Although these annoyance-specific associations with various health measures lend support to actions that may rely on an aggregate annoyance measure, it would be of interest to compare findings from stated choice experiments to results based on rated annoyance. Stated choice studies can estimate the value assigned to each wind turbine feature using a willingness to pay/accept model similar to that presented by Thanos Wardman and Bristow for aircraft noise valuation (Thanos et al. 2011). Finally, although aggregate annoyance has been presented as a construct that reflects a more complete measure of community annoyance toward wind turbines (Michaud et al. 2018), additional research could investigate indirect factors for their potential contribution to community annoyance (e.g., perceived impacts on property value, electricity costs, and wildlife). Similarly, perceived benefits to the environment could be evaluated as nullifying rated annoyance toward any given wind turbine feature.

As this area of research matures, new findings may identify an aggregate annoyance value that corresponds to a threshold for community acceptability. Although individual exposure response relationships with a clear point of departure in the curve can inform policy decisions, their interpretation can be complicated when separate exposure response functions differ in the overall prevalence of annoyance or when their pattern of change is inconsistent across multiple exposure categories. These issues can be addressed, in part, with an exposure response based upon an aggregate annoyance construct.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *Lancet, 383*(9925), 1325–1332.

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. *Psychiatry Research, 28*, 193–213.

Feder, K., Michaud, D. S., Keith, S. E., Voicescu, S. A., Marro, L., Than, J., Guay, M., Denning, A., Bower, T. J., Lavigne, E., Whelan, C., & van den Berg, F. (2015). An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines. *Environmental Research, 142*, 227–238.

Health Canada. Guidance for evaluating human health impacts in environmental assessment: noise. Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. 2016; Available at: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-evaluating-human-health-impacts-noise.html (Accessed on June 13, 2017).

Keith, S. E., Feder, K., Voicescu, S., Soukhovtsev, V., Denning, A., Tsang, J., Broner, N., Richarz, W., & van den Berg, F. (2016). Wind turbine sound pressure level calculations at dwellings. *The Journal of the Acoustical Society of America, 139*(3), 1436–1442.

Michaud, D. S., Bly, S. H. P., & Keith, S. E. (2008). Using a change in percent highly annoyed with noise as a potential health effect measure for projects under the Canadian environmental assessment act. *Canadian Acoustics, 36*(2), 13–28.

Michaud, D. S., Feder, K., Keith, S. E., Voicescu, S. A., Marro, L., Than, J., Guay, M., Bower, T., Denning, A., Lavigne, E., Whelan, C., Janssen, S. A., & van den Berg, F. (2016a). Personal and situational variables associated with wind turbine noise annoyance. *The Journal of the Acoustical Society of America, 139*(3), 1455–1466.

Michaud, D. S., Feder, K., Keith, S. E., Voicescu, S. A., Marro, L., Than, J., Guay, M., Denning, A., McGuire, D., Bower, T., Lavigne, E., Murray, B. J., Weiss, S. K., & van den Berg, F. (2016b). Exposure to wind turbine noise: perceptual responses and reported health effects. *The Journal of the Acoustical Society of America, 139*(3), 1443–1454.

Michaud, D. S., Feder, K., Keith, S. E., Voicescu, S. A., Marro, L., Than, J., Guay, M., Denning, A., Bower, T., Villeneuve, P., Russell, E., Koren, G., & van den Berg, F. (2016c). Self-reported and measured stress related responses associated with exposure to wind turbine noise. *The Journal of the Acoustical Society of America, 139*(3), 1467–1479.

Michaud, D. S., Marro, L., & McNamee, J. (2018). Derivation and application of a composite annoyance reaction construct based on multiple wind turbine features. *Canadian Journal of Public Health, 109*(2), https://doi.org/10.17269/s41997-018-0040-y.

Niemann, H., Bonnefoy, X., Braubach, M., Hecht, K., Maschke, C., Rodrigues, C., & Röbbel, N. (2006). Noise-induced annoyance and morbidity results from the pan-European LARES study. *Noise Health, 8*(31), 63–79.

Thanos, S., Wardman, M., & Bristow, A. L. (2011). Valuing aircraft noise: Statted choice experiments reflecting inter-temporal noise changes from airport relocation. *Environ Resour Econ, 50*, 559–583.

WHO. (2011). In L. Fritschi, A. L. Brown, R. Kim, D. Schwela, & S. Kephalopolous (Eds.), *Burden of disease from environmental noise. Quantification of healthy life years lost in Europe*. Bonn: World Health Organization, Regional Office for Europe.

WHOQOL Group. (1998). Development of the World Health Organization WHOQOL-BREF quality of life assessment. *Psychological Medicine, 28*, 551–558.

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An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines ☆

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ABSTRACT

Living within the vicinity of wind turbines may have adverse impacts on health measures associated with quality of life (QOL). There are few studies in this area and inconsistent findings preclude definitive conclusions regarding the impact that exposure to wind turbine noise (WTN) may have on QOL. In the current study (officially titled the *Community Noise and Health Study or CNHS*), the World Health Organization QOL-BREF (WHOQOL-BREF) questionnaire provided an evaluation of QOL in relation to WTN levels among randomly selected participants aged 18–79 (606 males, 632 females) living between 0.25 and 11.22 km from wind turbines (response rate 78.9%). In the multiple regression analyses, WTN levels were not found to be related to scores on the Physical, Psychological, Social or Environment domains, or to rated QOL and Satisfaction with Health questions. However, some wind turbine-related variables were associated with scores on the WHOQOL-BREF, irrespective of WTN levels. Hearing wind turbines for less than one year (compared to not at all and greater than one year) was associated with improved (i.e. higher) scores on the Psychological domain ($p=0.0108$). Lower scores on both the Physical and Environment domains ($p=0.0218$ and $p=0.0372$, respectively), were observed among participants reporting high visual annoyance toward wind turbines. Personal benefit from having wind turbines in the area was related to higher scores on the Physical domain ($p=0.0417$). Other variables significantly related to one or more domains, included sex, age, marital status, employment, education, income, alcohol consumption, smoking status, chronic diseases and sleep disorders. Collectively, results do not support an association between exposure to WTN up to 46 dBA and QOL assessed using the WHOQOL-BREF questionnaire.

Abbreviations: ANOVA, Analysis of Variance; CNHS, Community Noise and Health Study; dBA, A-weighted decibel; dBC, C-weighted decibel; MW, megawatt; ON, Ontario; PEI, Prince Edward Island; QOL, quality of life; SAS, Statistical Analysis System; SF-36®, Short Form Health Survey; WHO, World Health Organization; WHOQOL, World Health Organization Quality Of Life; WHOQOL-BREF, World Health Organization Quality Of Life—abbreviated version of the WHOQOL 100; WTN, wind turbine noise

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1. Introduction

Quality of life (QOL) evaluation in health research emerged in the 1970s in order to supplement traditional morbidity and mortality outcomes. The meaning of the concept of QOL and how it can be reliably evaluated has been studied for many years. The World Health Organization (WHO) defines QOL as "*an individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns*" (WHOQOL Group, 1994). Quality of life is a global measure, broader than health status, inherently subjective and pertains to all aspects of life important to the person (Harrison et al., 1996; Molzahn and Pagé, 2006). There is evidence that dissatisfaction with environment, psychological and/or social domains may impact physical health and well-being in individuals (Guite et al., 2006; Silva et al., 2012).

The methodologies and tools used in environmental noise studies are wide-ranging and have included participant diaries, observational checklists, specialized questionnaires, validated health measures scales and/or QOL scales. The use of a validated measure can be advantageous in that psychometric evaluation such as validity and reliability testing has been completed. In addition, the use of a standardized measure facilitates comparisons across studies enabling trends in research to be more easily examined.

Many QOL studies have used the World Health Organization QOL (WHOQOL)-100, a questionnaire consisting of 100 items divided into multiple domains, which has demonstrated discrimination between healthy and ill populations (WHOQOL Group, 1998). An abbreviated 26-item version (i.e. WHOQOL-BREF) has also been used in numerous studies to evaluate perceptions of health. This questionnaire, developed using data from 30 international field centres, has been found to be an effective cross-cultural assessment of QOL with good to excellent psychometric properties of reliability and validity (Kalfoss et al., 2008; Skevington et al., 2004). The WHOQOL-BREF consists of 4 domains, Physical Health, Psychological, Social Relationships, and Environment. Each domain is comprised of multiple questions that are considered together in the derivation of each domain score. In addition to the 4 domains, the WHOQOL-BREF includes two standalone questions to assess rated QOL and Satisfaction with Health (WHOQOL Group, 1994).

Some environmental noise studies have utilized QOL measures to quantify and compare community response to different noise sources (Shepherd et al., 2010; Welch et al., 2013), with the general observation that increasing exposure to noise is associated with decreased QOL. As reliance on wind power as a source of energy increases, the introduction of wind farms into communities is sometimes resisted or negatively received based, at least in part, on the perception that exposure to wind turbine noise (WTN) has adverse impacts on health and QOL. In a review of literature related to the health effects of WTN, the Council of Canadian Academies (2015) concluded that the only health effect with sufficient evidence for a causal association with exposure to WTN was long term annoyance. Among the Council's key findings was an acknowledgement that there was a paucity of epidemiological studies to draw upon and those that did exist suffered from methodological problems that included, but were not limited to weak statistical power, bias, and lack of controls. Other reviews by researchers and government agencies have reached similar conclusions (Chief Medical Officer of Health Ontario, 2010; Knopper et al., 2014; MassDEP and MDPH, 2012; Merlin et al., 2014; Oregon Health Authority, 2013; Schmidt and Klokker, 2014).

In comparison to the large body of scientific literature examining the response to transportation noise, there are few original epidemiological studies that have investigated the possible impact on QOL among communities living within the vicinity of wind turbines and among those studies, only a limited number of them have utilized validated instruments to examine QOL (Onakpoya et al., 2014). Shepherd et al. (2011) reported that individuals who lived near a wind farm scored worse on general QOL and on the Physical and Environment domains of the WHOQOL-BREF compared to a geographically and socioeconomically matched group living at least 8 km from any wind farms. Conflicting results were found in two other wind turbine studies (Mroczek et al., 2012; Nissenbaum et al., 2012), where QOL was evaluated using a Short Form Health Survey (SF-36®) to examine health outcomes in individuals who lived close to wind turbines and those who lived further away. Nissenbaum et al. (2012) reported lower scores on the mental, but not physical component of the SF-36®, among 38 participants living between 375 m and 1400 m of a wind turbine when compared to 41 participants living between 3.3 km and 6.6 km from a wind turbine. This is in contrast to the findings from a much larger study by Mroczek et al. (2012) where *improved* QOL for all SF-36® domains was found among those living at the closest distance to a wind farm (i.e. < 700 m), in comparison to those living beyond 1500 m. In an extended analysis, Mroczek et al. (2015) reaffirmed a higher reported QOL among participants living closer to wind turbines, relative to those living further away and reported that the stage of the wind farm development was an important factor in this regard. These incongruent results, in addition to their methodological issues, small sample sizes and low response rates underscored the need for more research.

Where wind turbines are concerned, it has also been shown that there can be adverse community reactions to features that go beyond WTN emissions. In particular, self-reported health effects have been attributed to features such as shadow flicker. Wind turbine shadow flicker is a phenomenon caused by the flickering effect of rotating blades periodically casting shadows over some but not all neighbouring properties and through windows (Bolton, 2007; Department of Energy and Climate Change (DECC), 2011; Saidur et al., 2011). With their blade length accounted for, utility-scale wind turbines can reach 130 m and wind farms can include dozens of wind turbines. Their height necessitates aircraft warning signals (e.g. blinking lights on the turbine nacelle) and the visual intrusion of wind turbines on the landscape, in addition to WTN, are features that are known to underlie the response to wind turbines (Harding et al., 2008; Pedersen and Larsman, 2008; Pohl et al., 1999; Smedley et al., 2010; van den Berg et al., 2008). While the annoyance response to shadow flicker and/or blinking lights on top of wind turbines has been investigated (Katsaprakakis, 2012; Pohl et al., 2000, 2012), the only field study to assess QOL measures as a function of shadow flicker exposure was published in German by Pohl et al. (1999). In this study, exposure to shadow flicker was related to decreased QOL and elevated annoyance (Pohl et al., 1999).

In assessing the potential contribution that exposure to wind turbines may have on health and QOL, it is important to consider personal and situational factors that may influence reported QOL. For instance, expectations of negative reactions and worry about perceived risk may play a role in self-reported health impacts related to wind turbines (Crichton et al., 2014; Henningsen and Priebe, 2003). Others have found attitudinal factors, personality traits and personal benefit from wind turbines influenced the magnitude of the annoyance to wind turbines; which in turn may be responsible for reported health effects (Chapman et al., 2013; Rubin et al., 2014; Taylor et al., 2013; Pedersen et al., 2009). Regardless of the mechanisms, it is well known that self-reported health is highly correlated with QOL (Bowling, 1995; Hutchinson et al., 2004).

The objective of the present paper was to assess self-reported QOL among individuals living in areas with varying levels of WTN exposure. To this end, the WHOQOL-BREF was administered as part of Health Canada's CNHS. The underlying hypothesis in the current study is that if QOL is adversely impacted by WTN exposure, participants living in areas with higher exposures to WTN would yield lower scores on the WHOQOL-BREF.

2. Methods

2.1. Sample design

2.1.1. Target population, sample size and sampling frame strategy

A detailed description of the study design and methodology, the target population, final sample size and allocation of participants, as well as the strategy used to develop the sampling frame has been described by Michaud et al. (2013) and Michaud (2015). Briefly, the study locations were drawn from areas in southwestern Ontario (ON) and Prince Edward Island (PEI) where there were a sufficient number of dwellings within the vicinity of wind turbine installations. There were 2004 potential dwellings identified from the ON and PEI sampling regions, which included 12 and 6 wind farms, representing a total of 315 and 84 wind turbines respectively. The wind turbine electrical power outputs ranged between 660 kW and 3 MW (average 2.0 $\pm$ 0.4 MW). All turbines were modern monopole design with 3 pitch controlled rotor blades (~80 m diameter) upwind of the tower and most had 80 m hub heights. All dwellings within approximately 600 m from a wind turbine and a random selection of dwellings between 0.60 and 11.22 km were selected from which one person per household between the ages of 18 and 79 years was randomly chosen to participate. Several factors influenced the determination of the final sample size, including having adequate statistical power to assess the study objectives, and the time required for collection of data (Michaud et al., 2013). Taken together, it was determined that a sample size of approximately 1100 would be required to meet study objectives. It was likely that this sample size would be sufficient to detect statistically significant impacts on QOL in the current study given that Shepherd et al. (2011) reported a statistically significant impact on QOL using the WHOQOL-BREF among 39 participants living near wind turbines when compared to 158 participants living further away.

2.1.2. Wind turbine sound pressure levels at dwellings

Outdoor wind turbine sound pressure levels were estimated at each dwelling using both ISO 9613-1 and ISO 9613-2 (ISO 1993, 1996) as incorporated in the commercial software CadnaA version 4.4 (DataKustik GmbH®, 2014). The calculations included all wind turbines within a radius of 10 km, and were based on manufacturers' octave band sound power spectra at 8 m/s, standardized wind speed and favourable sound propagation conditions. Favourable conditions assume the dwelling is located downwind of the noise source, or a stable atmosphere and a moderate ground based temperature inversion. Although different wind speeds and temperature difference could not be considered in the model calculations due to a lack of relevant data, 8 m/s was considered a reasonable estimate of the highest noise exposure conditions. The manufacturers' data were verified for consistency using on-site measurements of wind turbine sound power. The standard deviation in sound levels was estimated to be 4 dB up to 1 km, and at 10 km the uncertainty was estimated to be between 10 dB and 26 dB. While calculations based on predictions of WTN levels reduces the risk of misclassification compared to direct measurements, the risk remains to some extent.

Outdoor WTN levels were also modeled in C-weighted values (dBC), however due to the similarity of the sound power spectra, dBC levels were highly correlated with dBA levels such that there was no additional benefit in using dBC in the current study. Unless otherwise stated, all dB references are A-weighted. A-weighting filters out high and low frequencies in a sound that the human auditory system is less sensitive to at low sound pressure levels.

2.2. Data collection

2.2.1. Questionnaire development, administration and refusal conversion strategies

The questionnaire instrument included the following modules: noise annoyance, health effects, sleep quality, perceived stress, lifestyle behaviours and prevalent chronic disease. QOL was assessed using the WHOQOL-BREF. This 26 item QOL instrument has shown good to excellent psychometric properties and is cross culturally sensitive (WHOQOL Group, 1998). The WHOQOL-BREF generates a profile and score for each of the 4 QOL domains; questions are centered around the meaning respondents attribute to each aspect of life and how problematic or satisfactory they perceive them to be (Skevington et al., 2004). The Physical Health domain includes questions pertaining to sleep, energy, mobility, the extent to which pain prevents performance of necessary tasks, the need for medical treatment to function in daily life, level of satisfaction with their capacity for work. The Psychological domain focuses on the ability to concentrate, self-esteem, body image, spirituality i.e. the extent to which they feel their life is meaningful, the frequency of positive or negative feelings i.e. blue mood, despair, anxiety, depression. The Social Relationships domain includes questions pertaining to satisfaction with personal relationships, social support systems and sexual satisfaction. The fourth domain, the Environment, includes questions related to safety and security, home and physical environment satisfaction, finance i.e. does the respondent have enough money to meet their needs, health/social care availability, information and leisure activity accessibility and transportation satisfaction (Skevington et al., 2004). In addition to the 4 domains, the WHOQOL-BREF includes two stand-alone questions, one pertaining to the respondents' rated QOL, and one related to their Satisfaction with Health. The WHOQOL-BREF instructions specify that this questionnaire is to be used without modification (WHOQOL-BREF, 1996).

Throughout data collection, the Health Canada study was officially referred to as the "*Community Noise and Health Study*" in an attempt to mask the true intent of the study, which was to investigate the association between health and WTN exposure. This approach is commonly used in epidemiological studies to avoid a disproportionate contribution from any group that may have distinct views regarding a study subject, such as wind turbines. Data collection took place through in-person interviews between May 2013 and September 2013 in southwestern ON and PEI. Once a roster of all adults, 18–79 years, living in the dwelling was compiled, a computerized method was used to randomly select one adult per household. No substitution was permitted; therefore, if the targeted individual was not at home or unavailable, alternate arrangements were made to encourage participation at a later time.

All 16 interviewers were instructed to make every reasonable attempt to obtain interviews, which included visiting the dwelling at various times of the day on multiple occasions and making contact by telephone when necessary. If the individual refused to participate, they were then contacted a second time by either the senior interviewer or another interviewer. If, after a second contact, respondents refused to participate, the case was coded as a final refusal.

2.2.2. Statistical analysis

The 4 domains are factors based on the 26 questions which make up the WHOQOL-BREF. As such they are treated as continuous outcomes with each domain score converted to scores ranging between 4 and 20, in accordance with the first transformation method outlined in the WHOQOL-BREF scoring instructions (WHOQOL-BREF 1996). The two stand-alone questions related to QOL rating and Satisfaction with Health were analysed separately, as recommended by WHOQOL-BREF (1996). These two questions include five point response categories for QOL: "*very poor*", "*poor*", "*neither poor nor good*", "*good*" and "*very good*" and for Satisfaction with Health: "*very dissatisfied*", "*dissatisfied*", "*neither satisfied nor dissatisfied*", "*satisfied*" and "*very satisfied*". Analysis was performed after collapsing the bottom two categories (i.e., for QOL "*very poor*" and "*poor*"; for Satisfaction with Health "*very dissatisfied*" and "*dissatisfied*") and comparing them to the top three. This approach produced the following derived variables: "*poor QOL*" vs. "*good QOL*" and "*dissatisfied with own health*" vs. "*satisfied with own health*". Therefore, unlike the 4 domains, these two questions are treated as binary outcomes.

The relationship between sensitivity to noise, QOL and WTN exposure was also considered. Sensitivity to noise was scored on the following five-point response scale: "*not at all*", "*slightly*", "*moderately*", "*very*" and "*extremely*". The response scale for this variable was dichotomized with "*high sensitivity*" including the "*very*" and "*extremely*" categories; and "*low sensitivity*" including "*not at all*", "*slightly*" and "*moderately*" categories. A sensitivity analysis was conducted to investigate the advantage of keeping the noise sensitivity as a 3 scale parameter ("*highly*", "*moderately*", "*low*"). Conclusions in the analysis were similar whether noise sensitivity was included as a dichotomized scale or a 3 scale parameter (i.e. there was no statistical difference in QOL domains between those having moderate noise sensitivity and low noise sensitivity). No additional information was gained by including the 3 scale parameter (results not shown).

The analysis for continuous and categorical outcomes follows the description outlined in Michaud et al. (2013). Final WTN categories (dBA) were defined as follows: {<25; 25–<30; 30–<35; 35–<40; and 40–46}. Univariate analyses of WHOQOL-BREF domains, rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables which could conceivably be expected to influence QOL. The analysis of each variable only adjusts for WTN exposure category and province, and interpretation of any individual relationship must therefore be made with caution. Multiple linear regression models for the domains (continuous outcomes) and multiple logistic regression models for the two stand-alone questions (binary outcomes) were developed using the stepwise method with a 20% significance entry criterion (determined from the univariate analyses, see Supplemental material). A 10% significance criterion was applied to retain variables in the model. The stepwise regression was carried out in three different ways: (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. In cases when cell frequencies were small (i.e. <5) in the contingency tables or logistic regression models, exact tests were used as described in Agresti (2002) and Stokes et al. (2000). Since this latter technique is very computationally intensive, the WTN level categories had to be treated as a continuous variable. All models were adjusted for provincial differences with province initially considered as an effect modifier. Since the interaction was not statistically significant, province was treated as a confounder in the linear and logistic regression models. Statistical analysis was performed using Statistical Analysis System (SAS) version 9.2. A 5% statistical significance level was implemented throughout unless otherwise stated. Pairwise tests or multiple comparisons were only conducted when the overall significance of the variable was less than 0.05. In addition, Tukey (for continuous outcomes) and Bonferroni (for binary outcomes) corrections were carried out to account for all pairwise comparisons to ensure that the overall Type I (false positive) error rate was less than 0.05. Only variables which are conceptually, and/or have been previously found to be related to QOL were included in the analysis.

3. Results

3.1. Wind turbine sound pressure levels at dwellings, response rates and sample characteristics

Calculated outdoor sound pressure levels reached levels as high as 46 dB. Calculations are representative of typical worst case long term (1 year) average WTN levels. Initially, 2000 addresses were targeted, with 4 additional addresses added during field investigations. Of the 2004, 1570 addresses were considered to be valid dwellings, from which 1238 occupants agreed to participate in the study (606 males, 632 females). This produced a final calculated response rate of 78.9%. The 434 dwellings that were found to be out-of-scope was anticipated based on previous surveys carried out in rural Canadian areas and on Census data forecasting a higher out-of-scope dwelling rate in PEI compared to ON. A characterisation of the out-of-scope locations is provided in Michaud (2015).

Factors that might be expected to influence QOL, such as self-reported prevalence of chronic disease, health conditions, noise sensitivity and reporting to be highly sleep disturbed in any way, for any reason, were all found to be equally distributed across WTN categories (Michaud, 2015).

3.2. Internal consistency of the WHOQOL-BREF domains

Table 1 presents the summary statistics and Cronbach's alpha for the WHO domains. Cronbach's alpha, a measure of the internal consistency of the facets/domains, was above the recommended 70% for all domains except Social Relationships (Cronbach's alpha=66%). This indicates that the correlation within the data for the three items used to determine the Social Relationships domain was found to be questionable within the current study. Caution is therefore advised when interpreting the results within this domain. In the case of a Cronbach's alpha of <0.70, it is recommended that the item(s) least correlated with the construct be dropped one at a time. However, this approach would yield a Social domain that consists of only two questions. Furthermore, analysis of individual items is not recommended as there is a risk of considerable random measurement error (McIver and Carmines, 1981; Nunnally and Bernstein, 1994; Spector, 1992).

3.3. Univariate analysis of variables related to the WHOQOL-BREF

Univariate analyses of WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables including, but not limited to, chronic

Table 1
Summary of the WHOQOL-BREF domains.

Domain	Mean (SD)	Range	Cronbach's alpha	Standardized Cronbach's alpha	*n*
Physical Health	16.06 (3.03)	(4, 20)	0.86	0.86	1236
Psychological	15.99 (2.43)	(4, 20)	0.79	0.80	1236
Social Relationships	16.46 (2.83)	(4, 20)	0.64	0.66	1233
Environment	16.47 (2.20)	(7, 20)	0.72	0.73	1237

SD, standard deviation.

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Table 2a
Multiple linear regression model: Physical Health domain.

Variable	Groups in Variable[a]	LSM (95%CI)[b] (R^2=0.45, n=945)[e]	PWC[c]	p-Value[d]
WTN levels (dB)	< 25 (n=84)	13.11 (12.32, 13.90)		0.1689
	25– < 30 (n=95)	13.35 (12.55, 14.15)		
	30– < 35 (n=304)	13.31 (12.65, 13.98)		
	35– < 40 (n=521)	13.71 (13.08, 14.34)		
	40–46 (n=234)	13.45 (12.81, 14.10)		
Province	PEI (n=227)	13.49 (12.79, 14.19)		0.3415
	ON (n=1011)	13.28 (12.72, 13.84)		
Personal benefit	Yes (n=110)	13.68 (12.91, 14.45)	A	0.0415
	No (n=1075)	13.10 (12.57, 13.62)	B	
Employed	Yes (n=722)	13.85 (13.22, 14.49)	A	< 0.0001
	No (n=515)	12.92 (12.31, 13.53)	B	
Marital status	Married/common-law (n=848)	13.47 (12.89, 14.05)	AB	0.0141
	Widowed/separated/divorced (n=215)	13.76 (13.10, 14.43)	A	
	Single, never been married (n=172)	12.92 (12.20, 13.65)	B	
Audible rail noise	Yes (n=227)	13.58 (12.91, 14.26)		0.0568
	No (n=1011)	13.19 (12.61, 13.77)		
Visual annoyance to turbines	High (n=159)	13.11 (12.41, 13.81)	A	0.0193
	Low (n=1075)	13.67 (13.09, 14.24)	B	
Alcohol use	Do not drink alcohol (n=274)	13.16 (12.52, 13.80)	AB	0.0069
	≤ 3 Times per month (n=474)	13.06 (12.44, 13.68)	A	
	1–3 Times/week (n=325)	13.61 (12.96, 14.26)	B	
	≥ 4 Times/week (n=164)	13.72 (13.00, 14.44)	B	
Smoking status	Current (n=284)	13.12 (12.48, 13.76)	A	0.0273
	Former (n=423)	13.38 (12.74, 14.02)	AB	
	Never (n=531)	13.66 (13.02, 14.29)	B	
Migraines[f]	Yes (n=289)	12.99 (12.34, 13.63)	A	0.0001
	No (n=948)	13.79 (13.17, 14.40)	B	
Dizziness	Yes (n=273)	12.85 (12.21, 13.50)	A	< 0.0001
	No (n=965)	13.92 (13.31, 14.54)	B	
Tinnitus	Yes (n=293)	13.16 (12.53, 13.80)	A	0.0237
	No (n=944)	13.61 (12.99, 14.22)	B	
Chronic pain	Yes (n=293)	12.21 (11.58, 12.84)	A	< 0.0001
	No (n=943)	14.56 (13.93, 15.19)	B	
Arthritis	Yes (n=402)	13.12 (12.50, 13.74)	A	0.0043
	No (n=835)	13.66 (13.03, 14.29)	B	
Diabetes	Yes (n=113)	13.06 (12.33, 13.79)	A	0.0197
	No (n=1123)	13.72 (13.14, 14.29)	B	
Medication for high blood pressure, past month	Yes (n=370)	13.14 (12.51, 13.77)	A	0.0093
	No (n=866)	13.63 (13.01, 14.25)	B	
Chronic bronchitis/emphysema/COPD	Yes (n=71)	12.87 (12.07, 13.67)	A	0.0027
	No (n=1165)	13.90 (13.36, 14.45)	B	
Diagnosed sleep disorder	Yes (n=119)	12.84 (12.14, 13.54)	A	< 0.0001
	No (n=1119)	13.93 (13.33, 14.53)	B	

COPD, chronic obstructive pulmonary disease, LSM, least square mean; ON, Ontario; PEI, Prince Edward Island; PWC, pairwise comparison; WTN, wind turbine noise. Table footnotes are applicable for Tables 2a–2d.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Based on the multiple linear regression model adjusted for all other variables in the model and 95% Tukey adjusted confidence interval.

[c] Where overall p-value is < 0.05, pairwise comparisons were conducted. After adjusting for multiple comparisons, groups with the same letter are statistically similar, groups with different letters are statistically different.

[d] Overall p-value from multiple linear regression model testing the significance of the variable.

[e] Only participants with complete records were considered in the final model.

[f] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

diseases, self-reported health conditions, socio-demographic characteristics, audibility of wind turbines, WTN annoyance, annoyance with the visual aspect of wind turbines and other variables related to the perception of wind turbines, which could conceivably be expected to influence QOL. Included among these variables was personal benefit. In this study, personal benefit refers to those who reported to benefit in any way from having a wind turbine in their area, including receiving rent, payments or other indirect benefits from community improvements. The primary objective in the current analysis was to use multiple regression models to identify the variables that have the strongest statistical association with the WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions. All explanatory variables significant at the 20% level in the univariate analysis were considered in the multiple regression models. The univariate analyses are available in Supplemental material.

3.4. Multiple linear regression models for WHOQOL-BREF domains

Multiple linear regression models to describe the variability in the WHOQOL-BREF domains were developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in Supplemental material. The final models for the three approaches to stepwise regression as listed in the statistical methods section produced nearly

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Table 2b
Multiple linear regression model: Psychological domain.

Variable	Groups in Variable	LSM (95%CI) (R^2=0.25, n=949)	PWC	p-Value
WTN levels (dB)	< 25 (n=84)	15.13 (14.38, 15.88)		0.6002
	25– < 30 (n=95)	14.98 (14.19, 15.76)		
	30– < 35 (n=304)	14.79 (14.17, 15.40)		
	35– < 40 (n=521)	15.02 (14.45, 15.58)		
	40–46 (n=234)	14.81 (14.23, 15.39)		
Province	PEI (n=227)	14.63 (14.00, 15.27)	A	0.0018
	ON (n=1011)	15.26 (14.72, 15.79)	B	
Personal benefit from having wind turbines in the area	Yes (n=110)	15.13 (14.43, 15.84)		0.1512
	No (n=1075)	14.76 (14.26, 15.26)		
Age group	≤ 24 (n=72)	15.33 (14.42, 16.25)	AB	0.0230
	25-44 (n=331)	14.71 (14.12, 15.30)	AB	
	45-64 (n=547)	14.60 (14.07, 15.13)	A	
	65+ (n=288)	15.14 (14.53, 15.74)	B	
Marital status	Married/common-law (n=848)	15.33 (14.77, 15.89)	A	0.0013
	Widowed/separated/divorced (n=215)	14.71 (14.07, 15.36)	B	
	Single, never been married (n=172)	14.80 (14.15, 15.45)	AB	
Employed	Yes (n=722)	15.14 (14.56, 15.72)	A	0.0265
	No (n=515)	14.75 (14.17, 15.33)	B	
Level of education	≤ High school (n=678)	14.62 (14.06, 15.18)	A	0.0109
	Trade/certificate/college (n=469)	14.76 (14.18, 15.34)	A	
	University (n=90)	15.45 (14.75, 16.15)	B	
Sensitivity to noise	High (n=175)	15.12 (14.49, 15.75)		0.0947
	Low (n=1059)	14.77 (14.22, 15.32)		
Alcohol use	Do not drink alcohol (n=274)	14.92 (14.33, 15.51)		0.0565
	≤ 3 Times per month (n=474)	14.67 (14.10, 15.25)		
	1–3 Times/week (n=325)	15.16 (14.55, 15.77)		
	≥ 4 times/week (n=164)	15.03 (14.35, 15.70)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	14.54 (14.02, 15.05)	A	0.0108
	Less than 1 year (n=61)	15.54 (14.72, 16.36)	B	
	1 year or more (n=522)	14.76 (14.19, 15.32)	A	
Migraines	Yes (n=289)	14.74 (14.15, 15.34)	A	0.0364
	No (n=948)	15.14 (14.57, 15.72)	B	
Dizziness	Yes (n=273)	14.32 (13.72, 14.92)	A	< 0.0001
	No (n=965)	15.57 (15.00, 16.14)	B	
Tinnitus	Yes (n=293)	14.72 (14.12, 15.31)	A	0.0138
	No (n=944)	15.17 (14.60, 15.74)	B	
Chronic pain	Yes (n=293)	14.45 (13.85, 15.05)	A	< 0.0001
	No (n=943)	15.44 (14.87, 16.00)	B	
Diabetes	Yes (n=113)	14.72 (14.03, 15.40)		0.0721
	No (n=1123)	15.17 (14.66, 15.69)		
Diagnosed sleep disorder	Yes (n=119)	14.25 (13.59, 14.91)	A	< 0.0001
	No (n=1119)	15.64 (15.10, 16.18)	B	

identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Tables 2a–2d present a detailed account of the demographic, wind-turbine related, personal and health-related variables found to be most strongly associated with the WHOQOL-BREF domains. The final multiple linear regression models accounted for 16%, 24%, 25% and 45% of the variance in the Social Relationships, Environment, Psychological and Physical Health domains, respectively. As shown in Tables 2a–2d, WTN exposure was not found to be significant in any domain, even after adjusting for the other factors. Also, no differences between provinces were observed among domains with the exception of the Psychological domain, where ON had higher domain values than PEI (p=0.0018). A notable observation was that high visual annoyance with wind turbines was associated with lower scores on the Physical Health (Table 2a) and Environment (Table 2d) domains, p=0.01931 and p=0.0096, respectively.

3.5. Multiple logistic regression models, QOL, Satisfaction with Health

Multiple logistic regression models to describe the variability in the two stand-alone questions of the WHOQOL-BREF (QOL and Satisfaction with Health) were also developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in the Supplemental Material. The stepwise regression was carried out in a similar fashion as for the 4 domains i.e., (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. The final models for the three approaches to stepwise regression listed above produced nearly identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Multiple logistic regression models for prevalence of those who rated their QOL to be "*poor*" (includes the ratings "*very poor*" and "*poor*") and reported to be "*dissatisfied*" with their health (includes ratings "*very dissatisfied*" and "*dissatisfied*") are presented in

Table 2c
Multiple linear regression model: Social Relationships domain.

Variable	Groups in variable	LSM (95%CI) (R^2=0.16, n=987)	PWC	p-Value
WTN levels (dB)	< 25 (n=84)	14.57 (13.73, 15.42)		0.7298
	25– < 30 (n=95)	14.95 (14.07, 15.83)		
	30– < 35 (n=304)	14.42 (13.72, 15.13)		
	35– < 40 (n=521)	14.60 (13.92, 15.27)		
	40–46 (n=234)	14.59 (13.88, 15.29)		
Province	PEI (n=227)	14.43 (13.67, 15.19)		0.1225
	ON (n=1011)	14.82 (14.25, 15.40)		
Personal benefit from having wind turbines in the area	Yes (n=110)	14.58 (13.76, 15.39)		0.7560
	No (n=1075)	14.68 (14.12, 15.23)		
Sex	Male (n=606)	14.41 (13.75, 15.07)	A	0.0154
	Female (n=632)	14.84 (14.20, 15.49)	B	
Age group	≤ 24 (n=72)	15.27 (14.25, 16.29)	A	0.0029
	25-44 (n=331)	14.65 (13.96, 15.34)	A	
	45-64 (n=547)	14.04 (13.41, 14.67)	B	
	65+ (n=288)	14.55 (13.85, 15.26)	AB	
Marital status	Married/common-law (n=848)	15.52 (14.88, 16.17)	A	< 0.0001
	Widowed/separated/divorced (n=215)	13.95 (13.22, 14.68)	B	
	Single, never been married (n=172)	14.41 (13.65, 15.16)	B	
Employed	Yes (n=722)	14.84 (14.19, 15.50)	A	0.0368
	No (n=515)	14.41 (13.75, 15.07)	B	
Façade type	Fully bricked (n=340)	15.13 (14.46, 15.80)	A	0.0012
	Partially bricked (n=218)	14.19 (13.44, 14.95)	B	
	No brick/other (n=680)	14.55 (13.92, 15.18)	B	
Audible rail noise	Yes (n=227)	14.42 (13.69, 15.15)		0.0742
	No (n=1011)	14.83 (14.24, 15.43)		
Migraines	Yes (n=289)	14.38 (13.68, 15.07)	A	0.0296
	No (n=948)	14.88 (14.24, 15.51)	B	
Dizziness	Yes (n=273)	14.22 (13.53, 14.91)	A	0.0004
	No (n=965)	15.03 (14.39, 15.67)	B	
Chronic pain	Yes (n=293)	14.32 (13.65, 14.99)	A	0.0049
	No (n=943)	14.93 (14.28, 15.58)	B	
Chronic bronchitis/emphysema/COPD	Yes (n=71)	14.16 (13.30, 15.03)	A	0.0140
	No (n=1165)	15.09 (14.53, 15.64)	B	
Diagnosed sleep disorder	Yes (n=119)	14.27 (13.50, 15.03)	A	0.0167
	No (n=1119)	14.99 (14.37, 15.60)	B	

Tables 3a and 3b. In both models there was no statistically significant association between WTN levels and the prevalence rates for reporting "*poor*" QOL or "*dissatisfied*" Satisfaction with Health, even after adjusting for the other demographic, wind-turbine related and personal and health-related variables (as listed in Tables 3a and 3b). Prevalence rates for both QOL and Satisfaction with Health were similar in both ON and PEI. Together, these variables accounted for 31% and 29% of the variance in rated QOL (Table 3a) and Satisfaction with Health, respectively (Table 3b).

A summary table highlighting all variables retained in the multiple regression models for the 4 WHOQOL-BREF domains and two stand-alone questions is presented as Table 4.

4. Discussion

The present study findings do not support an association between exposure to WTN up to 46 dBA and any of the WHOQOL-BREF domains (Physical Health, Psychological, Social Relationships and Environment) or the two stand-alone questions pertaining to rated QOL and Satisfaction with Health. Participants who were exposed to higher WTN levels did not rate their QOL or Satisfaction with Health significantly worse than those who were exposed to lower WTN levels, nor did they report having significantly worse outcomes in terms of factors that comprise the 4 domains. This is contrary to the findings of Shepherd et al. (2011) who also measured QOL using the WHOQOL-BREF questionnaire. Shepherd et al. (2011) reported significantly lower mean Physical and Environment domain scores and QOL rating among the 39 participants (drawn from 56 dwellings) within 2 km of a wind turbine compared to the 158 participants (drawn from 250 dwellings) that were located at least 8 km from a wind farm. It is difficult to compare these findings with the current study insofar as the participants living within 2 km of a wind turbine in Shepherd et al. (2011) were reportedly exposed to WTN levels ranging from 20 to 50 dB. This encompasses the entire range of exposure in the present study.

A study by Nissenbaum et al. (2012) assessed QOL using the SF-36® questionnaire and utilized an approach similar to Shepherd et al. (2011). Nissenbaum et al. (2012) compared QOL scores among two distance groups from two wind farms. These authors reported lower mean scores for the mental component of the SF-36® among a group of 38 participants from 65 identified adults living between 375 m and 1400 m from the nearest wind turbine when compared to a group of 41 participants living between 3.3 km and 6.6 km away. For the same reasons outlined above concerning Shepherd et al. (2011), it is difficult to compare the findings from the current study to those reported by Nissenbaum et al. (2012). Additionally, a different QOL instrument, the SF-36®, was used in the Nissenbaum et al. (2012) study. The SF-36®, also used in a Polish wind turbine study by Mroczek et al. (2012), is a valuable tool in assessing health and functional status. However, the SF-36® does not examine perceptions of health and well-being to the same degree as the WHOQOL-BREF, nor does it include satisfaction with the living environment and neighbourhood (Asnani et al., 2009; Cruice et al., 2000). The inclusion of

Table 2d
Multiple linear regression model: Environment domain.

Variable	Groups in variable	LSM (95%CI) (R^2=0.24, n=985)	PWC	p-Value
WTN levels (dB)	<25 (n=84)	16.28 (15.58, 16.98)		0.3681
	25–<30 (n=95)	15.71 (14.99, 16.44)		
	30–<35 (n=304)	15.75 (15.16, 16.34)		
	35–<40 (n=521)	15.82 (15.28, 16.36)		
	40–46 (n=234)	15.73 (15.17, 16.28)		
Province	PEI (n=227)	15.76 (15.15, 16.36)		0.2759
	ON (n=1011)	15.96 (15.45, 16.47)		
Personal benefit from having wind turbines in the area	Yes (n=110)	15.92 (15.26, 16.57)		0.6324
	No (n=1075)	15.80 (15.31, 16.29)		
Age group	≤24 (n=72)	16.34 (15.56, 17.12)	A	<0.0001
	25-44 (n=331)	15.45 (14.90, 16.00)	B	
	45-64 (n=547)	15.42 (14.89, 15.95)	B	
	65+ (n=288)	16.22 (15.63, 16.82)	A	
Level of education	≤High school (n=678)	15.60 (15.06, 16.14)	A	0.0228
	Trade/certificate/college (n=469)	15.67 (15.13, 16.21)	A	
	University (n=90)	16.31 (15.63, 16.99)	B	
Income	<60k (n=531)	15.33 (14.78, 15.89)	A	<0.0001
	60–100k (n=300)	15.95 (15.37, 16.52)	B	
	≥100k (n=220)	16.29 (15.72, 16.87)	B	
Property ownership	Own (n=1076)	16.05 (15.52, 16.58)		0.0591
	Rent (n=162)	15.66 (15.06, 16.27)		
Façade type	Fully bricked (n=340)	16.09 (15.53, 16.64)		0.0790
	Partially bricked (n=218)	15.74 (15.12, 16.35)		
	No brick/other (n=680)	15.75 (15.21, 16.30)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	15.89 (15.38, 16.39)		0.0731
	Less than 1 year (n=61)	16.10 (15.35, 16.86)		
	1 year or more (n=522)	15.59 (15.05, 16.12)		
Visual annoyance to turbines	High (n=159)	15.58 (14.97, 16.18)		0.0096
	Low (n=1075)	16.14 (15.60, 16.68)		
Turbine shadow flicker annoyance	High (n=96)	16.08 (15.43, 16.73)		0.0916
	Low (n=1137)	15.64 (15.11, 16.16)		
Alcohol use	Do not drink alcohol (n=274)	15.79 (15.22, 16.37)		0.0690
	≤3 Times per month (n=474)	15.73 (15.19, 16.28)		
	1–3 Times/week (n=325)	16.14 (15.56, 16.72)		
	≥4 Times/week (n=164)	15.77 (15.15, 16.39)		
Smoking status	Current (n=284)	15.56 (14.98, 16.13)	A	0.0134
	Former (n=423)	15.95 (15.39, 16.51)	AB	
	Never (n=531)	16.07 (15.51, 16.62)	B	
Migraines	Yes (n=289)	15.68 (15.12, 16.24)	A	0.0354
	No (n=948)	16.04 (15.49, 16.59)	B	
Dizziness	Yes (n=273)	15.58 (15.01, 16.15)	A	0.0013
	No (n=965)	16.14 (15.59, 16.69)	B	
Tinnitus	Yes (n=293)	15.65 (15.09, 16.21)	A	0.0132
	No (n=944)	16.06 (15.51, 16.62)	B	
Chronic pain	Yes (n=293)	15.60 (15.04, 16.16)	A	0.0013
	No (n=943)	16.12 (15.57, 16.66)	B	
Asthma	Yes (n=101)	15.61 (14.96, 16.25)	A	0.0373
	No (n=1137)	16.11 (15.60, 16.62)	B	
Diagnosed sleep disorder	Yes (n=119)	15.51 (14.89, 16.14)	A	0.0020
	No (n=1119)	16.20 (15.68, 16.73)	B	

environmental and neighbourhood satisfaction would seem to be particularly relevant in the context of wind turbines and how they may impact QOL. Although there is some evidence that indicates the WHOQOL-BREF and SF-36® are comparable in measuring QOL among different clinical populations (Asnani et al., 2009; Hsiung et al., 2005), it is not clear whether this would also apply to communities living within the vicinity of wind turbine installations.

In contrast to Nissenbaum et al. (2012), Mroczek et al. (2012) reported significantly improved QOL on all eight scales of the SF-36® among a Polish population of 220 individuals living within 700 m of a wind farm compared to the 424 individuals living beyond 1500 m. Mroczek et al. (2012) noted that some individuals received economic benefit associated with wind turbines, however this variable was not included in their analysis. Furthermore, Mroczek et al. (2012) concluded that close proximity to wind farms did not result in worsening of QOL, and suggested future research include questions about economic benefit from both land rental for wind farm construction and possible employment in the wind industry.

The influence that economic benefit may have on QOL is uncertain. Receiving personal benefit, when analysed alone, was related to all 4 WHOQOL-BREF domains as well as QOL and Satisfaction with Health stand-alone questions. However, when other variables were also considered in the multiple regression models the relationships changed and personal benefit was only found to be (marginally) related to the Physical Health domain (p=0.0415). This finding was independent of WTN exposure. In relation to personal benefit, a similar finding was reported by van den Berg et al. (2008), who

Table 3a
Multiple logistic regression model: QOL rating.

Variable	Groups in variable[a,b]	QOL rating[c]	
		OR (CI)[d]	p-Value[e]
		(n=946, R^2=0.31, H–L p=0.6796)[f]	
Intercept			0.0001
WTN levels (dB)[g]		1.02 (0.80, 1.32)	0.8523
Province	ON/PEI (n=1011, n=227)	0.66 (0.30, 1.45)	0.3030
Personal benefit[h]	No/yes (n=1075, n=110)	2.51 (0.55, 11.54)	0.2361
Marital status	Married/common-law (n=848)	0.40 (0.18, 0.91)	0.0293
	Widowed/separated/divorced (n=215)	0.37 (0.14, 0.98)	0.0444
	Single, never been married (n=172)	Reference	
Employment	Yes/no (n=722, n=515)	0.56 (0.31, 1.01)	0.0521
Sensitivity to noise	High/low (n=175, n=1059)	1.90 (1.00, 3.62)	0.0516
Dizziness	Yes/no (n=273, n=965)	3.34 (1.88, 5.95)	$<$0.0001
Chronic pain	Yes/no (n=293, n=943)	3.43 (1.93, 6.09)	$<$0.0001
Asthma	Yes/no (n=101, n=1137)	3.72 (1.76, 7.86)	0.0006
High blood pressure	Yes/no (n=372, n=862)	3.06 (1.69, 5.55)	0.0002
Heart disease	Yes/no (n=95, n=1142)	0.42 (0.15, 1.16)	0.0927
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	4.56 (2.33, 8.94)	$<$0.0001

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Where a reference group is not specified it is taken to be the last group.

[c] The multiple logistic regression is modeling the probability of a respondent as rating their quality of life as "Poor" which includes those that responded "Poor" and "Very Poor".

[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR <1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.

[e] p-Value significance is in relation to the reference group.

[f] H–L: Hosmer–Lemeshow test, $p>0.05$ indicates a good fit.

[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.

[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.

Table 3b
Multiple logistic regression model: Satisfaction with Health

Variable	Groups in variable[a,b]	Satisfaction with Health[c]	
		OR (CI)[d]	p-Value[e]
		(n=989, R^2=0.29, H–L p=0.9214)[f]	
Intercept			$<$0.0001
WTN levels (dB)[g]		0.99 (0.82, 1.18)	0.8726
Province	ON/PEI (n=1011, n=227)	0.94 (0.54, 1.64)	0.8243
Personal benefit[h]	No/yes (n=1075, n=110)	1.21 (0.52, 2.82)	0.6544
Alcohol consumption	Do not drink alcohol (n=274)	Reference	
	$\leq$3 Times/month (n=474)	1.10 (0.68, 1.78)	0.7067
	1–3 Times/week (n=325)	0.50 (0.28, 0.90)	0.0202
	$\geq$4 Times/week (n=164)	0.34 (0.16, 0.74)	0.0062
Hear aircraft	Yes/no (n=609, n=629)	0.54 (0.36, 0.82)	0.0036
Sensitivity to noise	High/low (n=175, n=1059)	1.55 (0.94, 2.53)	0.0834
Migraines[i]	Yes/no (n=289, n=948)	1.60 (1.00, 2.57)	0.0491
Dizziness	Yes/no (n=273, n=965)	2.07 (1.31, 3.26)	0.0017
Chronic pain	Yes/no (n=293, n=943)	3.92 (2.49, 6.18)	$<$0.0001
Arthritis	Yes/no (n=402, n=835)	1.65 (1.06, 2.57)	0.0281
Diabetes	Yes/no (n=113, n=1123)	1.72 (0.94, 3.18)	0.0811
Heart disease	Yes/no (n=95, n=1142)	1.74 (0.91, 3.31)	0.0939
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	2.62 (1.52, 4.52)	0.0005

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Where a reference group is not specified it is taken to be the last group.

[c] The multiple logistic regression is modeling the probability of a respondent as rating their satisfaction with health as "Dissatisfied" which includes those that responded "Dissatisfied" and "Very Dissatisfied".

[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR <1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.

[e] p-Value significance is in relation to the reference group.

[f] H–L: Hosmer–Lemeshow test, $p>0.05$ indicates a good fit.

[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.

[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.

[i] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

Table 4
Summary of variables retained in multiple regression models for WHOQOL-BREF

	Domains				Stand-alone questions	
	Physical	Psychological	Social Relationships	Environment	Rated QOL as *poor*	Rated Satisfaction with Health as *dissatisfied*
Demographic variables						
Province		X				
Sex			X			
Age group		X	X	X		
Marital status	X	X	X		x	
Employment	X	X	X		x	
Smoking status	X			X		
Level of education		X		X		
Income				X		
Alcohol use	X	x		x		X
Property ownership				x		
Façade type			X	x		
Audible aircraft						X
Audible rail	x		x			
Wind turbine related variables						
Number of years turbines audible		X		x		
Personal benefit	X					x
Visual annoyance	X			X		
Shadow flicker annoyance				x		
Personal and health-related variables						
Sensitivity to noise		x			x	x
Migraines		X	X	X		X
Dizziness	X	X	X	X	X	X
Chronic pain	X	X	X	X	X	X
Diagnosed sleep disorder	X	X	X	X	X	X
Tinnitus	X	X		X		
Arthritis	X					X
High blood pressure					X	
Medication for high blood pressure	X					
Chronic bronchitis/emphysema/COPD	X		X			
Diabetes	X	x				x
Heart disease					x	x
Asthma				X	X	

All variables marked in the table were statistically significant at $p < 0.10$, variables marked with an upper case X are statistically significant at $p < 0.05$. WHO, World Health Organization; QOL, quality of life. Rated QOL as "Poor" includes participants that responded "Poor" and "Very Poor"; Rating Satisfaction with Health as "Dissatisfied" includes participants that responded "Dissatisfied" or "Very Dissatisfied".

concluded that '*those benefiting are more usually 'healthy farmers', have a more positive view on the visual impact of wind turbines and are relatively young and well educated*'.

Although exposure to WTN was not found to be related to the 4 domains or the QOL or Satisfaction with Health questions, there were specific wind turbine-related variables, beyond personal benefit, that did have an influence on some of these outcomes and which were retained in the multiple regression models. Reporting high visual annoyance from wind turbines was found to be related to lower scores on both the Physical Health and Environment domains of the WHOQOL-BREF, but was unrelated to Psychological, Social Relationships, or rated QOL or Satisfaction with Health. The link between high visual annoyance and lower Environment domain scores is not unexpected as this domain taps into the level of satisfaction respondents report with their physical living space and how healthy and safe they believe their physical environment to be (WHOQOL-BREF, 1996). It is therefore not unreasonable that the Environment domain score would be sensitive to one's annoyance towards the visual presence of wind turbines. In terms of the Physical Health domain, it could be speculated that a high visual annoyance with wind turbines may influence one or more of the facets which comprise this particular domain. It is also possible that the visual perception of wind turbines may have an influence on the perception of the sound levels produced by wind turbines. Visual attributes were found to have an influence on the auditory perception of wind turbines in a controlled laboratory study by Maffei et al. (2013) and may extend to field settings. Although this study represents a relatively new area of investigation, the findings of this study add to existing research that have reported visual disturbance from wind turbines or negative attitudes towards the visual impact of wind turbines on the landscape (Blackburn et al., 2009; Devine-Wright and Howes, 2010; Pasqualetti, 2011; Pedersen and Larsman, 2008; Pedersen and Persson Waye, 2007).

The CNHS study included questions to investigate the length of time respondents reported that wind turbines were audible as a proxy for their history of exposure to WTN. The rationale was to provide insight into whether individuals were adapting or becoming sensitized to WTN exposure over time. Comparisons between participants not hearing wind turbines at all and those who reported hearing them for less than or greater than or equal to 1 year, revealed that those who reported to have heard WTN for less than 1 year had slightly higher (i.e. mean difference between 0.78 and 1.0) scores on the Psychological domain, relative to the absent and greater than or equal to 1 year categories. The small changes between groups, the inconsistent pattern of response with extended audibility and the lack of longer term follow-up make it impossible to draw any meaningful conclusions from these results.

With respect to noise sensitivity, 14% of the respondents indicated that they were either very or extremely (i.e. highly) sensitive to noise in general, which is in line with the prevalence rates of 12% and 15% reported in previous studies (Miedema and Vos, 2003; van Kamp et al., 2004). In the univariate analysis, noise sensitivity was found to be significantly associated with Physical Health, Social Relationships, and Environment domains and marginally with the Psychological domain. In all cases, being highly noise sensitive was related to a worsening of QOL in these areas. Similarly, the odds of reporting poor QOL and Dissatisfaction with Health were higher among those who were highly noise sensitive. However, when considered along with other factors in multiple regression models for the different domains and two stand-alone WHOQOL-BREF questions, noise sensitivity becomes less relevant. This suggests that other factors, which included, but were not limited to, having chronic pain or a chronic disease, being unemployed and suffering from migraines, were more important in explaining the overall variance in the final models.

5. Conclusions

In the current study, the overall variance accounted for in the multiple regression models pertaining to the 4 WHOQOL-BREF domains was between 16% and 45%. The models for the two standalone questions, rated QOL and Satisfaction with Health, were also rather weak at 31% and 29%, respectively. These findings demonstrate that most of the variance in these models cannot be accounted for by the variables included in the current study. Many of the demographic and health-related variables previously shown to be related to QOL were statistically related to multiple QOL parameters assessed using the WHOQOL-BREF questionnaire. This demonstrates that the utilization of this tool in the current study was a sensitive measure for detecting changes in QOL. Therefore, it is notable that WTN levels up to 46 dB were not statistically related to any of the modeled outcomes.

The current study modeled WTN levels using a long term A-weighted metric, however it may be that a noise metric other than, or in addition to the A-weighting may reveal a stronger association with self-reported QOL. In the current study, C-weighted WTN levels were modeled in addition to A-weighted levels, however these results were not presented as the dBC and dBA values were highly correlated (Michaud, 2015). A large-scale wind turbine epidemiological/laboratory study conducted in Japan considered A- C- and G-weighted WTN levels, in addition to amplitude modulation, and concluded that the response to wind turbines was more accurately assessed using the A-weighted metric (Tachibana et al., 2014). However, they concluded that a quantification of amplitude modulation and tonality was warranted in future wind turbine studies, a conclusion echoed in a key finding of the Council of Canadian Academies (2015) following their review of the wind turbine literature. Therefore, a quantification of these sound characteristics may provide further insight into how WTN exposure may influence QOL.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.06.043.

References

Agresti, A., 2002. Categorical Data Analysis, 2nd edition. Wiley & Sons, Inc., New York.

Asnani, M.R., Lipps, G.E., Reid, M.E., 2009. Utility of WHOQOL-BREF in measuring quality of life in Sickle Cell Disease. Health Qual. Life Outcomes 7, 75. http://dx.doi.org/10.1186/1477-7525-7-75.

Blackburn, D., Rodrigue, L., Tardiff, I., Chagnon, M., Martel, K., Morasse, A., Pouliot, B., 2009. Éoliennes et santpublique. Synthèse des connaissances. Institut National de Sant Publique de Qubec, Qubec.

Bolton, R., 2007. Evaluation of Environmental Shadow Flicker Analysis for Dutch Hill Wind Power Project. Environmental Compliance Alliance, New York. Available at: ⟨http://docs.wind-watch.org/shadow.pdf⟩.

Bowling, A., 1995. The concept of quality of life in relation to health. Med. Secoli 7 (3), 633–645.

Chapman, S., St. George, A., Waller, K., Cakic, V., 2013. The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: support for the psychogenic, 'communicated disease' hypothesis. PLoS One 8 (10), e76584. http://dx.doi.org/10.1371/journal.pone.0076584 (eCollection 2013).

Chief Medical Officer of Health Ontario, 2010. The Potential Health Impact of Wind Turbines. Chief Medical Officer of Health (CMOH) Report. Queen's Printer for Ontario Toronto, ON, pp. 1–14. Available at: ⟨http://www.health.gov.on.ca/en/common/ministry/publications/reports/wind_turbine/wind_turbine.pdf⟩.

Council of Canadian Academies, 2015. Understanding the Evidence: Wind Turbine Noise. The Expert Panel on Wind Turbine Noise and Human Health. Council of Canadian Academies, Ottawa, Ontario. Available at: ⟨http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/wind-turbine-noise/WindTurbineNoiseFullReportEn.pdf⟩.

Crichton, F., Dodd, G., Schmid, G., Gamble, G., Cundy, T., Petrie, K.J., 2014. The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound. Health Psychol. 33 (12), 1588–1592. http://dx.doi.org/10.1037/hea0000037 (Epub 2013 Nov 25).

Cruice, M., Hirsch, F., Worrall, L., Holland, A., Hickson, L., 2000. Quality of life for people with aphasia: Performance on and usability of quality of life assessments. Asia Pac. J. Speech Lang. Hear. 5, 85–91. http://dx.doi.org/10.1179/136132800805577040.

DataKustik GmbH®, 2014. Software for Immission Protection. Available at: www.datakustik.com (Accessed 24.11.14).

Department of Energy and Climate Change, 2011. Update of UK Shadow Flicker Evidence Base: Final Report. Parsons Brinckerhoff, London, UK. Available at: ⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf⟩.

Devine-Wright, P., Howes, Y., 2010. Disruption to place attachment and the protection of restorative environments: a wind energy case study. J. Environ. Psychol. 30 (3), 271–280. http://dx.doi.org/10.1016/j.jenvp.2010.01.008.

Guite, H.F., Clark, C., Ackrill, G., 2006. The impact of the physical and urban environment on mental well-being. Public Health 120, 1117–1126.

Harding, G., Harding, P., Wilkins, A., 2008. Wind turbines, flicker, and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. Epilepsia 49 (6), 1095–1098. http://dx.doi.org/10.1111/j.1528-1167.2008.01563.x (Epub 2008 Apr 4).

Harrison, M.B., Juniper, E.F., Mitchell-DiCenso, A., 1996. Quality of life as an outcome measure in nursing research: "May you have a long and healthy life". Can. J. Nurs. Res. 28 (3), 49–68.

Henningsen, P., Priebe, S., 2003. New environmental illnesses: What are their characteristics? Psychother. Psychosom. 72 (5), 231–234.

Hsiung, P.C., Fang, C.T., Chang, Y.Y., Chen, M.Y., Wang, J.D., 2005. Comparison of WHOQOL-BREF and SF-36 in patients with HIV infection. Qual. Life Res. 14 (1), 141–150.

Hutchinson, G., Simeon, D.T., Bain, B.C., Wyatt, G.E., Tucker, M.B., Lefranc, E., 2004. Social and health determinants of well being and life satisfaction in Jamaica. Int. J. Soc. Psychiatry 50 (1), 43–53.

ISO, 1993. ISO-9613-1-Acoustics. Attenuation of Sound During Propagation Outdoors. Part 1: Calculation of the Absorption of Sound by the Atmosphere. International Organization for Standardization, Geneva.

ISO, 1996. ISO 9613-2-Acoustics. Attenuation of Sound During Propagation Outdoors. Part 2: General Method of Calculation. International Organization for Standardization, Geneva.

Kalfoss, M.H., Low, G., Molzahn, A.E., 2008. The suitability of the WHOQOL-BREF for Canadian and Norwegian older adults. Eur. J. Ageing 5, 77–89. http://dx.doi.org/10.1007/s10433-008-0070-z.

Katsaprakakis, D.A., 2012. A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete. Renew. Sustain. Energy Rev. 16 (5), 2850–2863. http://dx.doi.org/10.1016/j.rser.2012.02.041.

Knopper, L.D., Ollson, C.A., McCallum, L.C., Whitfield Aslund, M.L., Berger, R.G., Souweine, K., McDaniel, M., 2014. Wind turbines and human health. Front. Public Health 2 (63), 1–20. http://dx.doi.org/10.3389/fpubh.2014.00063.

Maffei, L., Iachini, T., Masullo, M., Aletta, F., Sorrentino, F., Senese, V.P., Ruotolo, F., 2013. The effects of vision-related aspects on noise perception of wind turbines in quiet areas. Int. J. Environ. Res. Pub. Health 10 (5), 1681–1697. http://dx.doi.org/10.3390/ijerph10051681.

Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH). 2012. Wind Turbine Health Impact Study: Report on Independent Expert Panel. Department of

Environmental Protection and Department of Public Health. Available at: ⟨http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf⟩ (Accessed 15.05.15).
Merlin, T., Newton, S., Ellery, B., Milverton, J., Farah, C., 2014. Systematic Review of the Human Health Effects of Wind Farms. National Health and Medical Research Council, Canberra ACT. Available at: ⟨https://digital.library.adelaide.edu.au/dspace/handle/2440/87923⟩.
McIver, J.P., Carmines, E.G., 1981. Unidimensional Scaling. Sage, Thousand Oaks, CA.
Michaud, D.S., Keith, S.E., Feder, K., Soukhovtsev, V., Marro, L., Denning, A., McGuire, D., Broner, N., Richarz, W., Tsang, J., Legault, S., Poulin, D., Bryan, S., Duddeck, C., Lavigne, E., Villeneuve, P.J., Leroux, T., Weiss, S.K., Murray, B.J., Bower, T., 2013. Self-reported and objectively measured health indicators among a sample of Canadians living within the vicinity of industrial wind turbines: social survey and sound level modelling methodology. Noise News Int. 21, 14–27.
Michaud D.S. (2015) Self-reported and objectively measured outcomes assessed in the Health Canada wind turbine noise and health study: Results support an increase in community annoyance, Internoise, San Francisco, California, USA, August 9-12, 2015.
Miedema, H.M., Vos, H., 2003. Noise sensitivity and reactions to noise and other environmental conditions. J. Acoust. Soc. Am. 113 (3), 1492–1504. http://dx.doi.org/10.1121/1.1547437.
Molzahn, A.E., Pagé, G., 2006. Field testing the WHOQOL-100 in Canada. Can. J. Nurs. Res 38 (3), 106–123.
Mroczek, B., Kurpas, D., Karakiewicz, B., 2012. Influence of distances between places of residence and wind farms on the quality of life in nearby areas. Ann. Agric. Environ. Med. 19 (4), 692–696.
Mroczek, B., Banaś, J., Machowska-Szewczyk, M., Kurpas, D., 2015. Evaluation of quality of life of those living near a wind farm. Int. J. Environ. Res. Public Health 12, 6066–6083. http://dx.doi.org/10.3390/ijerph120606066.
Nissenbaum, M.A., Aramini, J.J., Hanning, C.D., 2012. Effects of industrial wind turbine noise on sleep and health. Noise Health 14 (60), 237–243. http://dx.doi.org/10.4103/1463-1741.102961.
Nunnally, J.C., Bernstein, I.H., 1994. Psychometric Theory, 3rd ed. McGraw-Hill, New York.
Onakpoya, I.J., O'Sullivan, J., Thompson, M.J., Heneghan, C.J., 2014. The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. Env. Int. 82, 1–9.
Oregon Health Authority, 2013. Strategic Health Impact Assessment on Wind Energy Development in Oregon. Office of Environmental Public Health Public Health Division, Salem Oregon. Available at: ⟨https://public.health.oregon.gov/HealthyEnvironments/TrackingAssessment/HealthImpactAssessment/Documents/Wnd%20Energy%20HIA/Wind%20HIA_Final.pdf⟩.
Pasqualetti, M.J., 2011. Opposing wind energy landscapes: a search for common cause. Ann. Assoc. Am. Geog. 101 (4), 907–917. Available at: ⟨http://climateshiftproject.org/wp-content/uploads/2013/04/Pasqualetti2011_OpposingWindEnergyCommonCauses_AnnalsGeogy.pdf⟩.
Pedersen, E., Persson Waye, K., 2007. Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments. Occup. Environ. Med. 64, 480–486.
Pedersen, E., Larsman, P., 2008. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J. Environ. Psychol. 28, 379–389. http://dx.doi.org/10.1016/j.jenvp.2008.02.009.
Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2009. Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am. 126 (2), 634–643. http://dx.doi.org/10.1121/1.3160293.
Pohl, J., Faul, F., Mausfeld, R., 1999. Belastigung durch periodischen Schattenwurf von Windenergieanlagen [Annoyance Caused by Periodical Shadow-Casting of Wind Turbines]. Institut fur Psychologie Christian-Albrechts-Universität zu Kiel, Kiel, pp. 1–83. ⟨http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Feldstudie.pdf⟩ (Accessed 15.05.15).
Pohl, J., Faul, F., Mausfeld, R., 2000. Belastigung durch periodischen Schattenwurf von Windenergieanlagen: Ergebnisseeiner Feldstudie und einer Laborpilotstudie [Annoyance Caused by Periodical Shadow- Casting of Wind Turbines: Results of a Field Study and A Laboratory Pilot Study]. Institut fur Psychologie Christian-Albrechts-Universität zu Kiel, Kiel, pp. 11–18. ⟨http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Laborstudie%20Schattenwurf.pdf⟩ (Accessed15.05.15).
Pohl, J., Hubner, G., Mohs, A., 2012. Acceptance and stress effects of aircraft obstruction markings of wind turbines. Energy Policy 50, 592–600. http://dx.doi.org/10.1016/j.enpol.2012.07.062.
Rubin, G.J., Burns, M., Wessely, S., 2014. Possible psychological mechanisms for "wind turbine syndrome". On the windmills of your mind. Noise Health 16 (69), 116–122. http://dx.doi.org/10.4103/1463-1741.132099.
Saidur, R., Rahim, N., Islam, M., Solangi, K., 2011. Environmental impact of wind energy. Renew. Sustain. Energy Rev. 15 (5), 2423–2430. http://dx.doi.org/10.1016/j.rser.2011.02.024.
Schmidt, J.H., Klokker, M., 2014. Health effects related to wind turbine noise exposure: a systematic review. PLoS One 9 (12), e114183. http://dx.doi.org/10.1371/journal.pone.0114183.
Shepherd, D., Welch, D., Dirks, K.N., Matthews, R., 2010. Exploring the relationship between noise sensitivity and health-related quality of life in a sample of adults exposed to environmental noise. Int. J. Environ. Res. Public Health 7 (54), 3579–3594. http://dx.doi.org/10.3390/ijerph7103580.
Shepherd, D., McBride, D., Welch, D., Dirks, K.N., Hill, E.M., 2011. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 13 (54), 333–339. Available from: ⟨http://www.noiseandhealth.org/text.asp?2011/13/54/333/85502⟩.
Silva, J., de Keulenaer, F., Johnstone, N., 2012. Environmental Quality and Life Satisfaction: Evidence Based on Micro-Data. OECD Environment Working Papers, No. 44. OECD Publishing, http://dx.doi.org/10.1787/19970900.
Skevington, S.M., Sartorius, N., Amir, M., WHOQOL Group, 2004. Developing methods for assigning quality of life in different cultural settings: the history of the WHOQOL instruments. Soc. Psychiatry Psychiatr. Epidemiol. 39, 1–8.
Smedley, A.R., Webb, A.R., Wilkins, A.J., 2010. Potential of wind turbines to elicit seizures under various meteorological conditions. Epilepsia 51 (7), 1146–1151. http://dx.doi.org/10.1111/j.1528-1167.2009.02402.x.
Spector, P., 1992. Summated Rating Scale Construction. Sage, Thousand Oaks, CA.
Stokes, M.E., Davis, C.S., Koch, G.G., 2000. Categorical Data Analysis Using the SAS System, second edition. SAS Institute Inc., Cary, NC.
Tachibana, H., Yano, H., Fukushima, A., Shinichi, S., 2014. Nationwide field measurement of wind turbine noise in Japan. Noise Control Eng. J. 62 (2), 90–101. http://dx.doi.org/10.3397/1/376209.
Taylor, J., Eastwick, C., Wilson, R., Lawrence, C., 2013. The influence of negative oriented personality traits on the effects of wind turbine noise. Pers. Individ. Diff. 54, 338–343. http://dx.doi.org/10.1016/j.paid.2012.09.018.
van den Berg, F., Pedersen, E., Bouma, J., Bakker, R., 2008. WINDFARM Perception: Visual and Acoustic Impact of Wind Turbine Farms on Residents. Final Report. University of Groningen. Available at: ⟨http://cordis.europa.eu/documents/documentlibrary/124729401EN6.pdf⟩.
van Kamp, I., Job, R.F., Hatfield, J., Haines, M., Stellato, R.K., Stansfeld, S.A., 2004. The role of noise sensitivity in the noise–response relation: a comparison of three international airport studies. J. Acoust. Soc. Am. 116 (6), 3471–3479.
Welch, D., Shepherd, D., Dirks, K.N., McBride, D., Marsh, S., 2013. Road traffic noise and health-related quality of life: a cross-sectional study. Noise Health 15 (65), 224–230. Available at: ⟨http://www.noiseandhealth.org/text.asp?2013/15/65/224/113513⟩.
World Health Organization (WHO), 1996. WHOQOL-BREF: Introduction, Administration, Scoring and Generic Version of the Assessment: Field Trial Version. World Health Organization, Geneva. Available at: ⟨http://www.who.int/mental_health/media/en/76.pdf⟩.
World Health Organization Quality Of Life (WHOQOL) Group, 1994. Development of the WHOQOL: rationale and current status. Int. J. Ment. Health 23 (3), 24–56.
WHOQOL Group, 1998. Development of the World Health Organization WHOQOL-BREF quality of life assessment. Psychol. Med. 28, 551–558.

The effects of environmental and classroom noise on the academic attainments of primary school children

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The effects of environmental and classroom noise on the academic attainments of primary school children

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While at school children are exposed to various types of noise including external, environmental noise and noise generated within the classroom. Previous research has shown that noise has detrimental effects upon children's performance at school, including reduced memory, motivation, and reading ability. In England and Wales, children's academic performance is assessed using standardized tests of literacy, mathematics, and science. A study has been conducted to examine the impact, if any, of chronic exposure to external and internal noise on the test results of children aged 7 and 11 in London (UK) primary schools. External noise was found to have a significant negative impact upon performance, the effect being greater for the older children. The analysis suggested that children are particularly affected by the noise of individual external events. Test scores were also affected by internal classroom noise, background levels being significantly related to test results. Negative relationships between performance and noise levels were maintained when the data were corrected for socio-economic factors relating to social deprivation, language, and special educational needs. Linear regression analysis has been used to estimate the maximum levels of external and internal noise which allow the schools surveyed to achieve required standards of literacy and numeracy. [DOI: 10.1121/1.2812596]

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I. INTRODUCTION

Children are exposed to many different types of noise while at school. Previous studies have shown that schools may be exposed to high levels of environmental noise, particularly in urban areas.[1,2] Sources include road traffic, trains, aircraft, and construction noise. Inside schools a wide range of noise levels have been measured,[3–7] the levels varying significantly between different types of space and different classroom activities.[1] For much of the day in a primary school classroom, young children are exposed to the noise of other children producing "classroom babble" at levels typically of around 65 dB(A) L_{Aeq},[1] while the typical overall exposure level of a child at primary school has been estimated at around 72 dB(A) L_{Aeq}.[1]

The effects of noise on children and their teachers have been investigated in many studies in the past 40 years. It is generally accepted that noise has a detrimental effect upon the cognitive development of primary school children, and that older children in this age group are more affected than the younger children.[8,9] Two major reviews of previous work in this area, published in the early 1990s, concluded that chronic noise exposure of young children has an adverse effect, particularly upon their reading ability.[10,11]

Most of the previous work has concerned the effects of environmental noise, notably aircraft noise, upon children. Exposure to high levels of aircraft noise has been found to affect memory and reading ability, and to reduce motivation in school children.[11–15] These effects appear to be long term; noise reduction inside a school has been found to have little immediate effect upon children's performance[16] while another study found that when an airport was closed it took several years for the detrimental effects of noise exposure to cease.[13] These results suggest that noise reduces the learning trajectories of the pupils involved so that extended periods of teaching and learning are required for children to reach typical levels of performance.

In addition to aircraft noise other types of environmental noise, including that from railways[17,18] and road traffic,[19] have been found to affect reading. Road traffic noise outside schools, at levels of around 70 dB(A), has also been found to reduce children's attention.[20,21]

While there is a large body of work concerning the effects of external environmental noise upon children at school, there have been far fewer investigations into the effects of typical classroom noise upon children's performance. However in recent years evidence has been found to suggest that noise inside the classroom affects letter, number, and word recognition.[10,22–25]

It is thus now generally accepted that all types of noise exposure at school affect children's learning and academic performance. The majority of the previous studies have com-

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pared the performance of children exposed long term to significant levels of environmental noise with that of children with low noise exposure, or have examined the effects of noise reduction on children's performance. There have been few studies which have demonstrated a dose/response relationship between noise and effects on children's performance, thereby making it difficult to determine threshold levels at which adverse effects occur, which in turn makes it difficult to establish specific guideline values to prevent such effects.[26]

In recent years several countries have introduced standards and guidelines relating to the acoustic design of schools and classrooms. For example, in the United States ANSI standard S12.60,[27] published in 2002, sets out guideline values for noise levels, reverberation times, and sound insulation in schools. Since 2003 new school buildings in England and Wales must comply with the Building Regulations. The acoustic requirements are specified in Building Bulletin 93 (BB93),[28] published in 2003. The requirements of S12.60 and BB93 are similar, for example the maximum noise level specified by both for empty classrooms is 35 dB(A) L_{Aeq}. However, in general the noise specifications for classrooms are based upon speech intelligibility requirements, rather than the levels of noise which have direct detrimental effects upon children's performance in the classroom.

In the study described here noise levels measured outside 142 primary schools in central London (UK), and inside a range of spaces inside 16 schools have been compared with assessment scores of the schools in national standardized tests. The approach taken enables the effects on children at school of different levels and types of noise to be investigated. It is also possible to compare the impact of various types of noise upon different aged children across a variety of academic tasks. In addition, this approach allows the most important property of the noise (for example, its background, maximum, or ambient level) in relation to academic performance to be determined, an issue that has not been considered in previous studies.

A simultaneous study by the authors[29] used experimental testing to investigate the effects of environmental and classroom noise on children's performance on a range of tasks in the classroom. It will be seen that the results of the two investigations are complementary and advance the understanding of the different ways in which children's academic performance and development are affected by noise.

II. MATERIALS AND METHODS

A. Procedure

The study investigated the effects of chronic noise exposure upon children's academic attainments by comparing measured noise levels with recognized standardized measures of children's attainments in primary school. The relationships between attainment scores for individual schools and both external (environmental) and internal noise were examined. The effects of acute exposure to environmental and classroom noise were also investigated in the above-mentioned complementary experimental study.[29]

B. Measures of children's attainments: Standardized assessment tests (SATs)

In the 1990s a standard national curriculum was introduced for all schools in England and Wales. To complement this curriculum, standardized assessment tests (SATs) in various subjects including English, Mathematics, and Science were introduced across the age range at both primary and secondary school level. The majority of children at state schools take these tests at the ages of 7 ("Key Stage 1"), 11 ("Key Stage 2") and 14 ("Key Stage 3") years. Average results for all schools in all subjects are published by the Department for Education and Skills. The published school data consist of the percentages of children in each school who reach a recognized criterion level in each subject at each stage. Average school scores for each stage are also published. Each year the UK government sets targets for literacy and numeracy in primary schools by specifying Key Stage 2 SAT scores which schools must aim to achieve. At the time of the survey the target scores for schools were 75% for Key Stage 2 Mathematics and 80% for Key Stage 2 English.

The study described here concerned children of primary school age. The relevant test data for comparison with noise were therefore Key Stage 1 and Key Stage 2 SAT results. At Key Stage 1 (KS1) the assessment includes both teacher assessments and national standardized tests, which are combined to give a single score for each subject for each child. At Key Stage 2 (KS2) children sit for standard nationwide examinations. Between two and four examinations are taken in each subject, the examination results being averaged to give a single mark for each subject.

The subjects assessed at the two stages at the time of this study were as follows: Key Stage 1 (Year 2 of primary school, 7 years of age on average): Reading; Writing; Spelling; and Mathematics. Key Stage 2 (Year 6 of primary school, 11 years of age on average): English; Mathematics; and Science.

The schools' attainment scores in each subject, plus average scores, at Key Stage 1 and Key Stage 2, were compared with noise levels measured inside and outside the schools.

C. Selection of study areas and schools

The areas chosen for the study were based upon the local government boroughs of London, of which there are 33. It was important for the study that the boroughs chosen should be representative of London as a whole in terms of noise exposure, academic achievements, and demographic characteristics in order to reduce the number of potentially confounding variables.

It was decided that boroughs in which aircraft were the dominant environmental noise source should be excluded from the survey, as there was already a considerable body of research on the effects of aircraft noise on children. There was also a concurrent study of the effects of aircraft noise on children in schools to the west of London, around Heathrow airport.[14] Furthermore, there were fewer detailed studies of the impact of general environmental noise than of aircraft

TABLE I. SAT results, demographic factors, and external noise levels for the three boroughs.

Stage	Subject	Borough A Mean	Borough A s.d.	Borough B Mean	Borough B s.d.	Borough C Mean	Borough C s.d.
Key Stage 1 test results	Reading	76.1	14.1	74.7	13.2	78.4	16.9
	Writing	76.8	14.9	74.8	13.9	78.2	16.9
	Spelling	63.8	17.1	59.3	17.2	64.7	18.4
	Maths	86.4	8.9	83.5	12.0	86.4	13.2
Key Stage 2 test results	English	68.5	18.5	69.8	15.7	69.5	16.6
	Maths	66.1	16.2	67.0	15.7	68.2	19.1
	Science	77.9	15.9	81.0	12.6	78.9	17.3
Demographic factors	% FSM	38.8	19.3	41.5	14.2	33.6	10.7
	% EAL	43.9	19.2	35.3	16.8	39.6	17.7
	% SEN	10.3	2.9	28.3	10.0	26.2	7.8
External noise levels	$L_{\mathrm{Aeq,5\ min}}$	57.4	8.8	56.2	9.4	58.9	7.4
	$L_{\mathrm{A10,5\ min}}$	59.4	9.0	58.4	9.9	61.2	7.7
	$L_{\mathrm{A90,5\ min}}$	49.2	7.7	46.5	9.3	50.2	8.2
	$L_{\mathrm{A99,5\ min}}$	47.0	7.4	44.3	9.2	47.8	8.2
	$L_{\mathrm{Amax,5\ min}}$	70.5	10.5	68.3	17.0	72.0	9.0
	$L_{\mathrm{Amin,5\ min}}$	46.0	7.5	41.3	12.4	47.0	8.3

noise. Therefore, in selecting boroughs for the purpose of this study those affected particularly by aircraft noise were excluded.

Remaining boroughs were examined to ensure that their primary school academic attainments and demographic characteristics (see Sec. II D) were typical of London as a whole. The distributions of SAT results in boroughs were studied in order to select boroughs for which (a) test scores displayed an acceptable range, as indicated by the standard deviations of the SAT results in all subjects and (b) the mean scores for reading, writing, and mathematics were not above the mean score of all London boroughs. Of the boroughs selected in this way agreement was obtained from the Directors of Education of three boroughs to participate in the project. Borough A is a suburban London borough, all schools being within approximately 6 miles of central London. Boroughs B and C, on the other hand, are more centrally located, with all schools within a distance of approximately 3 miles from central London. Demographic differences between the boroughs are discussed in Sec. II D.

Means and standard deviations of the subject scores for the three boroughs are shown in Table I. Analysis of variance showed that there was no significant difference between the subject scores for the three boroughs.

It can be seen from Table I that there was in general close agreement between mean subject scores in the three boroughs, while borough C displayed slightly higher standard deviations in most subjects indicating a wider spread of scores in this borough.

D. Demographic characteristics

The socio-economic characteristics of schools in the boroughs were also examined. The data considered were the percentages of children in each school receiving free school meals (FSM); the percentages of children for whom English is an additional language (EAL); and the percentages of children with special educational needs (SEN). The percentage of children receiving free school meals is commonly accepted as a reliable indicator of social disadvantage in an area.[30,31]

The means and standard deviations of these data for the three chosen boroughs are also given in Table I. Analysis of variance showed that there were some differences between the boroughs, particularly in the distributions of children with special educational needs. There were considerably fewer children with special needs in (suburban) borough A while the percentages for the central boroughs were similar and around 2.5 times the percentage in borough A.

A major difference between the boroughs is in the density of population. At the time of the surveys the populations per square kilometer of the three boroughs were approxi-

TABLE II. Internal noise levels.

	School location: Occ teach space	Unocc teach space	Corr/ foyer /stair	Occ hall	Unocc hall	Class (age group): Nurs (3–4)	Rec (4–5)	Yr 1 (5–6)	Yr 2 (6–7)	Yr 3 (7–8)	Yr 4 (8–9)	Yr 5 (9–10)	Yr 6 (10–11)
L_{Aeq}	72.1	47.0	58.1	73.4	53.2	71.9	73.9	74.3	66.3	68.9	69.6	73.2	71.2
L_{A90}	54.1	36.9	44.6	55.1	44.3	57.3	62.3	61.0	51.3	52.5	49.8	53.8	52.9

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mately as follows: borough A 7600; borough B 12 200, and borough C 10 100. Boroughs B and C therefore represent the more densely populated inner city areas, while borough A is more typical of suburban boroughs.

E. Noise surveys

Noise levels were measured outside all the state-funded primary schools in boroughs A ($N=53$) and B ($N=50$) and outside a majority of the 61 schools in borough C ($N=39$). Of these, eight schools in boroughs A and B were also selected for internal surveys. The eight schools were chosen to reflect the full range of external noise levels measured, the external L_{Aeq} levels of the 16 schools ranging from 49 to 75 dB(A). The measurement methods, noise levels, and noise sources present have been described elsewhere.[1] The external and internal levels that have been used in examining the impact of noise upon test results are summarized in the following.

1. External levels

Table I also shows the means and standard deviations of various environmental noise parameters measured in the three boroughs. These levels were measured at, or have been normalized to, a distance of 4 m from the school façade during the school day.[1]

It can be seen that the levels were reasonably consistent across the three boroughs, with borough C having slightly higher levels than the other two boroughs. This was to be expected as this borough is the one nearest central London. The mean levels in borough B were slightly lower than might be expected given that this is also an inner city borough. However many of the schools in this area are situated in the middle of housing estates or on side streets, and are thus sheltered to some extent from the noise of road traffic, the main noise source in the areas surveyed.[1] This is illustrated by the larger standard deviations of noise levels in borough B.

2. Internal levels

In the internal school noise survey levels were measured in classrooms and other areas around a school. Most spaces were measured in both occupied and unoccupied conditions. The averaged ambient (L_{Aeq}) and background (L_{A90}) levels for the types of spaces considered in each school are shown in Table II.

Internal levels were also categorized according to the age of the class; the average L_{Aeq} and L_{A90} levels for different age groups in each school are also shown in Table II. For the purposes of analyzing the effects, if any, of noise on SAT results noise levels for Year 2 and Year 6 are the only ones considered in the subsequent discussion.

F. Analyses

In order to study the impact, if any, of noise on children's attainment the noise levels measured inside and outside the schools were correlated with the SAT scores for the academic year in which the noise survey was carried out.

TABLE III. Borough A: Correlation coefficients between test scores and external noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	−0.34[b]	−0.31[b]	−0.37[a]	−0.33[b]
KS1 Maths	−0.34[b]	−0.27	−0.43[a]	−0.34[b]
KS2 English	−0.37[a]	−0.39[b]	−0.40[a]	−0.33[b]
KS2 Maths	−0.40[a]	−0.46[b]	−0.40[a]	−0.36[a]
KS2 Science	−0.40[a]	−0.45[b]	−0.42[a]	−0.37[a]
KS1 average	−0.36[b]	−0.32[b]	−0.40[a]	−0.36[b]
KS2 average	−0.41[a]	−0.45[a]	−0.43[a]	−0.37[a]

[a]Significant at 1% level.
[b]Significant at 5% level.

For external noise it was found that results for L_{A90}, L_{A99}, and L_{Amin} were very similar, as would be expected and was confirmed by factor analysis. Therefore in the following sections, relationships between SAT results and L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} only are considered. These are the most commonly cited measures of environmental noise and are generally considered to capture the key features of the noise environment.

Similarly, factor and correlation analysis showed a close relationship among results for KS1 literacy-related tests Reading, Writing, and Spelling, as would be expected. Therefore, in the subsequent analysis and discussion, of these tests, results are presented for KS1 Reading only as being a reliable indicator of the younger children's attainments in literacy.

Correlation and regression analysis were carried out for the noise and test data. The noise levels were correlated with subject and average school SAT scores. Obviously any relationships found between noise and SAT scores in this way could be due to social or other factors rather than representing a direct effect of noise on academic performance. In order to eliminate the effects of socio-economic factors, partial correlations were carried out, in which the schools' data on children with FSM, EAL, and SEN were controlled for.

Current guidance on choosing a site for new school buildings in England and Wales recommends an upper limit of 60 dB $L_{Aeq,30\ min}$ at the boundary of school premises.[28] For this reason, in addition to considering all schools mea-

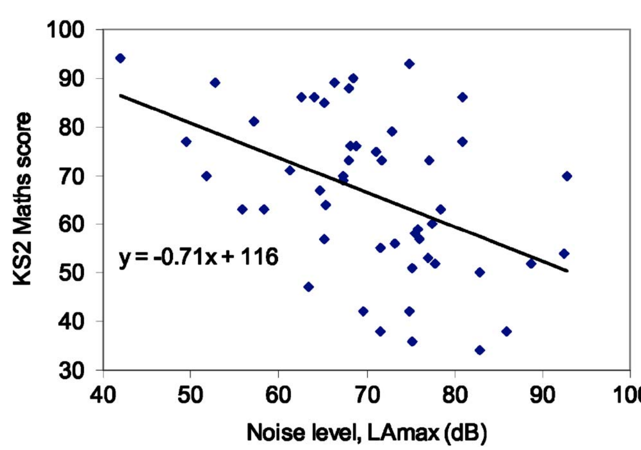

FIG. 1. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and Key Stage 2 Mathematics scores in borough A.

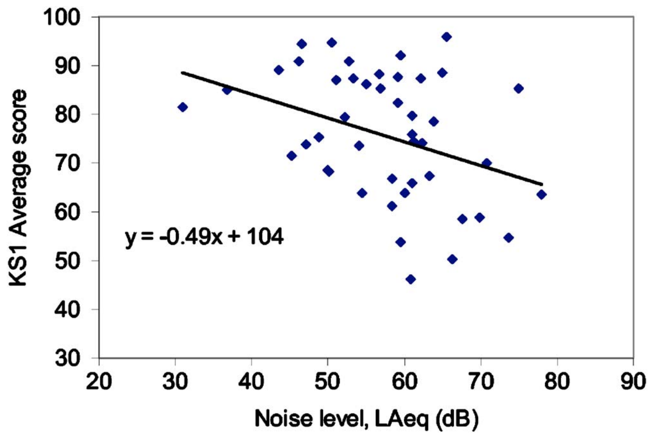

FIG. 2. (Color online) Scatter diagram illustrating relationship between external L_{Aeq} and average Key Stage 1 scores in borough A.

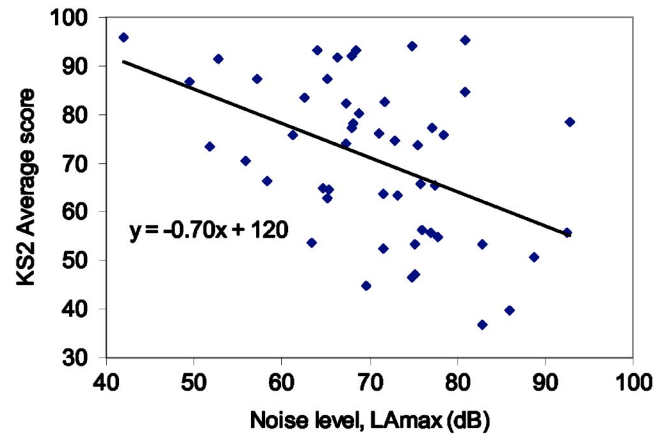

FIG. 3. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and average Key Stage 2 scores in borough A.

sured in each borough, those schools where the measured external L_{Aeq} levels are greater than or equal to 60 dB(A) have been considered separately.

III. RESULTS: RELATIONSHIPS BETWEEN EXTERNAL NOISE AND TEST RESULTS

The values of the noise parameters L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} measured outside each school were compared with average and subject SAT scores for the younger (aged 7 years) and older (aged 11 years) children.

The Pearson correlation coefficients between average and subject scores and external noise levels were calculated for all schools in boroughs A, B, and C. Table III shows the coefficients for borough A. It can be seen that there were negative relationships between external noise and SATs for all scores, that is, the greater the noise level the lower the school test performance score. Furthermore, all except one of the relationships were significant at the 1% or 5% level. However, for both boroughs B and C the correlation coefficients were very small, varying from −0.15 to 0.28. There were no significant relationships and the coefficients were very similar for the two boroughs. This may be due to the differences between the central and suburban boroughs reflected in the SEN data shown in Table I, and also to the different characteristics of the boroughs as represented by their population densities, discussed in Sec. II D. For this reason the two central boroughs (B and C) are considered together and separately from the suburban borough (A) in the following discussion.

A. Borough A

1. All schools

Table III shows that when all schools in borough A are considered there were significant negative relationships between all SAT scores and all external noise parameters, except for KS1 Mathematics and L_{Amax}. The relationships were stronger for Key Stage 2 subjects, suggesting that noise has more of an impact upon the performance of the older children. A possible explanation for this is that the older children have been exposed to the noise for a longer period of time. This is consistent with the results of previous research demonstrating the effects of long-term noise exposure.[13–16] However, it is also possible that the nature and demands of the tasks for older children differ from those of the younger children and are more vulnerable to the effects of noise.

At Key Stage 1 and for KS2 English the external noise level with the strongest correlation with test scores was the background level, as measured by L_{A90}. For other subjects at Key Stage 2, L_{Amax} was the parameter which had the strongest association with test scores. This suggests that the younger children were affected by general external background noise, while the older children were more affected by individual external noise events such as motorbikes or lorries

TABLE IV. Borough A: Correlation coefficients between test scores and external noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.17	−0.26	−0.32[b]	−0.15	−0.26	−0.29[b]	−0.11	−0.24	−0.35[b]	−0.16	−0.25	−0.31[b]
KS1 Maths	−0.23	−0.28	−0.32[b]	−0.15	−0.22	−0.24	−0.29	−0.35[b]	−0.41[a]	−0.24	−0.28	−0.33[b]
KS2 English	−0.17	−0.27[b]	−0.34[b]	−0.25	−0.38[a]	−0.37[a]	−0.08	−0.23	−0.39[a]	−0.12	−0.22	−0.31[b]
KS2 Maths	−0.23	−0.32[b]	−0.38[a]	−0.36[a]	−0.44[a]	−0.44[a]	−0.10	−0.25	−0.38[a]	−0.19	−0.27	−0.35[a]
KS2 Science	−0.25	−0.32[b]	−0.39[a]	−0.34[b]	−0.42[a]	−0.44[a]	−0.19	−0.30[b]	−0.41[a]	−0.23	−0.29[b]	−0.36[a]
KS1 average	−0.20	−0.29	−0.34[b]	−0.17	−0.27	−0.30[b]	−0.18	−0.29	−0.39[a]	−0.21	−0.28	−0.35[b]
KS2 average	−0.25	−0.33[b]	−0.39[a]	−0.36[a]	−0.45[a]	−0.44[a]	−0.14	−0.28[b]	−0.41[a]	−0.20	−0.28[b]	−0.36[a]

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE V. Schools in boroughs B and C with external $L_{Aeq} \geq 60$ dB(A): Correlation coefficients between test scores and noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	−0.40[b]	−0.40[b]	−0.22	−0.36[b]
KS1 Maths	−0.10	−0.09	−0.03	−0.20
KS2 English	−0.39[b]	−0.43[a]	−0.37[b]	−0.38[b]
KS2 Maths	−0.21	−0.31	−0.15	−0.27
KS2 Science	−0.25	−0.36[b]	−0.15	−0.24
KS1 average	−0.31	−0.31	−0.12	−0.28
KS2 average	−0.30	−0.39[b]	−0.24	−0.32

[a]Significant at 1% level.
[b]Significant at 5% level.

passing the school. This is consistent with the findings of previous research,[12–18] which has found that reading is affected by noise caused by individual external sources such as trains or planes. It is also consistent with a questionnaire survey of children carried out by the authors which found that older, Key Stage 2 age, children were more aware of external noise than the younger children at Key Stage 1. The subject showing the strongest negative effect of noise (with background levels at Key Stage 1 and with maximum levels at Key Stage 2) was Mathematics. The mathematics assessment at Key Stage 2 is complex, involving orally presented mental arithmetic, written arithmetic, and word problems. Thus performance at these tasks is vulnerable to the effects of noise on both reading and speeded responses, two areas which have been found to be affected by noise in previous studies.[10–18,29]

Figures 1–3 give examples of scatter diagrams relating external noise levels and SAT scores. Figure 1 shows the relationship between L_{Amax} and Key Stage 2 Mathematics scores; Fig. 2 shows the scatter diagram of L_{Aeq} and average Key Stage 1 score; and Fig. 3 average Key Stage 2 score and L_{Amax}. Regression lines relating external noise levels and SAT scores are also shown in Figs. 1–3. The implications of these relationships are discussed in Sec. V.

Table IV shows the partial correlation coefficients obtained when the data for borough A were controlled for the FSM, EAL, and SEN data. It can be seen that when social deprivation (as measured by FSM data) was taken into account there was still a negative relationship between external noise and test scores, but there were fewer significant relationships than with the uncorrected data. However, L_{Amax} was still significantly correlated with two subject scores (Mathematics and Science) and the average score at Key Stage 2. The strongest relationship was again with the Mathematics scores. When potential language demands (as indicated by EAL data) were accounted for there were still strong associations between L_{Amax} and all subjects at Key Stage 2, with Mathematics again being the subject most strongly related to noise. As with the uncorrected data, KS1 Mathematics scores were most strongly, and significantly, related to the external background noise level. When controlling for SEN, it can be seen that the pattern was very similar to that for the uncorrected data, with KS2 Mathematics and Science again being the subjects most affected by external noise, and L_{Amax} having the strongest negative relationship with test scores at Key Stage 2.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

When considering only those schools with external L_{Aeq} levels of 60 dB(A) or more in borough A (N=22), KS1 Mathematics was the only subject significantly related to noise, being significantly related at the 5% level to L_{A90}. This significant relationship was maintained when the data were corrected for socio-economic factors, becoming significant at the 1% level when correcting for SEN.

B. Boroughs B and C

1. All schools

As mentioned previously, there were no significant relationships between test scores and external noise for the central London boroughs when all schools in the two boroughs were considered. The reason for the difference between these schools and those in borough A is unclear, but may be related to the discrepancies in the percentages of children with special needs in the central and suburban boroughs, or to the differing population characteristics between the boroughs.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

If only those schools where the external level exceeds 60 dB L_{Aeq} in the two boroughs were considered (N=35) then there were stronger negative relationships between SAT

TABLE VI. Schools in boroughs B and C with external $L_{Aeq} \geq 60$ dB(A): Correlation coefficients between test scores and noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.35[b]	−0.40[b]	−0.35[b]	−0.40[b]	−0.41[b]	−0.43[a]	−0.13	−0.22	−0.16	−0.23	−0.36[b]	−0.29
KS1 Maths	−0.00	−0.08	−0.02	−0.04	−0.10	−0.10	0.09	0.05	0.07	−0.04	−0.15	−0.10
KS2 English	−0.34[b]	−0.37[b]	−0.32	−0.46[a]	−0.46[a]	−0.48[a]	−0.30	−0.28	−0.29	−0.23	−0.32	−0.29
KS2 Maths	−0.09	−0.18	−0.11	−0.30	−0.32[b]	−0.34[b]	−0.01	−0.06	−0.05	−0.06	−0.21	−0.16
KS2 Science	−0.16	−0.23	−0.20	−0.35[b]	−0.37[b]	−0.37[b]	−0.03	−0.08	−0.09	−0.06	−0.19	−0.17
KS1 average	−0.25	−0.31	−0.25	−0.29	−0.31	−0.33	−0.02	−0.11	−0.04	−0.14	−0.28	−0.21
KS2 average	−0.22	−0.28	−0.23	−0.41[b]	−0.41[b]	−0.43[a]	−0.13	−0.16	−0.16	−0.13	−0.26	−0.22

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE VII. Internal noise: Correlation coefficients between test scores and Year 2 and Year 6 noise levels.

	Year 2 $N=11$		Year 6 $N=13$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	0.01	−0.12		
KS1 Maths	−0.17	−0.33		
KS2 English			−0.45	−0.48
KS2 Maths			−0.04	−0.00
KS2 Science			−0.36	−0.11
KS1 average	−0.15	−0.29		
KS2 average			−0.33	−0.25

scores and noise, as shown in Table V. For most external noise parameters, as with borough A schools, the relationships were stronger for Key Stage 2 results, and in general L_{Amax} was the parameter most closely related to test results. In these boroughs, however, English was the subject showing the greatest effect of noise. Both KS1 Reading and KS2 English scores were significantly related to external L_{Aeq}, L_{Amax}, and L_{A10} levels, while KS2 English was also significantly related to the background L_{A90} level. Unlike the suburban borough, Mathematics scores were not significantly related to any external noise parameter.

Table VI shows the correlations when the data were corrected for socio-economic factors. In all cases the results were very similar to those for the uncorrected data. KS1 Reading and KS2 English were the subjects most affected by external noise, KS2 English being significantly correlated with L_{Amax} at the 1% level and L_{Amax} again being the noise parameter with the strongest correlations with test scores. When correcting for EAL and SEN, all subjects at KS2 were significantly related to L_{Amax}. Relationships between KS2 English and L_{Amax} were significant at the 1% level, and stronger than for the uncorrected data.

IV. RESULTS: RELATIONSHIPS BETWEEN INTERNAL NOISE AND TEST RESULTS

In investigating relationships between internal noise and SATs, average and subject Key Stage 1 and Key Stage 2 SAT scores were correlated with relevant internal noise data. For this analysis, correlations were carried out for the complete set of 16 schools (eight in borough A and eight in borough B) for which internal noise data were available. The internal noise data that were used consisted of the L_{Aeq} and L_{A90} levels for Year 2 and Year 6 (as these are the years in which children sit for SATs); and in the various school locations which were measured.

A. Correlation with year group levels

Table VII shows the correlations between KS1 test scores and Year 2 noise levels, and between KS2 scores and Year 6 levels. It can be seen that there were negative relationships between all scores and noise levels, except for Key Stage 1 Reading; however, none of the correlations were significant, possibly because of the small sample size. The subject showing the strongest effect of internal noise was KS2 English, which was related to both L_{Aeq} and L_{A90} levels. This is consistent with the results of the parallel experimental testing,[29] which showed that classroom babble affected all tasks both verbal and nonverbal.

When the data were corrected for socio-economic factors KS2 English was still the subject most strongly affected by internal noise; when correcting for FSM there was a significant negative relationship ($r=-0.59$, $p<0.05$) between background noise (L_{A90}) in Year 6 classrooms and test scores for this subject.

B. Correlation with location levels

Table VIII shows the correlation coefficients between L_{Aeq} and L_{A90} levels for different school locations and subject test scores. There were negative correlations between all subject scores and all noise levels measured in occupied classrooms, unoccupied classrooms, and corridors and foyers. In general the relationships were strongest for occupied classrooms, with the background (L_{A90}) level being significantly related to test scores for most subjects. The subject most strongly affected by internal noise was again KS2 English, which was significantly correlated at the 1% level with occupied classroom L_{A90}. KS1 Mathematics was significantly related to L_{A90} in both occupied and unoccupied classrooms.

Figures 3–6 show scatter diagrams relating internal noise and KS2 English scores, KS1 average scores, and KS2

TABLE VIII. Internal noise: Correlation coefficients between test scores and school location noise levels.

	Occ class $N=16$		Unocc class $N=14$		Corridor/foyer $N=14$		Occ hall $N=8$		Unocc hall $N=7$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	−0.11	−0.60[b]	−0.33	−0.46	−0.38	−0.39	0.32	0.06	0.14	0.18
KS1 Maths	−0.12	−0.57[b]	−0.52	−0.55[b]	−0.38	−0.40	0.36	0.21	0.43	0.34
KS2 English	−0.55[b]	−0.77[a]	−0.08	−0.20	−0.53[b]	−0.62[b]	−0.12	−0.28	0.47	0.49
KS2 Maths	−0.22	−0.46	−0.06	−0.21	−0.47	−0.49	0.18	0.03	0.28	0.36
KS2 Science	−0.41	−0.50[b]	−0.14	−0.32	−0.38	−0.39	−0.09	−0.31	−0.19	−0.04
KS1 average	−0.16	−0.58[b]	−0.41	−0.51	−0.41	−0.39	0.24	0.06	0.15	0.18
KS2 average	−0.43	−0.64[a]	−0.10	−0.46	−0.49	−0.35	−0.00	0.03	0.15	0.35

[a]Significant at 1% level.
[b]Significant at 5% level.

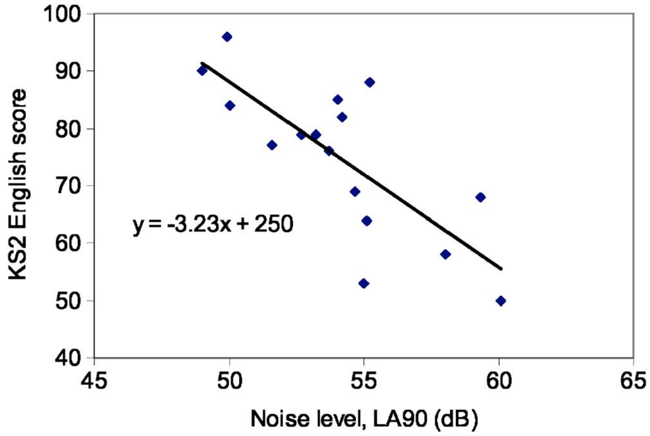

FIG. 4. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and Key Stage 2 English scores.

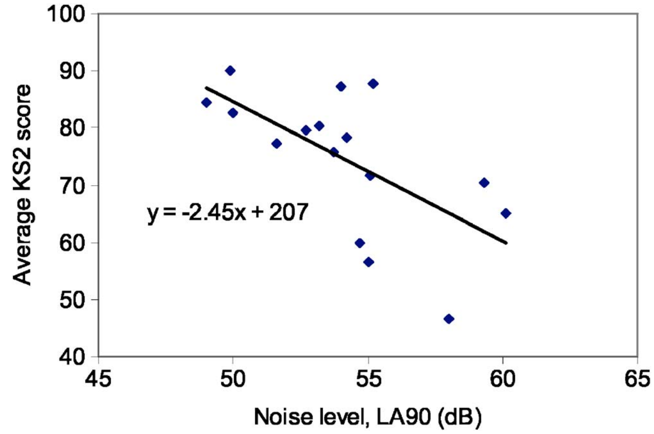

FIG. 6. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 2 scores.

average scores, respectively. Regression lines relating internal noise levels and SAT scores are also shown in Figs. 3–6 and are discussed in more detail in Sec. V.

It is interesting to note that there were consistently negative correlations between test scores and all noise levels in corridors and foyers, being significant again for KS2 English. While carrying out internal noise surveys it was subjectively apparent that the noise in such spaces gave a good indication of the general "noise climate" in a school.

It can be seen that there was no relationship between noise levels in school halls, occupied or unoccupied, and test scores. This is as would be expected and validates the fact that there are strong negative relationships between noise in classrooms and test results.

Tables IX and X show the correlation coefficients between test scores and L_{Aeq} and L_{A90} levels, respectively, in classrooms and circulation areas when the data were corrected for socio-economic factors. In general, relationships were slightly less strong when correcting for FSM and EAL but when correcting for SEN correlations coefficients were similar to those for the uncorrected data. KS2 English was still significantly correlated with L_{Aeq} in occupied classrooms

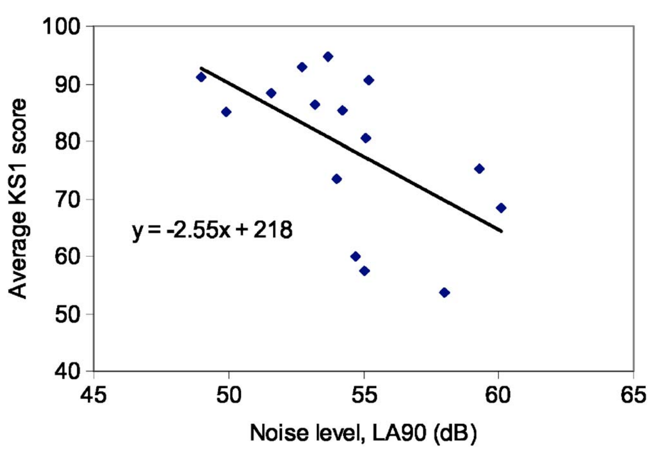

FIG. 5. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 1 scores.

and in corridors/foyers. When correcting for all factors there were significant correlations between KS2 English and L_{A90} in occupied classrooms and corridors/foyers.

V. QUANTIFYING THE EFFECTS OF NOISE

The regression lines relating noise levels and SAT scores for the most significant results have been calculated. In borough A these relationships have been used to investigate the implications of increases in external L_{Aeq}, L_{Amax}, and L_{A90} levels, and to establish the noise levels in this borough which correspond to the UK government targets in numeracy and literacy at the time of the survey (80% of children achieving required level in KS2 English and 75% in KS2 Mathematics). Similar analysis has been carried out for internal background (L_{A90}) levels in occupied classrooms.

A. External noise

The equations of the regression lines relating external noise (L_{Aeq}, L_{Amax}, and L_{A90} levels) and Key Stage 2 English and Mathematics scores in borough A are shown in Table XI. For completeness the relationships between noise and average Key Stage 1 and 2 scores are also shown. These linear relationships have been used to estimate the percentage decreases in the numbers of children achieving the required level for each 10 dB increase in external noise; these are also shown in Table XI. Table XI also shows the external noise levels, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

It can be seen that an increase of 10 dB(A) in external L_{Aeq}, L_{Amax}, and L_{A90} levels in borough A causes 5%, 4%, and 6% drops, respectively, in the number of children achieving the required levels at Key Stage 1, and drops of 7%, 9% and 9%, at Key Stage 2. This further illustrates the greater detrimental effect of noise on the older children in the primary school age range. The external L_{Aeq}, L_{Amax}, and L_{A90} levels corresponding to the UK government target for literacy are 42 dB(A), 54 dB(A), and 37 dB(A), respectively; for numeracy the corresponding levels are 44, 58, and 38 dB(A). It should be noted that these refer to external levels at a point 4 m from the school façade, and should be interpreted with caution as discussed in Sec. VI.

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TABLE IX. Internal noise: Correlation coefficients between test scores and school location L_{Aeq} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corridor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	0.11	0.13	−0.09	−0.05	−0.19	−0.34	−0.25	−0.33	−0.49
KS1 Maths	0.15	0.18	−0.14	−0.28	−0.42	−0.52	−0.23	−0.33	−0.42
KS2 English	−0.45	−0.44	−0.53[b]	0.32	0.11	−0.10	−0.43	−0.50	−0.71[a]
KS2 Maths	−0.07	−0.09	−0.24	0.23	0.07	−0.05	−0.38	−0.43	−0.51
KS2 Science	−0.33	−0.32	−0.38	0.04	−0.03	−0.15	−0.31	−0.34	−0.53
KS1 average	0.09	0.08	−0.15	−0.12	−0.29	−0.41	−0.27	−0.36	−0.49
KS2 average	−0.32	−0.31	−0.42	0.21	0.05	−0.12	−0.39	−0.45	−0.62[b]

[a]Significant at 1% level.
[b]Significant at 5% level.

B. Internal noise

The regression lines relating internal background L_{A90} levels in occupied classrooms and Key Stage 2 English and Mathematics scores are shown in Table XII. The linear relationships between noise and average Key Stage 1 and 2 scores are also shown. Table XII also shows the percentage decreases in the numbers of children achieving the required level in SATs for each 5 dB increase in internal background noise, plus the internal background noise levels in occupied classrooms, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

Table XII shows that there is a 13% reduction in the number of children achieving the required level at Key Stage 1 and a 12% reduction at Key Stage 2, for each 5 dB(A) increase in the background noise level in occupied classrooms. The background noise level corresponding to the government target for literacy is 53 dB(A) L_{A90}, while for numeracy it is 50 dB(A) L_{A90}. As with external levels, care is needed in interpreting these figures as discussed in Sec. VI.

VI. DISCUSSION

The study described here has shown that chronic exposure to noise at school has a detrimental effect upon children's academic performance, as measured by standard assessment testing in schools in England and Wales. These are consistent with the findings of previous studies and with the results of experimental testing of children carried out by the authors, as will be discussed in the following. Both external environmental noise heard inside a school and noise generated within a school have an impact upon children's test scores, but affect children in different ways. In addition to different subjects being affected by external and by school noise, the particular characteristics of the noise which impact upon children's performance differ between the two types of noise.

A. External noise

It was seen that different results were obtained for the suburban (A) and central (B and C) boroughs. For borough A there were strong relationships between all noise parameters and all test scores when all schools were considered, but for the other boroughs significant relationships were found when only the schools on the noisier sites were considered. The reasons for the discrepancies are not fully understood but may relate to differences in demographic, population, and/or noise characteristics between the boroughs. There may be "floor" effects for the inner city boroughs in that, however low the noise levels, the overall school test scores would not improve above a certain level. As was noted earlier the two central boroughs considered had high levels of children with SEN. The parallel experimental study carried out by the authors[29] showed that children with SEN were particularly vulnerable to the effects of noise so it is possible that this factor limits the overall achievements of these schools.

TABLE X. Internal noise: Correlation coefficients between test scores and school location L_{A90} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corrifor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.44	−0.47	−0.60[b]	−0.21	−0.30	−0.45	−0.26	−0.30	−0.40
KS1 Maths	−0.36	−0.40	−0.60[b]	−0.30	−0.40	−0.57[b]	−0.25	−0.29	−0.40
KS2 English	−0.66[a]	−0.69[a]	−0.76[a]	0.19	0.03	−0.17	−0.55[b]	−0.58[b]	−0.64[b]
KS2 Maths	−0.30	−0.36	−0.49	0.06	−0.07	−0.22	−0.40	−0.43	−0.48
KS2 Science	−0.42	−0.42	−0.48	−0.18	−0.21	−0.29	−0.31	−0.33	−0.40
KS1 average	−0.38	−0.44	−0.59[b]	−0.24	−0.36	−0.51	−0.26	−0.31	−0.41
KS2 average	−0.51[b]	−0.54[b]	−0.63[a]	0.01	−0.10	−0.26	−0.44	−0.47	−0.54

[a]Significant at 1% level.
[b]Significant at 5% level.

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TABLE XI. Borough A: Regression lines relating external noise levels and SAT scores.

	L_{Aeq}			L_{Amax}			L_{A90}		
	Regression equation	% drop ≈10 dB increase	Level ≈ target	Regression equation	% drop ≈10 dB increase	Level ≈ target	Regression equation	% drop ≈10 dB increase	Level ≈ target
KS2 English	$y=-0.76x+112$	8	42	$y=-0.70x+118$	7	54.2	$y=-0.95x+115$	10	36.8
KS2 Maths	$y=-0.72x+107$	7	44.4	$y=-0.71x+116$	7	57.7	$y=-0.82x+106$	8	37.8
KS1 average	$y=-0.49x+104$	5	⋯	$y=-0.37x+102$	4	⋯	$y=-0.63x+107$	6	⋯
KS2 average	$y=-0.73x+113$	7	⋯	$y=-0.70x+120$	7	⋯	$y=-0.87x+114$	9	⋯

In general, for the suburban borough and for the noisier schools in the inner city boroughs correlations between noise and test scores were stronger for Key Stage 2 scores than for those at Key Stage 1 suggesting that external noise has more of an effect on the older children. It has previously been found that the negative effects of environmental noise are long term.[13,16] The greater effect upon the older children may therefore reflect the fact that these children have been exposed to noise at school for a longer period than the younger children. It may also be due to the higher task demands required of the older children in their tests.

In general, over all boroughs, the noise parameter with the highest and most significant correlations with test scores was L_{Amax}, implying that noise of individual events may be the most important in affecting children's performance. However, in the suburban borough external background noise levels, L_{A90}, were also significantly related to test scores.

Significant relationships between tests scores and noise were maintained when the data were corrected for factors relating to social deprivation, non-native speaking, and additional educational needs. In particular in all boroughs (considering just the noisier schools in the inner city boroughs) all KS2 subjects remained significantly related to L_{Amax} while KS1 Reading was also significantly related to some noise parameters.

The dominant external noise source in the schools considered was road traffic.[1] These findings are thus consistent with the findings of other studies which have found that road traffic noise has an impact upon children's performance at school.[19–21] Furthermore, although schools exposed to aircraft noise were not included in the study, the close relationships between L_{Amax} and test scores suggest that the noise of individual events has an impact upon children's performance. This is thus consistent with the results of other studies which have found that both aircraft[12–16] and railway[17] noise affect children's performance.

The results also complement the findings of a questionnaire survey of children carried out by the authors which found that the older (Year 6) children were more aware of external noise than the younger children.[32] This is consistent with the finding that the test results of these children were more affected by noise than those of the younger children. Furthermore, annoyance caused by external noise among children was significantly related to external maximum noise levels, the levels that are found to have the most effect upon test scores.

Regression analysis has been used to estimate the noise levels corresponding to UK government targets in English and Mathematics in the suburban borough. In this borough those schools where the external L_{Amax} level 4 m from the school façade exceeds 54 dB(A), or L_{Aeq} exceeds 42 dB(A), fail to meet literacy and numeracy targets. These levels are considerably lower than those recommended in current guidelines,[28] and should be interpreted with caution. As can be seen from Figs. 1–3 there is considerable scatter around the regression lines; many schools with levels greater than these do achieve the SAT targets. Furthermore, there are many other factors apart from noise which may affect children's attainments; the regression analysis was carried out for uncorrected data where additional factors which may impact upon learning are not accounted for. These results may therefore not apply to schools in general.

TABLE XII. Regression lines relating L_{A90} in occupied classrooms and SAT scores.

	Occupied classrooms L_{A90}		
	Regression equation	% drop ≈5 dB increase	Level ≈ target
KS2 English	$y=-3.23x+250$	16	52.6
KS2 Maths[a]	$y=-1.87x+169$	9	50.3
KS1 average	$y=-2.55x+218$	13	⋯
KS2 average	$y=-2.45x+207$	12	⋯

Correlation ($r=-0.46$) not significant.

B. Internal noise

There were consistent negative relationships between test scores and L_{Aeq} and L_{A90} levels measured in occupied and unoccupied classrooms and corridors and foyers. The internal noise levels which had the strongest relationships with test scores were the background (L_{A90}) levels in occupied classrooms. All subjects except KS2 Mathematics were significantly correlated with these levels. KS1 Mathematics was also significantly correlated with L_{A90} measured in unoccupied classrooms and KS2 English with L_{Aeq} and L_{A90} measured in corridor and foyer areas. Many of the relationships, particularly those for KS2 English, were maintained when the data were corrected for socio-economic factors.

These results complement the results of the controlled experimental testing of children carried out by the authors in which children performed various tasks in different classroom noise conditions.[29] Classroom babble was found to decrease performance on both verbal and nonverbal tasks, with verbal tasks of reading and spelling being particularly affected. This is consistent with the finding that KS2 English test scores are strongly and significantly related to the ambient and background noise levels in classrooms.

Regression analysis showed that of the schools surveyed, in general those in which background (L_{A90}) levels in occupied classrooms exceed 50 dB(A) failed to meet government targets in literacy and numeracy. Current guidelines specify internal levels in classrooms in terms of ambient L_{Aeq} when both classrooms and the whole school are unoccupied. It is difficult, without further extensive noise surveys in schools both empty and occupied, to compare the occupied classroom background noise level with those in current standards. Furthermore, as with the external levels there is considerable scatter around the regression lines as can be seen in Figs. 4–6; therefore care should be taken when interpreting these results.

VII. CONCLUSION

This study has shown that chronic exposure to both external and internal noise has a detrimental impact upon the academic performance and attainments of primary school children. For external noise it appears to be the noise levels of individual events that have the most impact while background noise in the classroom also has a significant negative effect. Older primary school children, around 11 years of age, appear to be more affected by noise than the younger children.

In order to minimize the impact of noise upon children at school it is therefore necessary to consider two factors. The siting and the internal layout of a school should be such that classrooms are not exposed to high levels of noise from external sources such as road traffic. In addition it is essential to minimize background noise levels in the classroom to ensure that optimum conditions for teaching and learning are achieved.

Further field and experimental studies are required to determine the levels at which different types of external and internal noise affect children's academic performance in different circumstances.

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[1]B. Shield and J. E. Dockrell, "External and internal noise surveys of London primary schools," J. Acoust. Soc. Am. **115**, 730–738 (2004).

[2]E. Celik and Z. Karabiber, "A pilot study on the ratio of schools and students affected from noise," Proceedings of the International Symposium on Noise Control and Acoustics for Educational Buildings, Turkish Acoustical Society, Istanbul, May 2000, pp. 119–128.

[3]M. Hodgson, R. Rempel, and S. Kennedy, "Measurement and prediction of typical speech and background noise levels in university classrooms during lectures," J. Acoust. Soc. Am. **105**, 226–233 (1999).

[4]M. Picard and J. S. Bradley, "Revisiting speech interference in classrooms," Audiology **40**, 221–224 (2001).

[5]A. Moodley, "Acoustic conditions in mainstream classrooms," J. British Association of Teachers of the Deaf **13**, 48–54 (1989).

[6]B. Hay, "A pilot study of classroom noise levels and teachers' reactions," J. Voice **4**, 127–134 (1995).

[7]D. MacKenzie, "Noise sources and levels in UK schools," Proceedings of the International Symposium on Noise Control and Acoustics for Educational Buildings, Turkish Acoustical Society, Istanbul, May 2000, pp. 97–106.

[8]B. Berglund and T. Lindvall, "Community Noise," Archives of the Center for Sensory Research, Stockholm University and Karolinska Institute, **2**, 1–195 (1995).

[9]Institute for Environment and Health, "The non-auditory effects of noise," Report No. R10, 1997.

[10]R. Hetu, C. Truchon-Gagnon, and S. A. Bilodeau, "Problems of noise in school settings: A review of literature and the results of an exploratory study," J. Speech-Language Pathology and Audiology **14**, 31–38 (1990).

[11]G. W. Evans and S. J. Lepore, "Nonauditory effects of noise on children: A critical review," Children's Environments **10**, 31–51 (1993).

[12]S. Cohen, G. W. Evans, D. S. Krantz, and D. Stokols, "Physiological, motivational, and cognitive effects of aircraft noise on children. Moving from the laboratory to the field," Am. Psychol. **35**, 231–243 (1980).

[13]S. Hygge, G. W. Evans, and M. Bullinger, "The Munich Airport noise study: Cognitive effects on children from before to after the change over of airports," Proceedings Inter-Noise'96, Liverpool, UK, pp. 2189–2192.

[14]M. M. Haines, S. A. Stansfeld, J. Head, and R. F. S. Job, "Multi-level modelling of aircraft noise on performance tests in schools around Heathrow Airport London," J. Epidemiol. Community Health **56**, 139–144 (2002).

[15]C. Clark, R. Martin, E. van Kempen, T. Alfred, J. Head, H. W. Davies, M. M. Haines, B. Lopez, M. Matheson, and S. Stansfeld, "Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension: The RANCH project," Am. J. Epidemiol. **163**, 27–37 (2006).

[16]S. Cohen, G. W. Evans, D. S. Krantz, D. Stokols, and S. Kelly, "Aircraft noise and children: Longitudinal and cross-sectional evidence on adaptation to noise and the effectiveness of noise abatement," J. Pers Soc. Psychol. **40**, 331–345 (1981).

[17]A. L. Bronzaft and D. P. McCarthy, "The effect of elevated train noise on reading ability," Environ. Behav. **7**, 517–527 (1975).

[18]A. L. Bronzaft, "The effect of a noise abatement program on reading ability," J. Environ. Psychol. **1**, 215–222 (1981).

[19]J. S. Lukas, R. B. DuPree, and J. W. Swing, "Report of a study on the effects of freeway noise on academic achievement of elementary school children, and a recommendation for a criterion level for a school noise abatement program," J. Exp. Psychol. Learn. Mem. Cogn. **20**, 1396–1408 (1981).

[20]S. Sanz, A. M. Garcia, and A. Garcia, "Road traffic noise around schools: A risk for pupils' performance?," Int. Arch. Occup. Environ. Health **65**, 205–207 (1993).

[21]J. Romero and D. Lliso, "Perception and acoustic conditions in secondary Spanish schools," Proceedings of the 15th International Congress on Acoustics, Trondheim, Norway, 1995, pp. 271–274.

[22]F. Berg, J. Blair, and P. Benson, "Classroom acoustics: The problem, impact and solution," Language, Speech and Hearing Services in Schools **27**, 16–20 (1996).

[23]S. Airey and D. Mackenzie, "Speech intelligibility in classrooms," Proc. Institute of Acoustics **21**, 75–79 (1999).

[24]L. Maxwell and G. Evans, "The effects of noise on pre-school children's pre-reading skills," J. Environ. Psychol. **20**, 91–97 (2000).

[25]P. Lundquist, K. Holmberg, and U. Landstrom, "Annoyance and effects on work from environmental noise at school," Noise Health **2**, 39–46 (2000).

[26]World Health Organisation, *Guidelines for Community Noise* (Geneva, 1999).

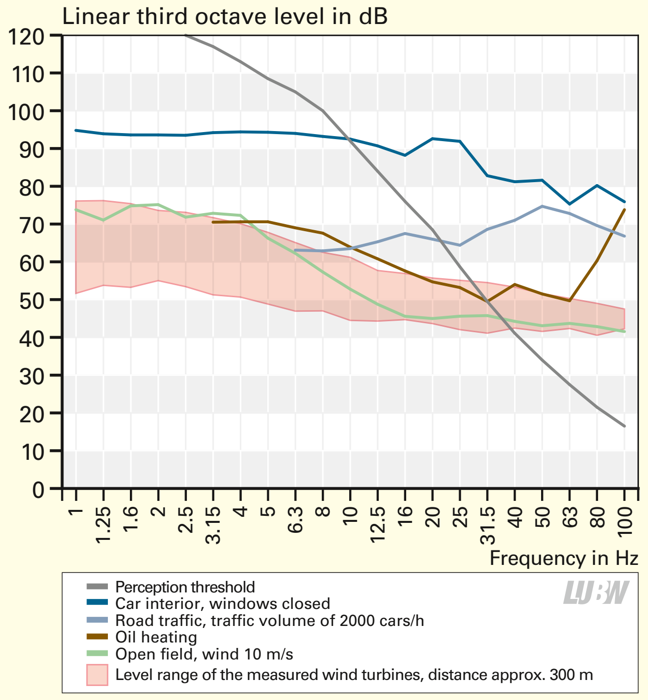
[27]American National Standards Institute, "ANSI S12.60-2002: Acoustical performance criteria, design requirements, and guidelines for schools," New York, 2002.

[28]Department for Education and Skills, "Building Bulletin 93: Acoustic design of schools," The Stationery Office, London, 2003.

[29]J. E. Dockrell and B. M. Shield, "Acoustical barriers in classrooms: The impact of noise on performance in the classroom," British Educational Research Journal **32**, 509–525 (2006).

[30]W. Williamson and D. D. Byrne, "Educational disadvantage in an urban

setting," in *Social Problems and the City*, edited by D. T. Herbert and D. M. Smith (Oxford University Press, Oxford, 1977).
[31]P. Sammons, A. West, and A. Hind, "Accounting for variations in pupil attainment at the end of Key Stage 1," British Educational Research Journal **23**, 489–511 (1997).
[32]J. E. Dockrell and B. M. Shield, "Children's perceptions of their acoustic environment at school and at home," J. Acoust. Soc. Am. **115**, 2964–2973 (2004).



Comparison of noise levels within a passenger car, near a road, on an open field, and from an oil heating with the level range of the measured wind turbines as well as the human perception threshold

CONCLUSION

Infrasound and low-frequency noise are an everyday part of our technical and natural environment. Compared with other technical and natural sources, the level of infrasound caused by wind turbines is low. Already at a distance of 150 m, it is well below the human limits of perception. Accordingly, it is even lower at the usual distances from residential areas. Effects on health caused by infrasound below the perception thresholds have not been scientifically proven. Together with the health authorities, we in Baden-Württemberg have come to the conclusion that adverse effects relating to infrasound from wind turbines cannot be expected on the basis of the evidence at hand.

The measurement results of wind turbines also show no acoustic abnormalities for the frequency range of audible sound. Wind turbines can thus be assessed like other installations according to the specifications of the TA Lärm (noise prevention regulations).

It can be concluded that, given the respective compliance with legal and professional technical requirements for planning and approval, harmful effects of noise from wind turbines cannot be deduced.

FURTHER INFORMATION

Detailed information on the measuring project is included in the document „Low-frequency noise incl. infrasound from wind turbines and other sources – Report on the results of the measurement project 2013-2015“. It can be downloaded in the LUBW online shop at www.lubw.de/servlet/is/262445.

Further information about wind energy and infrasound can be found in the leaflet „Windenergie und Infraschall – Tieffrequente Geräusche durch Windenergieanlagen“, which the LUBW has issued in cooperation with the public health authorities of Baden-Württemberg, and the publication „Fragen und Antworten zu Windenergie und Schall – Behauptungen und Fakten“. Both publications are in German language and can be downloaded or ordered using the search field on the LUBW home page www.lubw.de.

PICTURE CREDITS

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Comparative table of results

	Level in dB(G)
Wind turbines (at wind speed of 2-15 m/s)	
Turbine off, 120-190 m distance	50-75
Turbine on, 120-190 m distance	55-80
Turbine off, 650-700 m distance	50-75
Turbine on, 650-700 m distance	50-75
Road traffic	
Inner city (measured on balcony)	50-75
Inner city (measured in living quarters)	40-65
Inner city (traffic noise measuring station Karlsruhe)	65-75
Inner city (traffic noise measuring station Reutlingen)	70-80
Motorway (A5 near Malsch), 80 m distance	75
Motorway (A5 near Malsch), 260 m distance	70
Noise in passenger car (windows closed, 130 km/h)	105
Noise in minibus (windows closed, 130 km/h)	100
Urban environment	
Museum roof	50-65
City square	50-65
Interior	45-60
Rural area (at wind speed of 10 m/s)	
Open field (130 m from forest)	55-65
Edge of forest	50-60
Forest	50-60
Sources of noise in residential buildings	
Washing machine (all operating phases)	50-85
Heating (oil and gas, full load)	60-70
Refrigerator (full load)	60
Sea surf (literature source Turnbull/Turner/Walsh)	
Beach (25 m distance)	75
Rock cliff (250 m distance)	70

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Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg

Low-frequency noise incl. infrasound from wind turbines and other sources

Results of the measurement project 2013-2015

Baden-Württemberg

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THE ISSUE AT HAND

In addition to the usual audible sound, the noise coming from wind turbines also contains low frequencies including infrasound. Sound below the audible range, i. e. with frequencies of less than 20 hertz (Hz), is called infrasound. Noise is defined as low-frequency noise if substantial parts of it are in the frequency range below 100 hertz (Hz). Infrasound is thus a part of low-frequency sound.

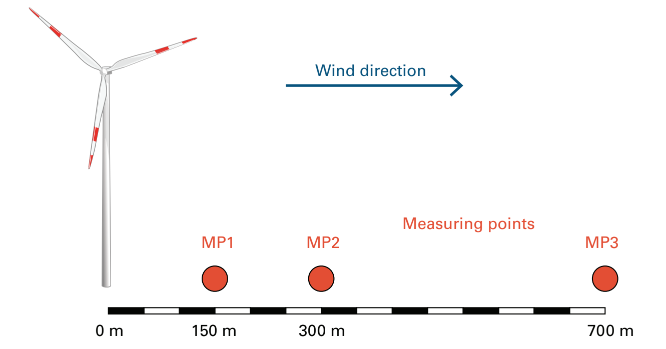
Our hearing is very insensitive to low frequencies. However, in the context of the development of wind power utilization, fears are often expressed that wind power plants might produce a great amount of infrasound. But how much infrasound do wind turbines really produce? This is the question the LUBW examined in an extensive measurement project. This leaflet summarizes the main results of the survey.

THE MEASUREMENT PROJECT

The acoustic examinations were carried out in the years 2013 through 2015 in cooperation with the company Wölfel Engineering GmbH & Co. KG in the vicinity of six wind turbines by different manufacturers and of different sizes. Additional vibration measurements were also carried out at one wind turbine. In order to appropriately classify the data collected, low-frequency sound from other sources was also measured and evaluated: effects of an urban road outside and inside a residential building, near a motorway, at two LUBW measuring stations for road traffic noise, as well as inside driving cars. Measurements without direct source reference were taken in the city centre of Karlsruhe. Furthermore, noise from technical home appliances, such as washing machine,

Evaluation of noise

Depending on the issue, the frequencies of sound are weighted differently. A-weighting is customary and expressed as dB(A), which roughly corresponds to human auditory perception. However, for the range of infrasound, so-called G-weighting, expressed in dB(G), is used. The G-weighting is focused at 20 Hz: The contributions of sound between 10 Hz and 25 Hz are strongly incorporated into the level, the contributions above and below only slightly. Unweighted levels (linear levels) are normally used for frequency analysis and the comparison with the perception threshold. In this case, all frequencies are weighted equally. The Figures in this leaflet show unweighted third octave spectra or narrow-band spectra.



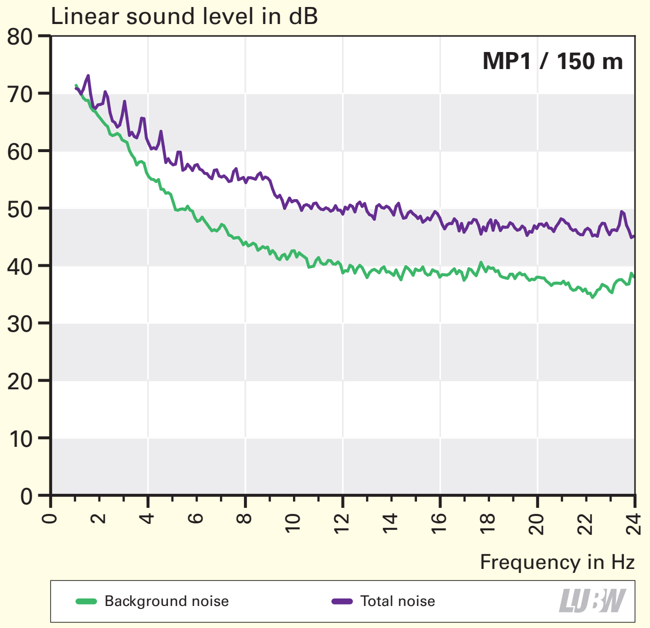
Exemplary measuring arrangement (not to scale)

refrigerator or heating, were also analysed in the way that they occur indoors. Additional measurements of natural infrasound in an open field, at the edge of a forest and in a forest rounded off the measurement programme.

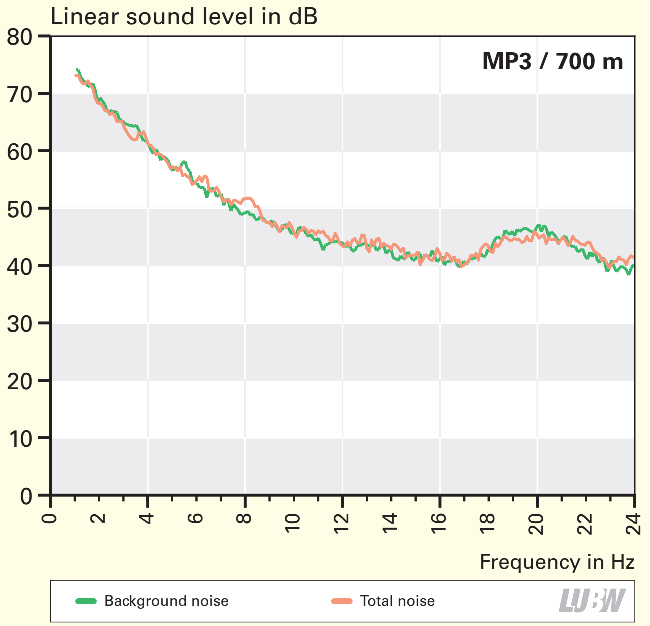
WIND TURBINES

Depending on the respective local conditions, the measurements at the six wind turbines were carried out at distances of approx. 150 m, 300 m and 700 m. The turbines covered a power range from 1.8 to 3.2 megawatts. It turned out that the infrasound coming from wind power plants can be detected by measurement rather well in the vicinity of the power plants. In addition to the noise of the wind turbine, sound generated by wind in the vicinity as well as wind-induced sound at the microphone are also generally picked up. In the narrowband spectrum, a typical sawtooth pattern can be seen below 8 Hz. This is due to the uniform movement of the rotor blades, which appears as a fundamental oscillation with harmonic waves (see Figure top of page 4).

With values of between 45 and 75 dB (unweighted), the infrasound third octave levels measured around the wind turbines are well below the human perception threshold as defined by DIN 45680 (draft 2013) even at close distances of around 150 m. The measured values show a wide range of variation. This is due to different environmental conditions and the varying noise components of the wind. At a distance of 700 m from the wind turbines, it was observed that when the turbine is switched on, the measured infrasound level did not increase notably or only to a limited



Background noise (turbine off) and total noise (background noise plus noise of the wind turbine) at a distance of 150 m at 6.5 m/s wind speed



Background noise (turbine off) and total noise (background noise plus noise of the wind turbine) at a distance of 700 m at 6.5 m/s wind speed

extent. At this distance, the infrasound is mainly induced by the wind and not generated by the power plants (see Figure bottom of page 4).

The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. The readings were well below the reference values in accordance with DIN 4150 Part 2. This standard applies for the assessment of vibrations that affect people in buildings. At distances required in the vicinity of residential areas for noise protection reasons alone, no relevant effects can thus be expected for residential buildings.

ROAD TRAFFIC

As expected, the measurements of noise from traffic showed a clear correlation between noise and traffic density. The higher the volume of traffic, the higher was the low-frequency noise level. Contrary to the situation with wind turbines, the levels caused by road traffic also occur directly near residential buildings. The G-rated infrasound levels near residential buildings were between 55 and 80 dB(G). Increased level values were observed mainly in the frequency range between 30 and 80 Hz. These noise components are well above the perception threshold in accordance with DIN 45680 (2013 draft). The measured low-frequency noise from road traffic is significantly louder than in the vicinity of wind turbines (see Figure on page 7). The infrasound and low-frequency noise levels dropped at night.

Much higher levels occur in the interior of a medium-sized car driving at 130 km/h. This does not actually concern an immission in an open environment, but it is an everyday situation, which many people are often exposed to for longer periods of time. The infrasound here is greater by several orders of magnitude than in the vicinity of wind turbines (see Figure page 7).

CITY CENTRE

The measurements in the city centre of Karlsruhe showed G-weighted infrasound levels that were mostly between 55 and 65 dB(G). At times, values above 70 dB(G) were even reached.

In the evenings, the G-level declined steadily. In the frequency range between 25 and 80 Hz, relatively high third octave levels of up to 60 dB (unweighted) were observed. These are probably due to traffic noise in the wider vicinity. G-levels of between 45 and 60 dB(G) were measured indoors.

TECHNICAL EQUIPMENT IN RESIDENTIAL BUILDINGS

The measurement of appliances in a residential building showed the highest G-weighted infrasound levels with up to 85 dB(G) during the spin cycle of washing machines. In some frequency ranges, the levels reach the human perception threshold in accordance with DIN 45680 (2013 draft). The linear third octave levels caused by an oil heating were between 50 and 75 dB (see Figure page 7).

RURAL ENVIRONMENT

The noise situation with the wind blowing in an open field, at the edge of a forest and in a forest is similar to that in the vicinity of a wind turbine. At a wind speed of 10 m/s in the open field, the measurements of 55 to 65 dB(G) on the open field showed slightly higher G-weighted infrasound levels than at the edge of the forest and in the forest, where 50 to 60 dB(G) were measured. This can be explained by the lower wind speed at the edge of the forest and in the forest. For audible sound, the noise level rises at the edge of the forest and in the forest compared to the open field. This is due to the rustling of leaves (see Figure page 7).

COMPARISON OF DIFFERENT SOURCES

The Figure on page 7 again illustrates the breadth of the linear third octave level for the respective wind turbines at a distance of approx. 300 m (red band). For comparison, the measurement results for the sound of traffic and nature as well as an oil heating system are also shown. What becomes apparent is the large distance between the turbine noise and the human perception threshold in the infrasound range.

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1 Background and introduction

There are currently (as of 31.12.2015) 445 wind turbines in operation in Baden-Wuerttemberg and 100 more under construction [1]. In the coming years many more will be added to that number. When it comes to the expansion of wind energy, the effects on humans and the environment need to be taken into account. Wind turbines make noise. In addition to the usual audible sound, they also generate low-frequency sounds or infrasound, i.e. extremely low tones.

Infrasound is described as the frequency range below 20 hertz (for explanations of important technical terms, please refer to Appendix A3). From a physical point of view, these noises are generated particularly through aerodynamic and mechanical processes, e.g. the flow around rotor blades, machine noise or the vibration of equipment components. Our hearing is very insensitive to low-frequency noise components. The wind energy decree of Baden-Wuerttemberg [1] includes, among other things, regulations and statements to protect the population against low-frequency noise and infrasound. However, within the scope of wind energy development, fears are commonly expressed that this infrasound may affect people or jeopardize their health.

In September 2012, the LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Wuerttemberg presented the concept for a measuring project, with which current data on low-frequency noise incl. infrasound from wind turbines and other sources was to be collected. As a result, the LUBW was entrusted with the implementation of the project by the Ministry of Environment, Climate and Energy Baden-Wuerttemberg. The company Wölfel Engineering GmbH + Co. KG was taken on board as a supporting measuring institute. The detailed planning and work was thus begun together at the beginning of 2013.

Within the project, numerous measurements near wind turbines and other sources as well as the associated analyses and evaluations were carried out. The results obtained are summarized in this measurement report. The LUBW wishes to use it as a contribution towards providing objectivity to the discussion. The report is aimed at the interested public as well as administrative bodies and professionals.

At this point we would like to thank all participants for enabling the measurements as well as the friendly support during the implementation, in particular the operators of wind turbines, the involved administrative authorities in Baden-Wuerttemberg and Rhineland-Palatinate, the State Museum of Natural History Karlsruhe and the Education Authority of Karlsruhe. The Bavarian State Office for the Environment and the State Office for the Environment, Nature Conservation and Geology Mecklenburg-Western Pomerania were kind enough to provide a number of pictures.

1) The terms "wind power plant" and "wind turbine" are synonymous. For our measurement project we have used the term "wind turbine" in the title. The German term is embedded in immissions law (fourth regulation on the implementation of the Federal Immission Control Act – Regulation on licensing requirements Appendices – 4. BImSchV, Appendix 1 no. 1.6.1 [2] [3]). In the text of this report the common term "wind power plant" may also be used.

2 Summary

In cooperation with Wölfel Engineering GmbH + Co. KG, the LUBW carried out the measurement project "Low-frequency noise incl. infrasound from wind turbines and other sources", which began in 2013. This report provides information on the results of the measurement project.

***Figure 2-1**: Wind turbines – how much infrasound do they emit? Photo: Wölfel company*

The aim of the project is to collect current data on the occurrence of infrasound (from 1 Hz) and low-frequency noise in the area of wind turbines and other sources. For this purpose, measurements were taken up to the end of 2015 in the areas around six wind turbines by different manufacturers and with different sizes, covering a power range from 1.8 to 3.2 megawatts (MW). Depending on local conditions, the distances to the wind turbines were approx. 150 m, 300 m and 700 m. The results of the measurements at the wind turbines are described and illustrated by means of graphs in Chapter 4. In addition to the acoustical analyses, vibration measurements were performed in the vicinity of a wind power plant in order to determine possible vibration emissions of the power plant on the environment. The procedure and the difficulties encountered are explained accordingly.

Since road traffic is also considered to be a source of infrasound and low-frequency noise, it stood to reason to extend the measurement project to cover that too. Chapter 5 provides results of measurements at an urban road, which took place both outside as well as inside a residential building. In addition, the data from the LUBW measurement stations for road traffic noise in Karlsruhe and Reutlingen were analysed and illustrated with respect to low-frequency noise and infrasound. Furthermore, results of own measurements at a motorway are also illustrated. This is supplemented by data from sound level measurements inside a moving car.

Measurements without reference sources during the day and at night took place in the centre of Karlsruhe on the Friedrichsplatz. At the same time, measurements were also taken on the roof of the natural history museum and in an interior room of the education authority (Chapter 6). Typical noise occurring in residential buildings through widespread technical equipment, such as washing machines, refrigerators or heating equipment, was also recorded and is presented in Chapter 7. In order to enable statements about natural sources of infrasound, measurements were taken on an open field, near a forest and in a forest. The measurement of low-frequency sound through sea surf is also introduced based on literature (Chapter 8). In Chapter 9, considerations are made for a monitoring station for the continuous monitoring of low-frequency noise incl. infrasound. Such an independently operating permanent measuring station could possibly be used when it comes to complaint cases.

The report at hand extends the previous interim report through further findings and contains a multiplicity of measurement results. It is aimed at both professionals as well as the interested general public. Great interest for our analyses was shown by the public and administrative bodies during the entire duration of the project. SWR TV even aired a report about the measurements. The LUBW will continue to pursue the issue in the future.

In addition to general information about infrasound, the appendices provide extensive explanations of technical terms and the technology used, as well as information on the sources.

Figure 2-2: *Impressions of the measurements during the execution of the measurement project. a) Construction of a wind measuring mast (top left) and b) of a measurement point (top right) during measurement at a wind turbine. c) and d) Setup of measurement points in the city centre of Karlsruhe (bottom). Photos: LUBW*

RESULTS

In summary, the measurements lead to the following findings:

- The infrasound being emanated from the wind turbines can generally be measured well in the direct vicinity. Discrete lines occur below 8 Hz in the frequency spectrum, which are attributed to the uniform movement of the individual rotor blades.

- For the measurements carried out even at close range, the infrasound level in the vicinity of wind turbines is – at distances between 120 m and 300 m – well below the threshold of what humans perceive in accordance with DIN 45680 (2013 Draft) [5] or ***Table A3-1***.

- At a distance of 700 m from the wind turbines, it was observed by means of measurements that when the turbine is switched on, the measured infrasound level did not increase or only increase to a limited extent. The infrasound was generated mainly by the wind and not by the turbines.

- The determined G-weighted levels [2)] at distances between 120 m and 190 m were between 55 dB(G) and 80 dB(G) with the turbine switched on, and between 50 dB(G) and 75 dB(G) with the turbine switched off. At distances of 650 m and 700 m, the G-levels were between 50 dB(G) and 75 dB(G) for both turbines switched

2) The G-level – expressed as dB(G) – represents a frequency-weighted single value of the noise in the low-frequency and infrasound range. The human ear is insensitive to any influences in this frequency range (for definition and measurement curve see Appendix A3).

on as well as off, see ***Table 2-1***. The large fluctuations are caused, among other things, by the strongly varying noise components due to the wind, as well as various different surrounding conditions.

- The infrasound and low-frequency noise measured in the vicinity of operating wind turbines consists of a proportion that is generated by the wind turbine, a proportion that occurs by itself in the vicinity due to the wind, and a proportion that is induced by the wind at the microphone. In this case the wind itself is thus always an "interference factor" when determining the wind turbine noise. The measured values are therefore subject to a wide spread.

- The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. At distances provided for residential areas alone due to noise protection issues, no relevant effects are to be expected for residential buildings.

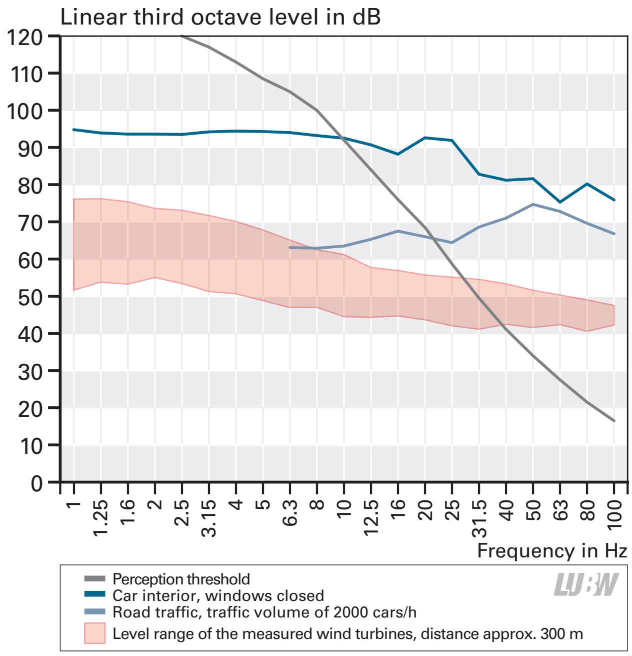


Figure 2-3: *Comparison of road noise inside and outside of motor vehicles with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections, see Section 4.1.*

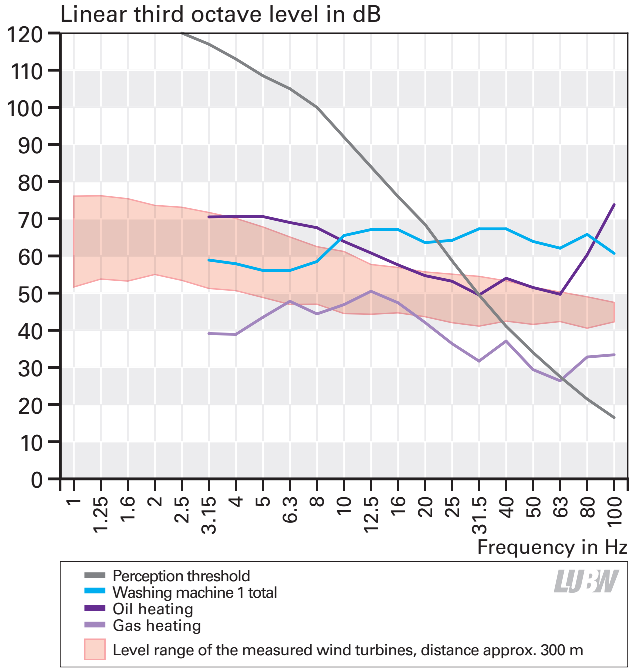
- It was possible to carry out the measurements for the low-frequency noise incl. infrasound resulting from road traffic during times without interfering wind noise. Contrary to the case with wind turbines, the measured levels also occur directly in areas with adjacent residential buildings. As expected, it was observed that the infrasound and low-frequency noise levels fell at night. Clear correlations with the amount of traffic were also ascertained. The higher the amount of traffic, the higher the low-frequency noise and infrasound levels.

- The infrasound noise levels of road traffic in the area of residential buildings in the vicinity in the individual third octave bands were a maximum of approx. 70 dB (unweighted), while the G-weighted level was in the range between 55 dB(G) and 80 dB(G).

- When it comes to the immission measurements of road traffic noise, increased levels in the area between approx. 30 Hz and 80 Hz were ascertained in the frequency spectra. The low-frequency noise in this area lies well above the perception threshold according to ***Table A3-1*** and is therefore more relevant with regards to its effect than the subliminal infrasound levels below 20 Hz. The levels of low-frequency noise in the observed situations of road traffic are significantly higher than in the vicinity of wind turbines (***Table 2-1***).

- The measurements in the city centre of Karlsruhe (Friedrichsplatz) showed that the G-weighted levels dropped from 65 dB(G) during the day to levels of around 50 dB(G) at night. Wind noise played no role for these measurements. Relatively high third octave levels up to 60 dB (unweighted) could be observed between 25 Hz and 80 Hz, probably deriving from traffic noise, even though the Friedrichsplatz is not located directly on a busy road.

- The highest levels in the context of the measurement project were measured in the interior of a mid-range car travelling at 130 km/h. Even though these are not immission levels that occur in a free environment, they are an everyday situation that many people are frequently subjected to for a longer period of time. The measured values for both the infrasound as well as the other



***Firgure 2-4**: Comparison of noise of technical appliances in residential buildings with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections, see Section 4.1.*

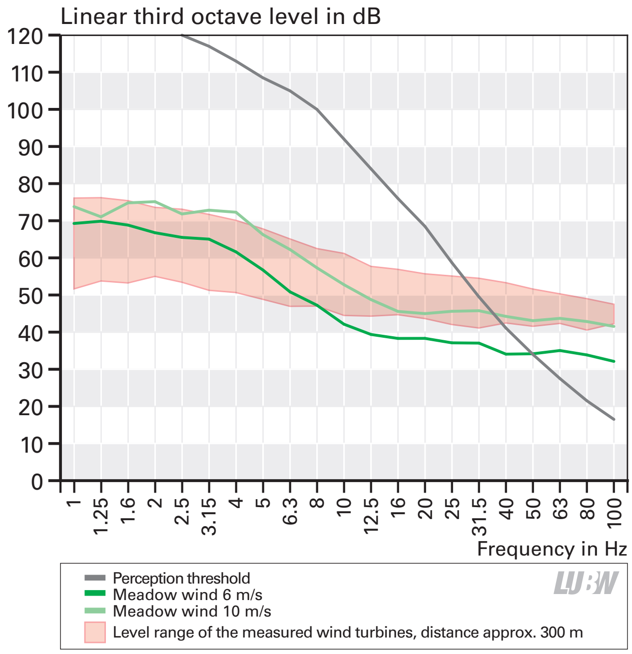


***Figure 2-5**: Comparison of noise situation in an open field (without source reference) with the level range of wind turbines at a distance of approx. 300 m as well as the perception threshold according to Table A3-1 regarding infrasound and low-frequency noise. For measuring corrections for wind turbines, see section 4.1.*

low-frequency areas are higher by several orders of magnitude than the values measured in road traffic or at the wind turbines.

- The measurement of appliances in a residential building showed the highest infrasound levels during the spin cycle of washing machines. In individual third octaves the levels reached the perception threshold according to ***Table A3-1***. As expected, it turned out that building components deaden higher-frequency noise significantly better than the low frequencies below 20 Hz.

- In a rural area, the spectral distribution of noise on an open field, the edge of a forest, in a forest with wind is in principle similar to in the vicinity of a wind turbine (***Figure 2-5***). For open fields, linear levels that are up to 30 dB higher than in a forest can be seen in the narrowband spectrum. Above 16 Hz, the differences are no longer as pronounced. Higher levels occur for A-weighted audible sound in the forest, which is attributable to the rustling of leaves.

CONCLUSION

Infrasound is caused by a large number of different natural and technical sources. It is an everyday part of our environment that can be found everywhere. Wind turbines make no considerable contribution to it. The infrasound levels generated by them lie clearly below the limits of human perception. There is no scientifically proven evidence of adverse effects in this level range.

The measurement results of wind turbines also show no acoustic abnormalities for the frequency range of audible sound. Wind turbines can thus be assessed like other installations according to the specifications of the TA Lärm (noise prevention regulations). It can be concluded that, given the respective compliance with legal and professional technical requirements for planning and approval, harmful effects of noise from wind turbines cannot be deduced.

***Table 2-1**: Comparative overview of results. The readings were often subject to considerable fluctuations. Here they were rounded to the nearest 5 dB, some are based on different averaging times. More information can be found in the relevant sections of the report. To enable a comparison of the results (measurements with/without reverberant plate) a correction was carried out; for more information see Section 4.1.*

Source/situation	Section	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB [1)]	Low-frequency third octave levels 25-80 Hz in dB [1)]
Wind turbines [2)]		**WT on / off**	**WT on**	**WT off**
– WT 1	4.2	700 m: 55-75 / 50-75 150 m: 65-75 / 50-70	– 150 m: 55-70	– 150 m: 50-55
– WT 2	4.3	240 m: 60-75 / 60-75 120 m: 60-80 / 60-75	– 120 m: 60-75	– 120 m: 50-55
– WT 3	4.4	300 m: 55-80 / 50-75 180 m: 55-75 / 50-75	– 180 m: 50-70	– 180 m: 45-50
– WT 4	4.5	650 m: 50-65 / 50-65 180 m: 55-65 / 50-65	– 180 m: 45-55	– 180 m: 40-45
– WT 5	4.6	650 m: 60-70 / 55-65 185 m: 60-70 / 55-65	– 185 m: 50-65	– 185 m: 45-50
– WT 6	4.7	705 m: 55-65 / 55-60 192 m: 60-75 / 55-65	– 192 m: 55-65	– 192 m: 45-50
Road traffic				
– Würzburg inner city, balcony [3)] – Würzburg inner city, living quarter [3)]	5.1	50-75 40-65	35-65 20-55	55-75 35-55
– Karlsruhe, noise measurement station [3)]	5.2	65-75	45-65	55-70
– Reutlingen, noise measurement station [3)]	5.2	70-80	50-70	55-75
– Motorway A5 near Malsch, 80 m [4)] – Motorway A5 near Malsch, 260 m [4)]	5.3	75 70	55-60 55-60	60-70 55-60
– Interior noise in passenger car 130 km/h [4)] – interior noise in minibus at 130 km/h [4)]	5.4	105 100	90-95 85-90	75-95 80-90
Urban background, Karlsruhe [3)]				
– roof of natural history museum – Friedrichsplatz – Interior	6	50-65 50-65 45-60	35-55 35-50 20-45	up to 60 up to 60 up to 55
Noise sources in residential buildings [5)]				
– Washing machine (all operating modes)	7.1	50-85	25-75	10-75
– Heating (oil and gas, full load)	7.2	60-70	40-70	25-60
– Refrigerator (full load)	7.2	60	30-50	15-35
Rural environment [6)]		**Wind 6 / 10 m/s**	**Wind 6 / 10 m/s**	**Wind 6 / 10 m/s**
– open field, 130 m from forest	8.1	50-65 / 55-65	40-70 / 45-75	35-40 / 40-45
– Edge of forest	8.1	50-60 / 50-60	35-50 / 45-75	35-40 / 40-45
– Forest	8.1	50-60 / 50-60	35-40 / 40-45	35-50 / 35-40
Sea surf				
– Beach, 25 m away	8.2	75	55-70	not reported
– Rock cliff, 250 m away	8.2	70	55-65	not reported

1) Linear third octave level (unweighted)
2) For wind turbines: From 10-second values (see illustrations of the G-level depending on the wind speed)
3) For road traffic (Würzburg) and urban background (Karlsruhe): From averaging levels over an hour
4) For federal motorway and car interior level: From averaging over several minutes
5) For noise sources in residential building: From averaging levels of typical operating cycles
6) The wind measurement was always carried out at the measurement point MP1 (open field).

3 Scope of analysis

The scope of analysis includes the following measurements and examinations:

- Measurement of low-frequency noise, including infrasound, from 1 Hz at a total of six different wind turbines at a distance of approx. 150 m, 300 m and 700 m respectively (if possible). In the process, the turbines were each turned on and off. The distances roughly correspond to the set reference intervals for emission measurements at close range (approx. 150 m), a roughly double distance in the immediate vicinity (approx. 300 m) and a distance that can occur for real noise immissions (700 m, see also planning information in the wind energy statute of Baden Wuerttemberg [1]).

- Comparative measurement of the noise immission in the sphere of influence of a road both outside as well as inside a residential building.

- Determination of low-frequency effects from 6.3 Hz of road traffic on the permanent monitoring stations in Karlsruhe and Reutlingen as well as at the A5 motorway near Malsch at different distances.

- Measuring of the infrasound levels within a passenger car travelling at 130 km/h.

- Determination of the urban background through a comparative measurement of the noise situation in Karlsruhe (Friedrichsplatz) without specific source reference both outside as well as inside a building.

- Comparative measurement of the noise situation in a rural area without a concrete source reference.

- Measurement of oscillations (vibrations) in the ground in the vicinity of a wind turbine.

- Elaboration of a feasibility concept for the conception of a self-sufficient permanent measuring station for low frequency noise incl. infrasound, in order to possibly measure the effects over a longer period of time (e.g. several weeks).

The following planned steps of the project have not yet been completed:

- Measurement of the direction dependency in the low-frequency frequency range based on four measurement points around a wind turbine. – This is where technical problems occurred during the measurement. They therefore have to be repeated.

- Measurement of low-frequency noise, including infrasound, from 1 Hz at a wind farm, incl. indoor measurement in a residential building at a distance of approx. 700 m to the nearest turbine. The wind turbines are switched on and off in the process. – The necessary meteorological conditions did not occur at the planned measuring location since commissioning in August 2014. It was therefore not possible to carry out a standard-compliant measurement. The measurement is to be carried out at a later date.

4 Wind turbines

The results of the six measurements that took place in the context of this project at wind turbines in Baden-Wuerttemberg, Rhineland-Palatinate and Bavaria are presented in the following (***Table 4-1***). The measurements were carried out by Wölfel Engineering GmbH + Co. KG, Höchberg, on behalf of the LUBW. The graphical representations of the emissions and immissions in the low-frequency range, both with the turbines switched on and off, are an integral part. The third octave levels enable a comparison with the human perception threshold. The A and G-weighted sound pressure levels are represented depending on the wind velocity for three different distances from the turbine. The A-weighted sound level – specified as dB(A) – simulates the human hearing sensitivity. The G-level – specified as dB(G) – represents a singular value, which rates only infrasound and parts of the low-frequency frequency range. The human ear is very insensitive to these frequency ranges (for more info please refer to ***Figure A3-1*** in Appendix A3). Additionally recorded narrow band spectra, all specified with a resolution of 0.1 Hz, are able to depict more clearly specific features of the noise characteristics of wind turbines. The level values in a spectrum depend on the selected resolution. Therefore, narrow band levels cannot be compared with third octave levels. Only third octave levels are suitable for comparisons with the hearing threshold, as it also corresponds to third octave levels.

All the following results of measurements on operating wind turbines also include the noise caused by the wind itself in the vicinity. In addition, in the case of strong wind, noise will inevitably be induced at the microphones despite the use of double wind screens. Therefore, the results of a measurement cannot be attributed to the respective wind turbine alone. The differences shown by the comparison of situations with the turbine switched on and off are therefore all the more important. When it comes to the noise measurements at roads (Chapter 5) and in the city centre (Chapter 6), the effects related to the wind are irrelevant. Thus, the measuring results for wind turbines and roads designate different situations, which cannot be directly compared with one another.

The selection of the wind turbines that were to be measured proved to be rather difficult. The initial contacts with operators were kindly set up by the Baden-Wuerttemberg approval authorities (district offices) after the LUBW had carried out a corresponding query. The participation of the turbine operators was on a voluntary basis. Some operators had concerns about participating in the project.

First, the locations were qualified from an acoustic perspective. Sites near busy roads, or other disruptive noise sources – including forests – were deemed unsuitable and thus rejected. Regarding more powerful turbines, the site search had to be extended by the LUBW to include Rhineland-Palatinate. In this case constructive support was also provided several times by the authorities. Not only weather-related restrictions had to be coped with (matching wind directions and wind speeds; strong winds resulting in termination of measuring due to automatic shutdown; snowfall in the vicinity) during the project. One wind power plant broke down shortly before the measurement and was

Table 4-1*: Overview of the wind power plants where measurements were carried out in the context of this project. The individual power plants and the associated results are described in more detail in Sections 4.2 to 4.7.*

Wind turbine (WT)	WT 1	WT 2	WT 3	WT 4	WT 5	WT 6
Manufacturer Model	REpower* MM92	Enercon E-66	Enercon E-82	REpower* 3.2M114	Nordex N117/2400	Enercon E-101
Nominal capacity	2.0 MW	1.8 MW	2.0 MW	3.2 MW	2.4 MW	3.05 MW
Rotor diameter	92 m	70 m	82 m	114 m	117 m	101 m
Hub height	100 m	86 m	138 m	143 m	140.6 m	135.4 m

* Senvion since 2014

inoperable for a longer period of time. One operator withdrew his consent to the measurement as the proposed turbine had difficulties with the acceptance inspection. A construction site was set up in the vicinity of another wind turbine, which caused background noise and thus made the measurement of the turbine noise impossible. This is just to show some of the challenges that had to be overcome during the project. The delays that were thus incurred were not foreseeable from the start.

Figure 4-1*: Model type WT 1, REpower MM92*

Figure 4-2*: Model type WT 2, Enercon E-66*

Figure 4-3*: Model type WT 3, Enercon E-82*

Figure 4-4*: Model type WT 4,* REpower 3.2M114

Figure 4-5*: Model type WT 5,* Nordex N117/2400

Figure 4-6*: Model type WT 6,* Enercon E-101

These images convey an impression of the examined wind power plants, covering the common power range between 1.8 MW and 3.2 MW. The hub height varies between 86 m and 143 m, the rotor diameter varies between 70 m and 117 m. Photos: batcam.de (left column), LUBW (Fig. 4-2 and 4-4), Lucas Bauer wind-turbine-models.com (Fig. 4-6)

4.1 Measurements and evaluations

The noise measurements were carried out according to DIN EN 61400-11 [6] and the technical guidelines for wind turbines [7] respectively. Furthermore, the noise immissions in the frequency range from 1 Hz were measured and further guidelines [8] [9] used if necessary.

These regulations describe noise measurement methods for determining the sound emissions of a wind turbine. They establish the procedures for the measurement, analysis and presentation of results of noise emitted by wind turbines. Likewise, requirements for the measuring devices and calibration are provided in order to ensure the accuracy and consistency of the acoustic and other measurements. This is where special microphones that can be applied from levels of 1 Hz onwards were used. The non-acoustic measurements that are necessary in order to determine the atmospheric conditions that are relevant for the determination of the noise emission are also described in more detail. All the parameters that are to be measured and illustrated, as well as the necessary data processing to determine these parameters are defined. For more details on measurement techniques, please refer to Appendix A4.

Based on the measurements, which – if possible – should be made at distances of approx. 150 m, 300 m and 700 m from the turbine (it was not always possible to observe these distances exactly), statements about emissions and immissions of the turbines can be made. The wind turbines that were to be measured were each operated in open operating mode, where the system is geared towards performance optimization. Experience has shown that the highest noise levels can be expected in this mode.

Over the entire measurement time, both third octave as well as octave bandwidths in the frequency range of 6.3 Hz to 10 Hz were formed and stored with the sound level meters used (see Appendix A4). From the recorded audio files, third octave and octave spectra were formed in the range of 1 Hz to 10 kHz as well as narrowband spectra in the range of 0.8 Hz to 10 kHz by means of digital filters. Times with extraneous noise were marked during the measurements and not used for the evaluations. The microphones were each mounted on a reverberant floor plate and provided with a primary and secondary wind screen (see ***Firgure 4.3-1***), in order to reduce or even avoid wind noise induced at the microphone. The use of a reverberant plate results in a doubling of sound pressure at the microphone, resulting in higher readings. When determining the sound power level, a correction of -6 dB therefore has to be undertaken afterwards. The correction was carried out in this report for the presentation of measured values only in the case of a comparison of results that emerged through different measuring arrangements (see ***Firgures 2-3 to 2-5*** as well as ***Table 2-1***) or comparisons with the perception threshold, e.g. in ***Figure 4.2-5***.

For some representations of the measuring results, the human perception threshold was inserted into the graphics as a comparison. This is where we used the values of DIN 45680 (2013 draft) [5]. These values are somewhat lower than those of the currently valid DIN 45680 (1997) [4] that are to be applied in accordance with the TA Lärm [10]. Below 8 Hz, the values of the standard work were supplemented by data from literature [11], see ***Table A3-1***. Further information is listed in Appendix A1 for the difficulties regarding the hearing and perception threshold. Graphical comparisons of the hearing and perception threshold are also presented there (***Figure A1-2***).

In addition to the sound level measurements, vibration measurements were also carried out at the foundation of wind turbine 5, and at distances of 32 m, 64 m and 285 m (see Section 4.8).

4.2 Noise at wind turbine 1: REpower MM92 – 2.0 MW

BASIC CONDITIONS

The wind turbine 1 (WT 1) is a power plant made by the company Repower, model MM92/100 (***Figure 4-1***) with a nominal generator capacity of 2.05 MW at a wind speed of 12.5 m/s at hub height. The rotor diameter is 92 m, the hub height above ground is 100 m. The immediate vicinity of the wind turbine is defined by agricultural land with individual trees scattered around. Adjacent to it are areas with conifer tree culitvation and forest. Further wind power plants are located in the wider vicinity of the wind turbine

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Figure 4.2-1: *Wind measurement mast with view in direction of the wind power plant being measured. Photo: Wölfel company*

being measured. These were switched off during the measurement period. A path in close proximity is allowed to be used only by agricultural traffic and is used only seldom. The measurements were carried out on 11.04.2013 between 8:00 a.m. and 4:00 p.m. The position of the microphone at the measurement point MP1 was at a distance of 150 m to the power plant in a downwind direction. This was in order to take into account the worst case scenario (support of sound propagation through the wind). Further measurement points MP2 and MP3 were located at intervals of 300 and 700 m in a downwind direction. ***Figure 4.2-1*** provides an impression. The measurement was carried out in a wind speed range of 5 to 14 m/s, a temperature range of 10 to 12 °C and an atmospheric pressure range of 946 to 951 hPa. The entire power range of the power plant was covered up to the nominal power. The turbulence intensity, which is basically a measure of the gustiness of the wind (see Appendix A3), was 18 %.

RESULTS: NARROW BAND LEVEL

Figure 4.2-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 150 m with a resolution of 0.1 Hz. The wind speed was 6.5 m/s. With the power plant switched on, six discrete maxima can be clearly seen in the infrasound range between 1 Hz and 5.5 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade of approximately 0.75 Hz, which corresponds with a frequency of the rotor of 15 rpm and the harmonic overtones at 1.5 Hz, 2.2 Hz, 3.0 Hz, 3.7 Hz, 4.5 Hz and 5.2 Hz (***Figure 4.2-2***). Further maxima were measured at 25 Hz and

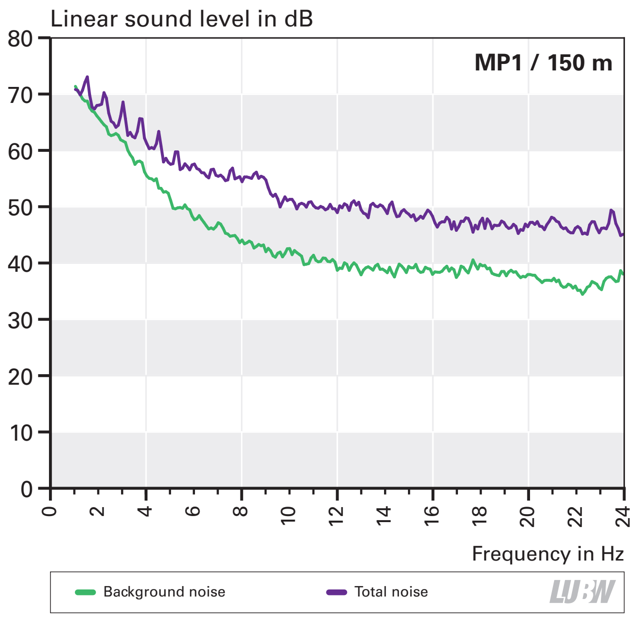

Figure 4.2-2: *Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 1 for the frequency range of infrasound*

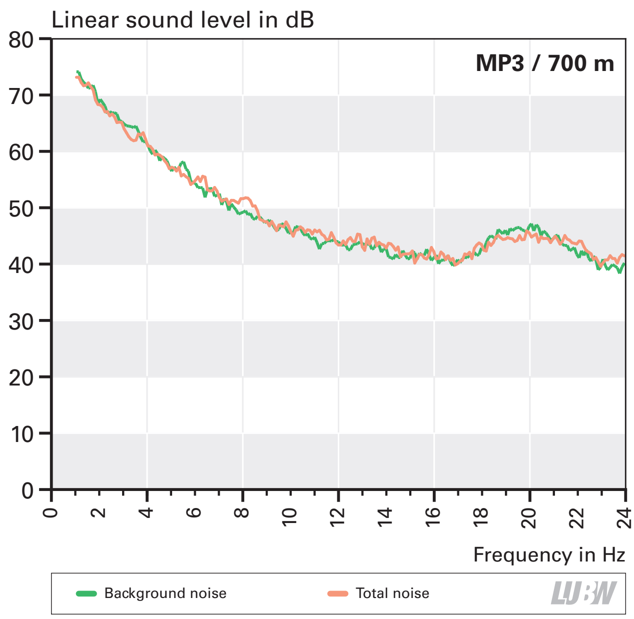

Figure 4.2-3: *Narrow band spectra of background noise and total noise at a far range from the wind turbine WT 1 for the frequency range of infrasound*

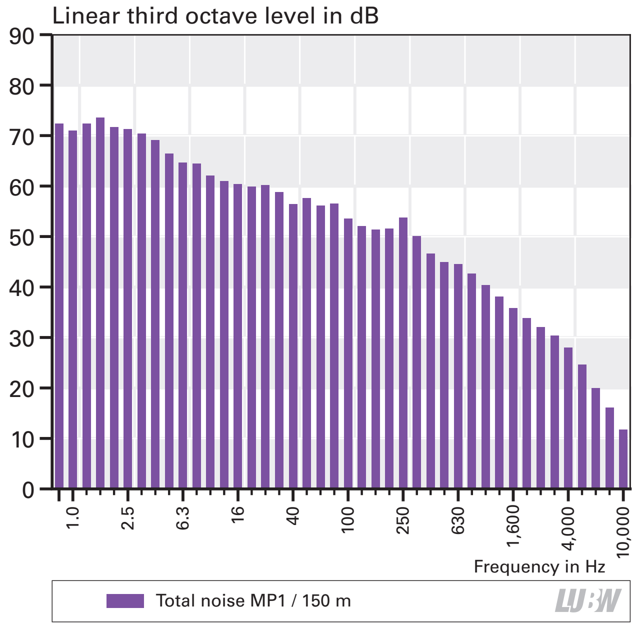

Figure 4.2-4*: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 1*

50 Hz, These are at a much lower level, and are attributable to the operation of the generator. The peaks disappear when the power plant is switched off.

Figure 4.2-3 shows the narrow band spectra of background noise and overall noise at the measurement point MP3 at a distance of 700 m. At this distance, no discrete infrasound maxima can be distinguished anymore when the power plant is on. There were no measurable differences in infrasound between the conditions "turbine on" and "turbine off" for this measurement at a distance of 700 m. This was apparently caused by the noise of wind and the surroundings. Here too, the wind speed was 6.5 m/s.

RESULTS: THIRD OCTAVE LEVEL

Figure 4.2-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 (150 m) for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 6.5 m/s. The level reduction due to the shutdown of the power plant is visible here in a considerably broader spectral range.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.2-5 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was

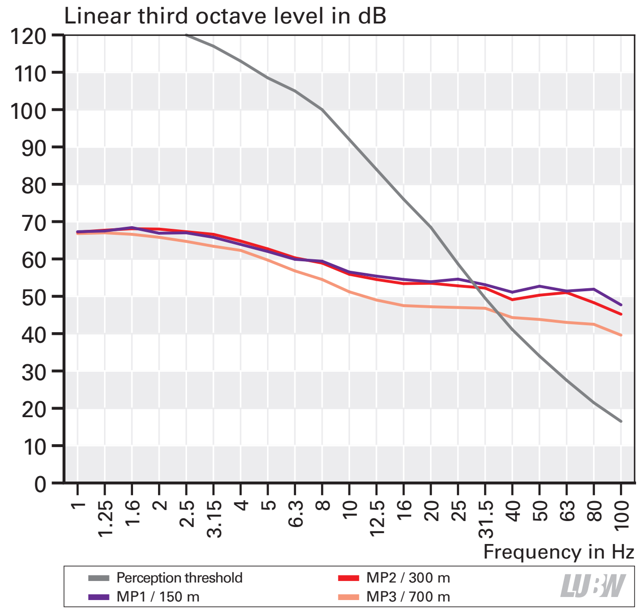

Figure 4.2-5*: Third octave spectra of total noise at the measurement points MP1 (150 m), MP2 (300 m) and MP3 (700 m) of WT 1, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

6.8 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. It is apparent that from about 6-8 Hz the overall noise becomes less with increasing distance to the power plant. The differences become clearer with increasing frequency. In terms of audible sound, this constitutes an audible effect. At the measure-

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ment point located at a distance of 700 m, the turbine is no longer constantly and at most only slightly noticeable; the curve is almost the same as for the background noise. In the infrasound range, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

The above charts reflect a concrete individual situation at a given wind speed (6.5 or 6.8 m/s respectively) as an example. However, the results were presented at different frequencies. Of course this is where the question arises as to what the relationships are like at different wind speeds. These were also measured, and the results are shown in ***Figure 4.2-6***. This figure is not easy to understand straight away and should therefore be explained step by step.

The three graphs represent the relationships at the respective measurement points at a distance of 150 m (upper figure), 300 m (middle figure) and 700 m (lower figure). The wind speed of 4.5 to 10.5 m/s is placed on the bottom, horizontal axis. The vertical axis represents the sound level values. Each point corresponds to a single measurement sequence of 10 seconds at a given wind speed. Violet dots, which depict the lower value area, represent audible sound with the turbine on, expressed in dB(A). It is easy to see at distances of 150 and 300 m that the audible sound increases slightly at wind speeds of 4.5 m/s up to just above 5.5 m/s, but then remains constant at higher wind speeds. How does this behave with low-frequency sound or infrasound respectively? In order to find out, the dependency of the G-weighted sound level, specified as dB(G), was examined.

The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. In the vicinity of the power plant, at a distance of 150 m (upper image), you can see clearly that the sound level is similarly dependent on the wind speed also in the low-frequency range (incl. infrasound) as is the case for audible sound when a power plant is switched on. Furthermore, it is also visible that there is a clear difference between the turbine being on and the turbine being off. The G levels are significantly higher when the turbine is on (red dots) than when it is switched off (green dots). At a distance of 300 m (middle image) this difference is already less pronounced, and at 700 m it is no longer recognizable. There is virtually no difference anymore between the red cluster of dots (turbine on) and the green cluster of dots (turbine off), regardless of the wind speed.

These readings also show clearly that the background noise through wind and vegetation, measured when the turbine is switched off (green dot cluster), is subject to strong scattering, i.e. particularly noticeable natural fluctuations. The values span a range of up to 20 dB(G). The measured sequences of the turbine noise, on the other hand, scatter significantly less, at least in the near-field.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.2-7 shows the A and G-weighted level curves between 11:00 a.m. and 3:00 p.m. at a distance of 150 m and 700 m. In addition, the operating conditions of the wind turbine (green = turbine on, light blue = turbine off) as well as periods of time with external noise (violet) are depicted. For the two level developments of measurement point MP1, the operational phase "turbine off" is easily recognisable through the considerably declining level developments. At the measurement point MP3, a drop in the level with the turbine turned off is barely distinguishable due to the fluctuating background noise – only the minima of the A level development are slightly lower than when the turbine is on. The G level development, however, covers nearly the same range of values as when the turbine is switched off.

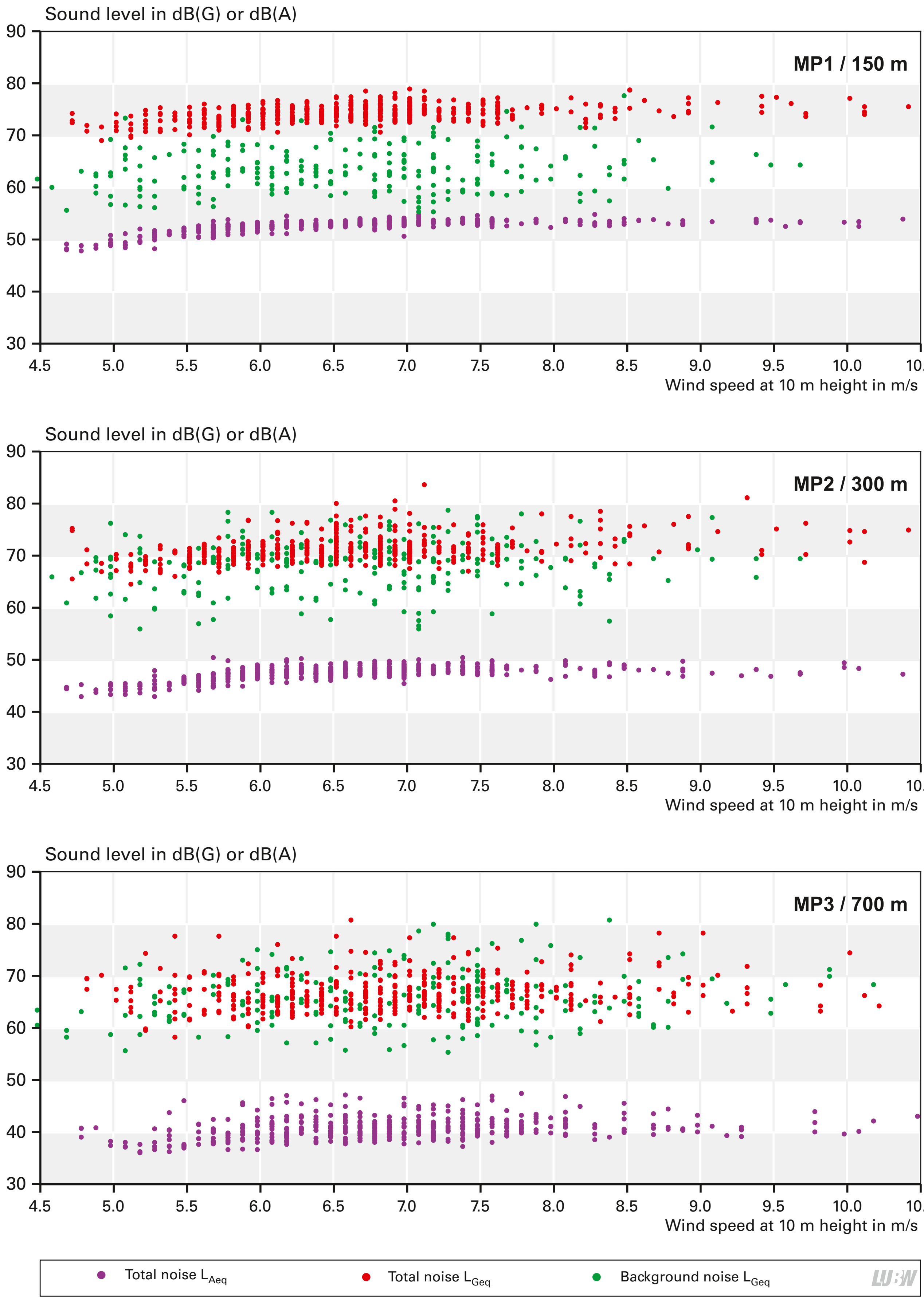

***Figure 4.2-6**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 1. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

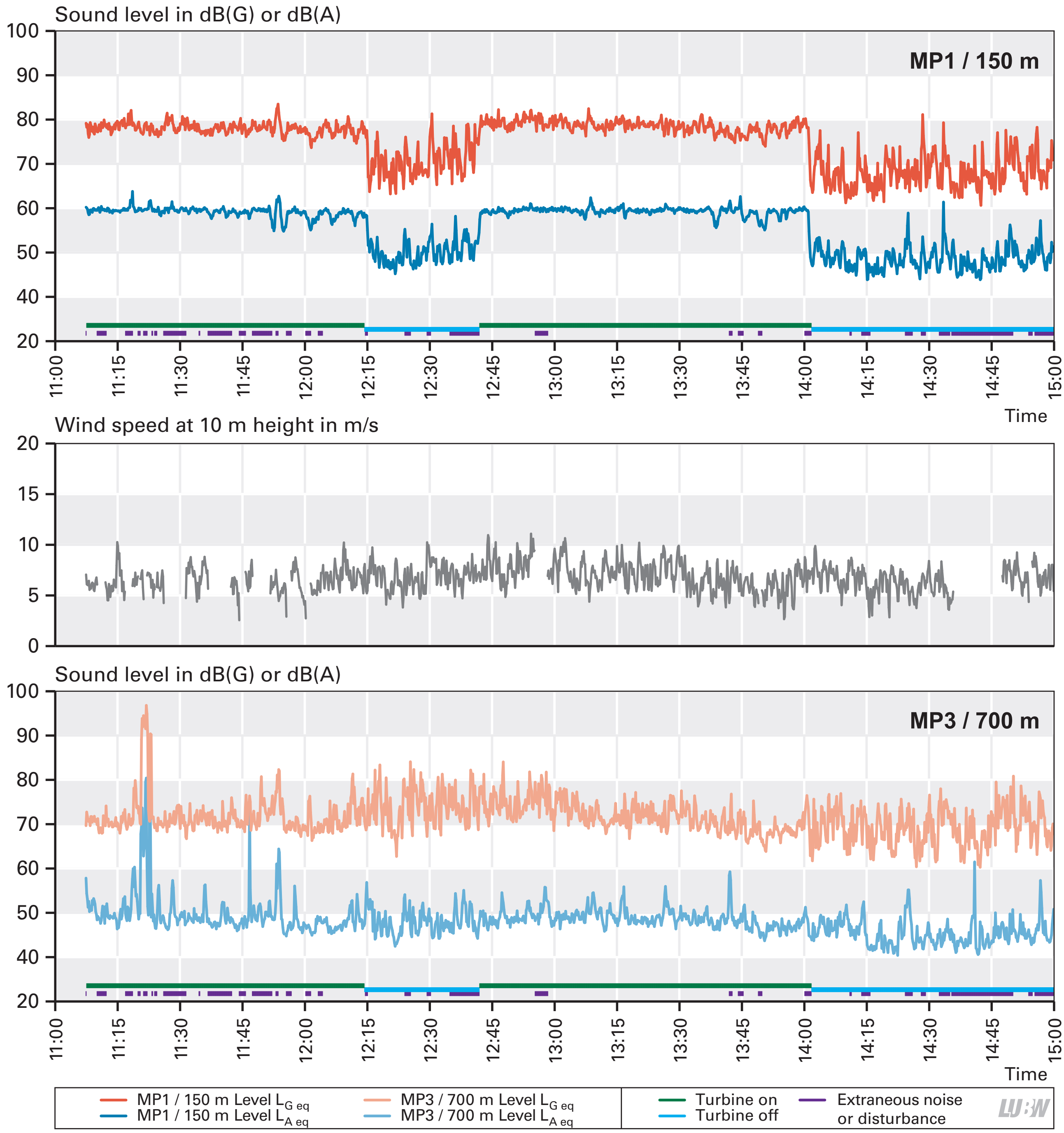

Figure 4.2-7: *Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 1*

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4.3 Noise at wind turbine 2: Enercon E-66 – 1.8 MW

BASIC CONDITIONS

The wind turbine 2 (WT 2) is a gearless unit by the company Enercon, Model E-66 18/70 (***Figure 4-2***) with a nominal generator capacity of 1.8 MW. The rotor diameter is 70 m, the hub height above ground is 86 m. The immediate vicinity of the turbine consists of agricultural land, with forest partly adjacent to it. Further wind turbines are located in the vicinity. These were completely turned off during the measurement period in order to prevent extraneous noise. A further wind power plant is located at a distance of about 1.5 km; this was in operation during the measurement period. A path in close proximity is allowed to be used only by agricultural traffic and is used very seldom. The measurements were carried out on 02.11.2013 between 10:00 a.m. and 6:00 p.m. The position of the microphone at the measurement point MP1 was at a distance of 120 m from the power plant, measurement point MP2 at a distance of 240 m, both in a downwind direction (in order to take into account the propagation of sound through the wind). The microphone at the measurement point MP3 was positioned at a distance of 300 m from the tower axis and deviated by 30° from the prevailing wind direction. A measurement point at a distance of 700 meters was not possible at this site. ***Figure 4.3-1*** provides an impression.

The measurement was performed in a wind speed range of 5 to 15 m/s (measured at 10 m height), a temperature range of 11 to 12.5 °C, an air pressure range of 926 to 927 hPa and in a power range of 0 to 1,800 kW. The turbulence intensity (see Appendix A3) during the measurement was 28 % and thus relatively high.

RESULTS: NARROW BAND LEVEL

Figure 4.3-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 120 m with a resolution of 0.1 Hz. The wind speed was 9 m/s. With the turbine turned on, several discrete maxima can be observed in the infrasound range below 8 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies are in accordance with the passage frequency of a rotor blade and its harmonic overtones. At 22.5 rpm, the speed at which the turbine was running, one can mathematically determine the peaks at 2.2 Hz, 3.4 Hz, 4.5 Hz, 5.6 Hz, 6.8 Hz and 7.9 Hz with good conformance. They disappear when the turbine is turned off; at a distance of 300 m they occur

Figure 4.3-1: *Measurement point MP1 with microphone, reverberant plate and dual wind screen. In the background: wind turbine WT 2 at a distance of 120 m. Photo: Wölfel company.*

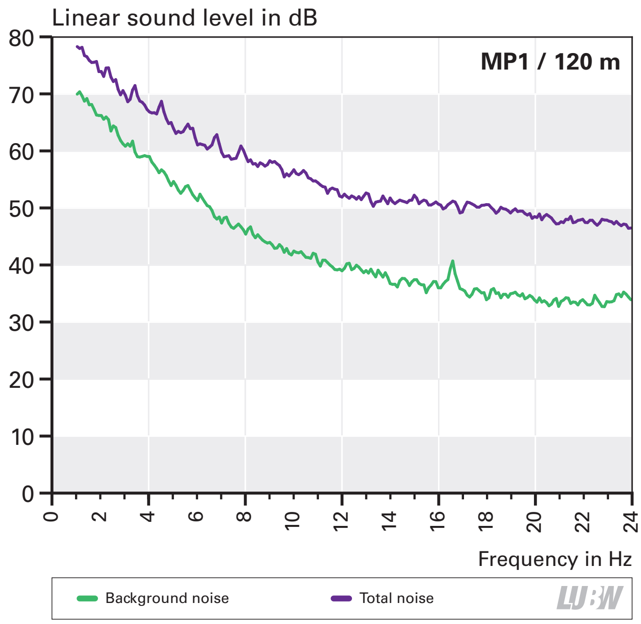

Figure 4.3-2 *Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 2 for the frequency range of infrasound*

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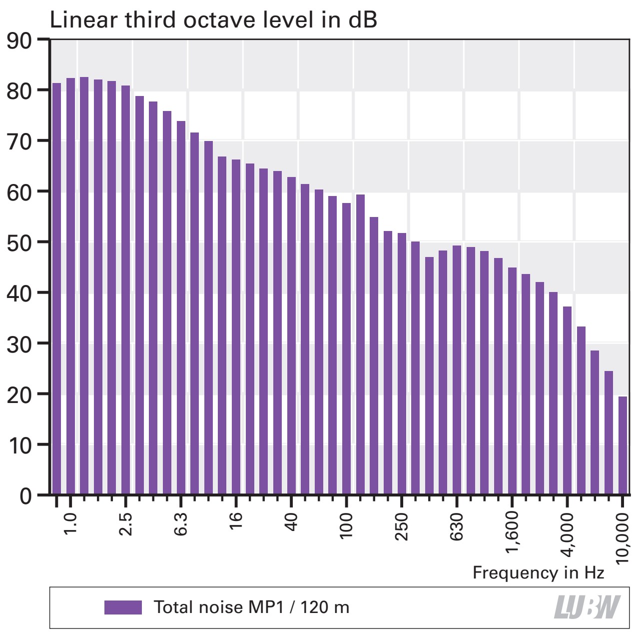

***Figure 4.3-3**: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 2*

only faintly (not shown). The level peak at approx. 17 Hz that is clearly visible in the background is probably due to extraneous noise.

RESULTS: THIRD OCTAVE LEVEL

Figure 4.3-3 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 120 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 9 m/s. The level reduction through switching off the turbine is recognizable in a much broader spectral range here.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.3-4 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 9 m/s. The background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP3 are further away from the turbine than measurement point MP1 (240 m and 300 m compared to 120 m). This is where somewhat lower values are also measured, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were taken and are depicted in ***Figure 4.3-5***. The three charts represent the conditions at distances of 120 m (MP1, upper figure), 240 m (MP2, middle figure) and 300 m with a lateral displacement by 30° to the wind direction (MP3, lower figure). The violet dots in the lower range of values represent audible sound, expressed in dB(A). In the upper image it

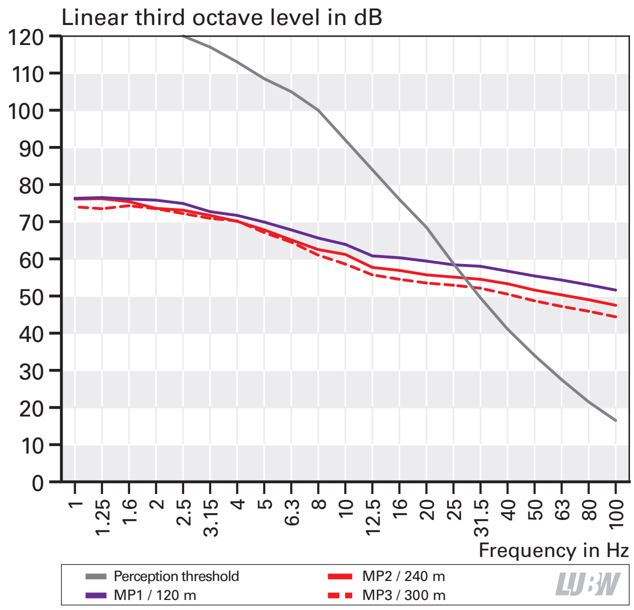

***Figure 4.3-4**: Third octave spectra of total noise at the measurement points MP1 (120 m), MP2 (240 m) and MP3 (300 m) of WT 2, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

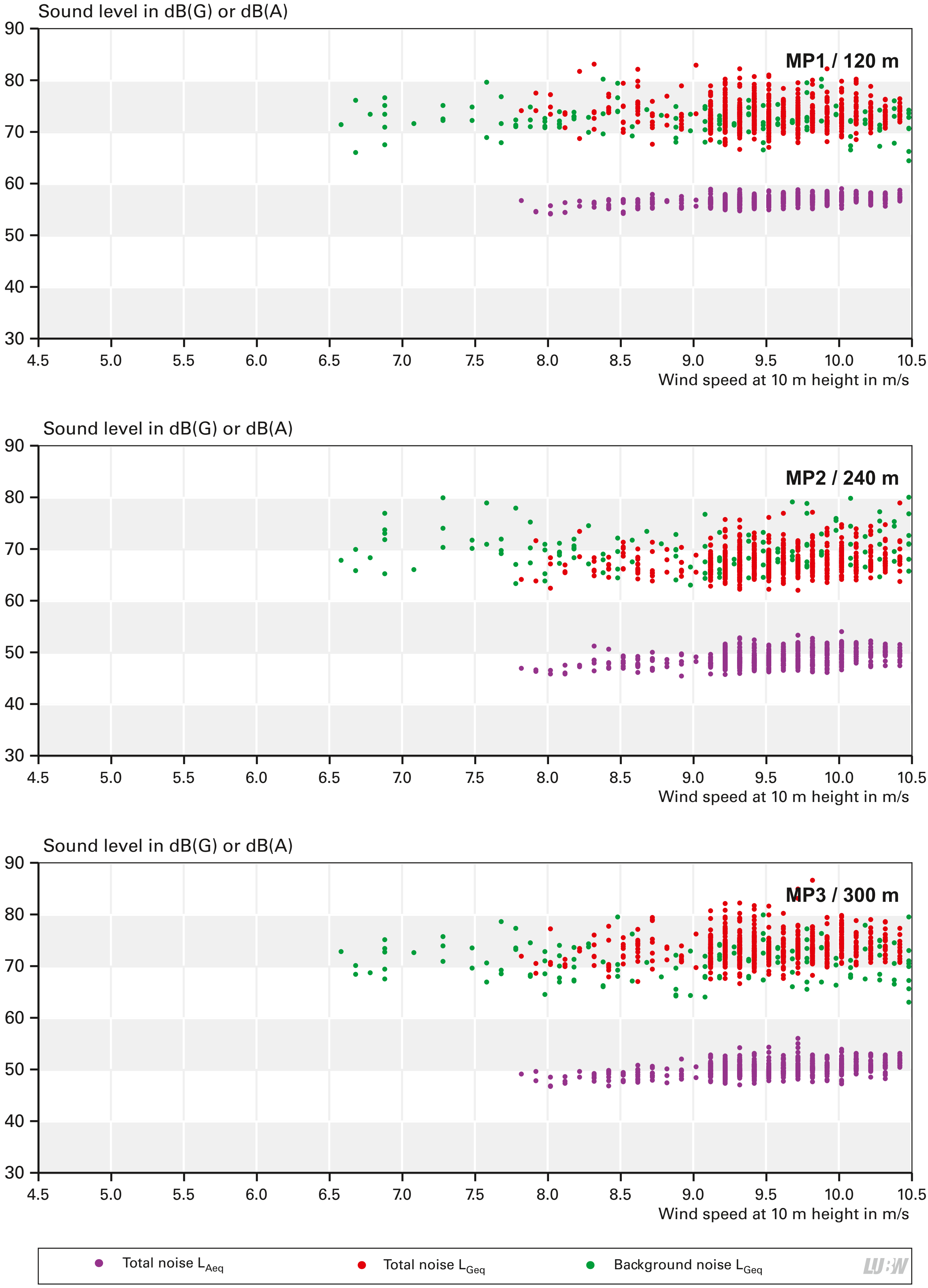

***Figure 4.3-5**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 2. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

can be seen clearly that the measured A levels are higher at a distance of 120 m than at the measurement points at a distance of 240 m and 300 m from the power plant. The turbine was perceived to be louder at a distance of 120 m than at a distance of 240 m.

The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. The upper image shows that at the measurement point MP1, i.e. in the near field at a distance of 120 m from the power plant, the G-weighted sound pressure level during operation of the wind power plant is approximately constant and minimally higher than that of the background noise when the turbine is not running. A similar situation is given at the measurement points MP2 and MP3. Hardly any differences can be seen between the measured values, as the red and green dot clusters pretty-much overlap each other.

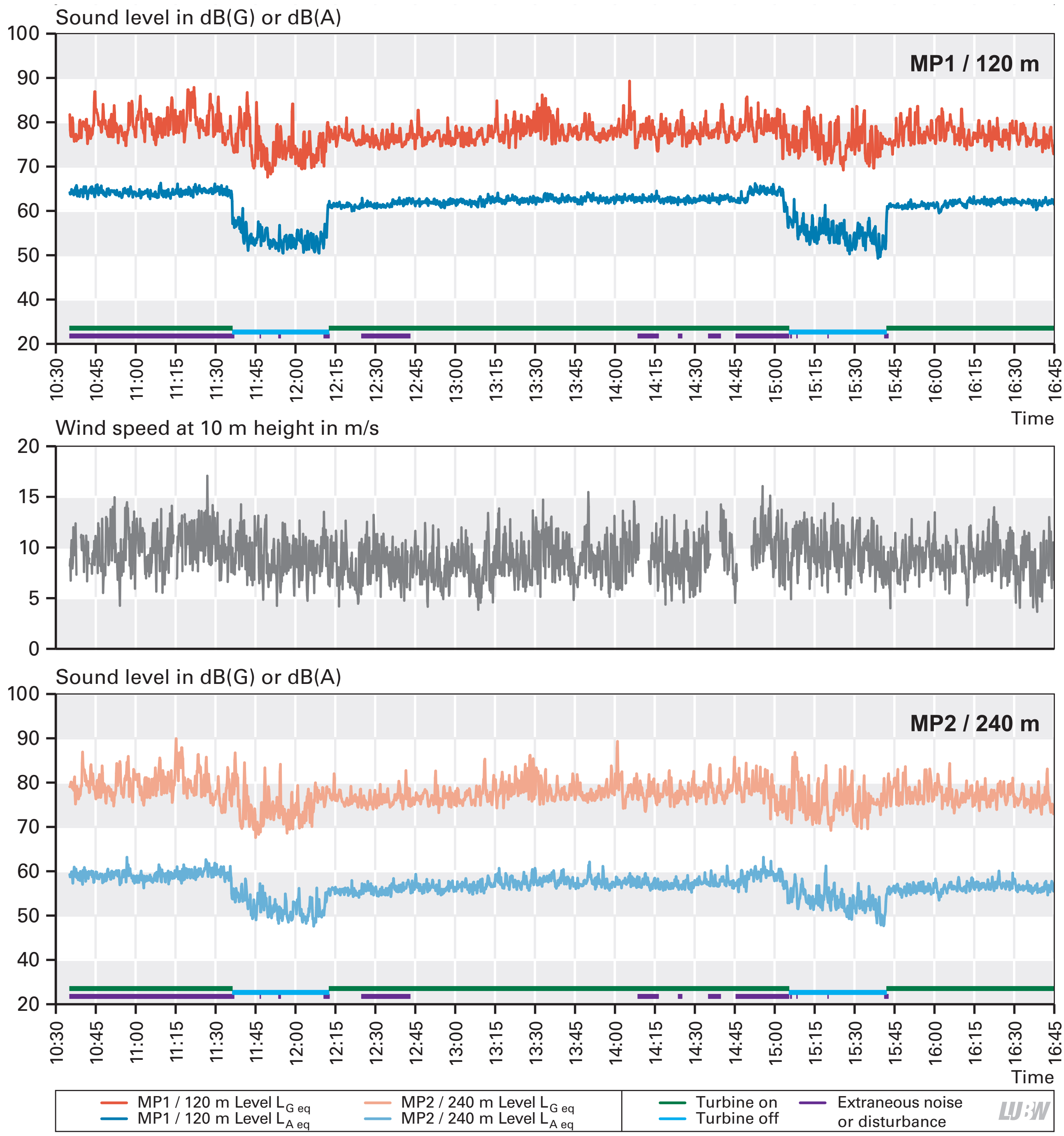

***Figure 4.3-6**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements at the wind turbine WT 2*

The relatively large scattering of the measured values for when the turbine is running and when it is not running, and the relatively high G-weighted sound pressure level – even when the turbine is off – are in this case probably due to the high wind speeds prevailing throughout. The measurements with the turbine in operation were taken in the range of 8 to 11.5 m/s (10 m height). In this case, part of the effect is potentially also attributable to wind-induced noise at the microphones.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.3-6 shows the A and G-weighted level curves between 10:30 a.m. and 5:00 p.m. at a distance of 120 m and 240 m. In addition, the operating conditions of the wind turbine (green = turbine on, light blue = turbine off) as well as periods of time with external noise (violet) are depicted. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP2, the level drop is less pronounced when the turbine is off, but still clearly recognizable.

Figure 4.4-1: *Wind turbine WT 3 in surroundings used for agricultural purposes. The measurement point with reverberant plate and dual wind screen can be seen in the foreground. Photo: Wölfel company*

4.4 Noise at wind turbine 3: Enercon E-82 – 2.0 MW

BASIC CONDITIONS

The wind turbine 3 (WT 3) is a gearless unit by the company Enercon, Model E-82 E2 (***Figure 4-3***) with a nominal generator capacity of 2.0 MW. The rotor diameter is 82 m, the hub height above ground is 138 m. As can be seen in ***Figure 4.4-1***, agriculturally used areas are located in the closer vicinity. An adjacent wooded area is located at a distance of about 400 meters. A dirt road is located in the immediate vicinity of the power plant, which is used only seldom by agricultural and forestry vehicles. A road is located at a distance of approx. 450 m from the power plant. During the measurement, no traffic noise was noticeable. Further wind turbines from other operators are located at a distance of 1,500 meters. These power plants located further away were in operation during the measurement period. The immissions were not subjectively noticeable during the background noise measurements. The nearest residential building is more than 1,000 meters away. The measurement was carried out on 15.10.2013 between 10:30 a.m. and 3 p.m. The microphone at the measurement point MP1 was located at a distance of 180 meters in a downwind direction from the tower axis, at the measurement point MP2 it was 300 m in a downwind direction. The microphone at the measurement point MP3 was also positioned at a distance of 300 meters, however at an angle of 90° to the downwind direction. A measurement point at a distance of 700 meters was not feasible due to the local conditions.

The measurement was performed in a wind speed range of 2 to 12 m/s (measured at 10 m height), a temperature range of 9 to 13 °C, an air pressure range of 931 to 934 hPa and in a power range of 0 to 2,070 kW. The turbulence intensity (see Appendix A3) during the measurement was 25 % and thus relatively high.

RESULTS: NARROW BAND LEVEL

Figure 4.4-2 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m with a resolution of 0.1 Hz. With the turbine turned on, several discrete maxima can be clearly observed in the infrasound range below 8 Hz. This con-

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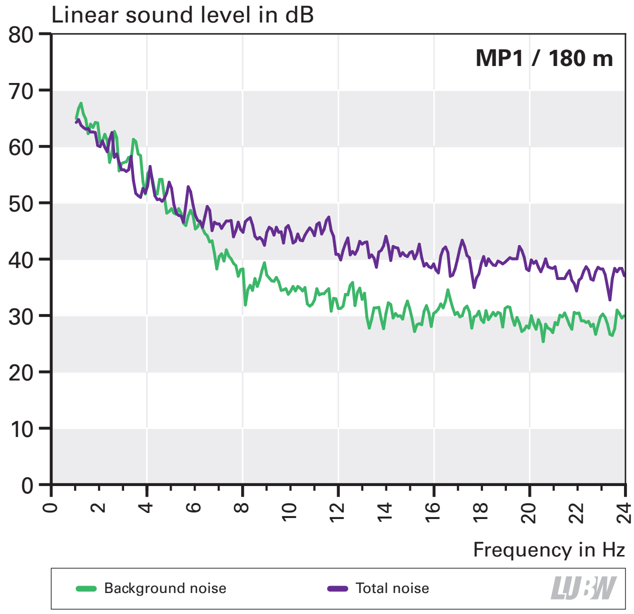

***Figure 4.4-2**: Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 3 for the frequency range of infrasound*

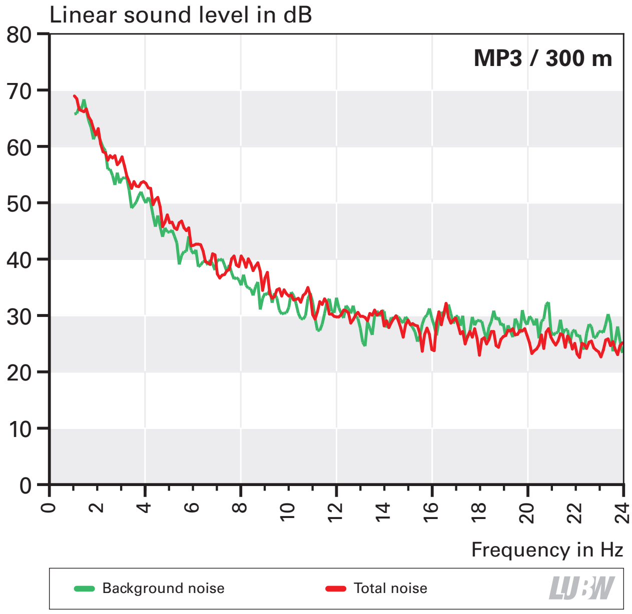

***Figure 4.4-3**: Narrow band spectra of background noise and total noise in the far range of the wind turbine WT 3 for the frequency range of infrasound*

cerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade (here about 0.83 Hz) and the associated harmonic overtones (2.5 Hz, 3.3 Hz, 4.1 Hz, 5 Hz, 5.8 Hz). The peaks disappear when the power plant is switched off, and occur only slightly at a distance of 300 m (***Figure 4.4-3***). The wind speed was 6 m/s during both measurements.

RESULTS: THIRD OCTAVE LEVEL

Figure 4.4-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 6 m/s. Here the level reduction through switching off the turbine is recognizable in a much broader spectral range.

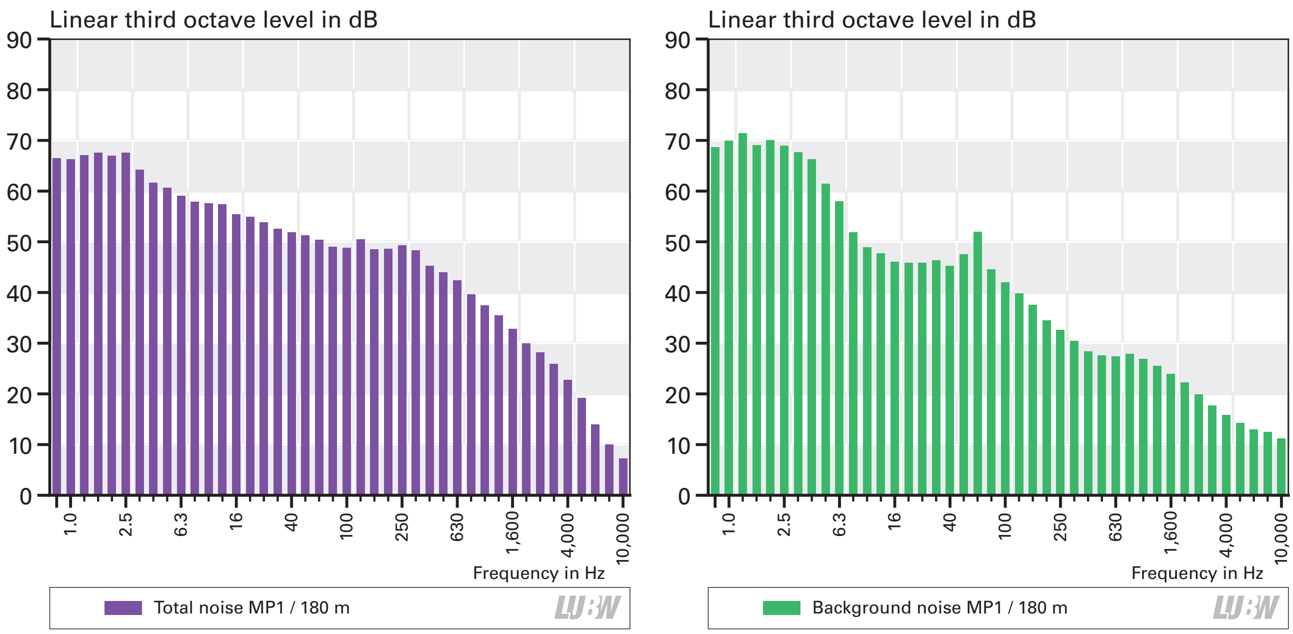

***Figure 4.4-4**: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 3*

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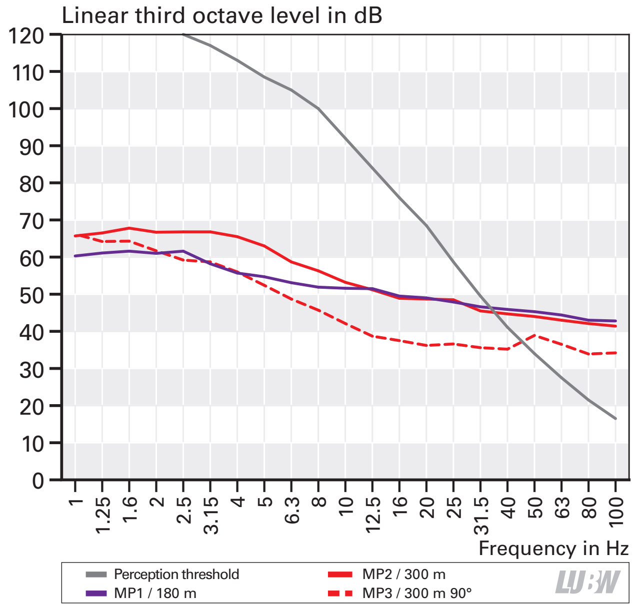

Figure 4.4-5*: Third octave spectra of the total noise at the measurement points MP1 (180 m), MP2 (300 m) and MP3 (300 m, offset by 90 °) of wind turbine 3, perception threshold according to Table A3-1 for comparison. The measured values were corrected according to Section 4.1.*

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.4-5 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP3 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 9 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP3 are further away from the power plant than measurement point MP1 (300 m compared to 180 m). Measurement point MP3 is offset to the downwind direction by 90°. Lower values are thus measured there than at measurement point MP2, which is equally far away. The measurement point MP2 is also closer to an existing nearby road than the measurement points MP1 and MP3, which could also be a reason for the slightly higher values. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.4-6***. The three charts represent the relationships at the respective measurement points at the distances 180 m (top), 300 m (centre) and 300 m with lateral offset by 90° to the downwind direction (bottom). Violet dots, which depict the lower curve, represent audible sound, expressed in dB(A). It can be clearly seen that at a distance of 180 m (top image) the measured A levels are higher than at the measurement points at a distance of 300 m from the turbine. The turbine was thus also clearly more perceptible at a distance of 180 m than at a distance of 300 m. The A level first rises with increasingly higher wind speed.

The red dots represent the G-weighted sound level when the wind power plant is switched on, the green dots when the power plant is switched off. Similarly to the A level, it can also be seen for the G level that – despite higher scattering – it increases somewhat with increasing wind speed, and then remains constant.

The top image shows that at MP1, i.e. in the near field at a distance of 180 m from the turbine, the G-weighted sound pressure level during operation of wind turbine 3 is significantly higher than the background noise when the turbine is off. This is far less pronounced at a distance of 300 meters (centre image) and barely detectable at a distance of 300 meters with 90° offset to the downwind direction (bottom image). The red and green dot clusters then overlap each other in many areas.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.4-7 shows the A and G-weighted level development between 10:15 a.m. and 2:45 p.m. for distances of 180 m and 300 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP2, the recognisable level drop is significantly weaker with the turbine switched off due to the fluctuating background noise.

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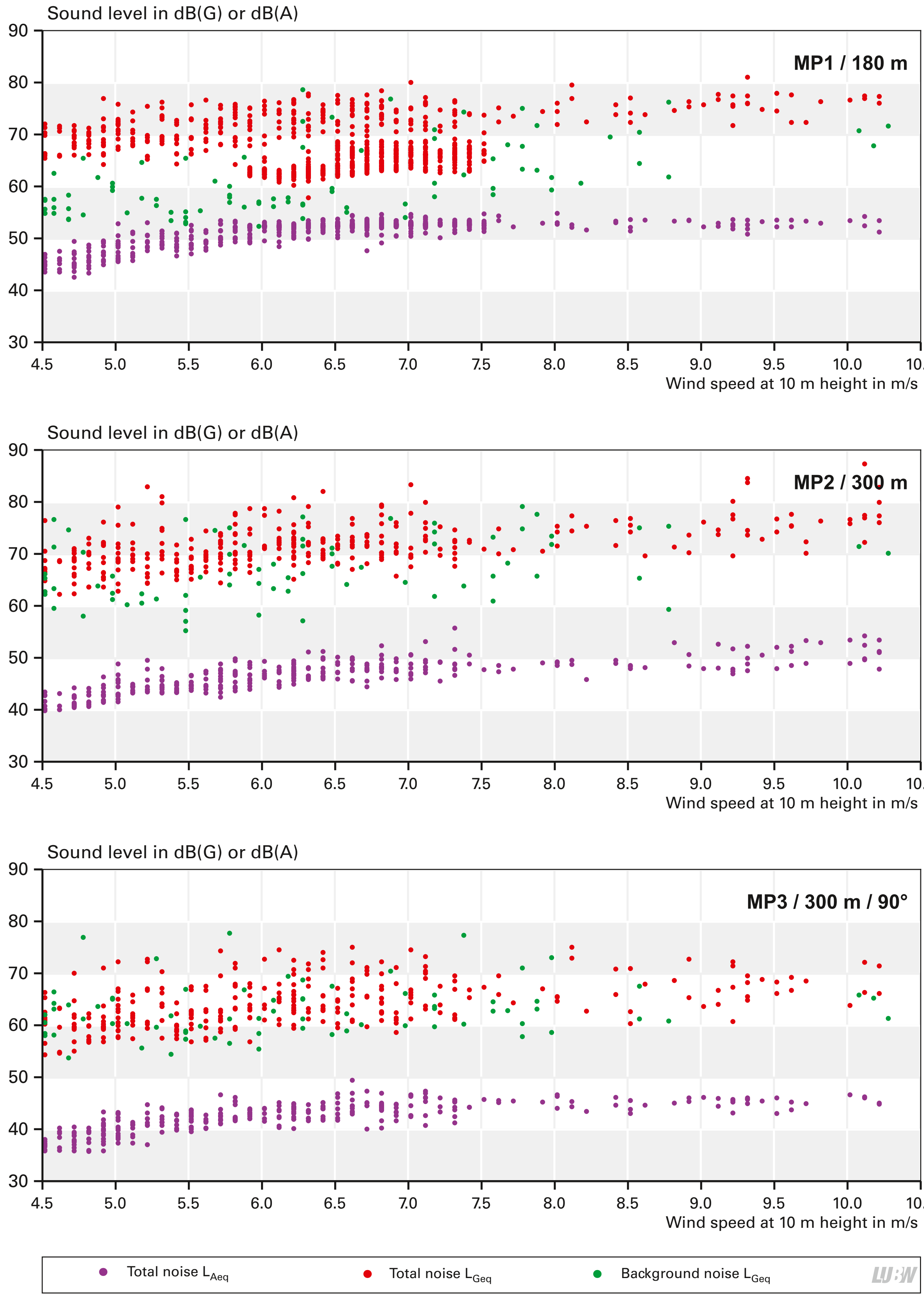

Figure 4.4-6*: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 3. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

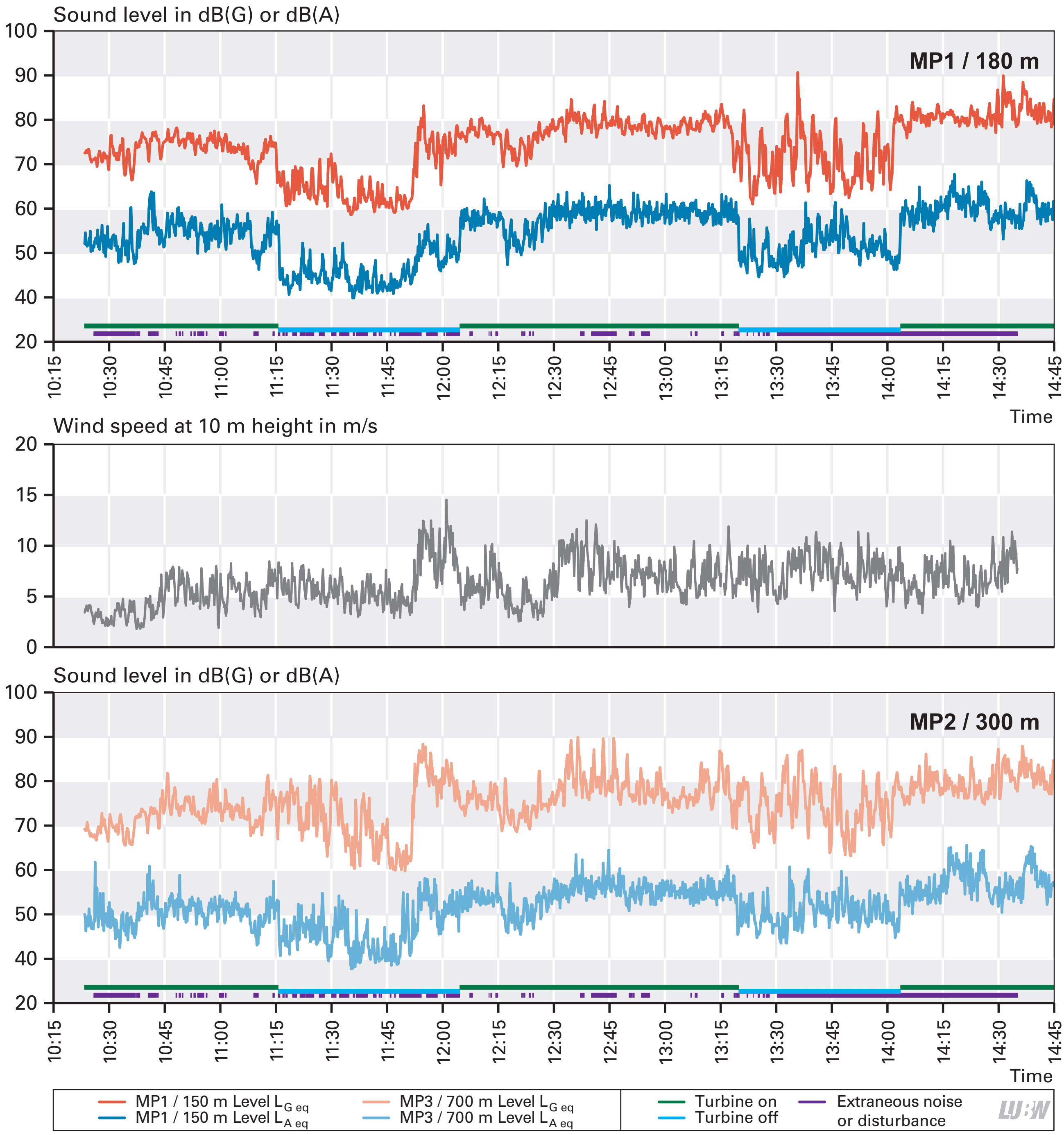

Figure 4.4-7*: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 3*

4.5 Noise at wind turbine 4: REpower 3.2M114 – 3.2 MW

BASIC CONDITIONS

The wind turbine 4 (WT 4) is a unit by the company RE-power, type 3.2M114 (***Figure 4-4***) with a nominal generator capacity of 3.2 MW. The rotor diameter is 114 m, the hub height 143 m.

The measured wind turbine is part of a wind farm with several other wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The vicinity of the turbine consists of agricultural land. A dirt road in the immediate vicinity of the measured turbine is rarely used by agricultural traffic. A forest is located further away. Further wind turbines were in operation at distances of 0.7 km and 2 km, in the opposite direction to the measurement points. Their noise could not be subjectively perceived at any time. The measurements were carried out on 20.03.2014 between 10:00 a.m. and 9:30 p.m. The position of the microphone at the measurement point MP1 was at a distance of 180 m from the turbine, measurement point MP2 and MP3 at a distance of 300 m and measurement point MP4 at a distance of 650 m, in a downwind direction respectively, in order to take into account the most adverse case (promotion of sound propagation through the wind). The measurement point MP2, located directly next to measurement point MP3, served as a comparative measurement point. Its microphone was provided with a primary wind screen and placed into an approx. 50 cm deep hole that was dug especially for that purpose. A secondary wind screen covered the hole flush. The parallel measurements were taken at the measurement points MP2 and MP3 in order to enable a comparison of the measurement values and enable conclusions to be made regarding wind-induced sound components arising at the microphone. The two measurement points MP2 and MP3, as well as the measured turbine, can be seen in ***Figure 4.5-1***. ***Figures 4.5-2 to 4.5-5*** provide an impression of the conditions on site and the measurement technology used.

The measurement was performed in a wind speed range of 3 to 7 m/s (measured at 10 m height), a temperature range

Figure 4.5-1 *(right): Measurement points MP2 and MP3 at a distance of 300 m from the tower axis. Reverberant plate and double wind screen (left), spanned hole in the ground (right). Photo: Wölfel company*

Figure 4.5-2*: View inside the power plant with 143 m hub height. Photo: LUBW*

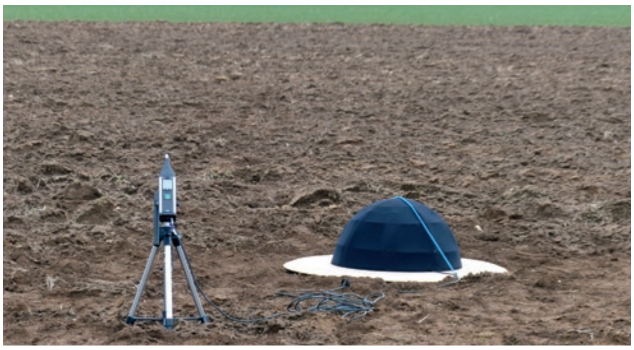

Figure 4.5-3*: Reverberant plate with mounted microphone and dual wind screen. The type DUO measurement device is mounted on a tripod next to it and is connected to the microphone via a measuring cable. Photo: LUBW*

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Figure 4.5-4: *Anemometer mast for measuring wind speed and wind direction, air pressure, humidity and temperature. The mast is extended to 10 m (not yet extended in the image). Photo: LUBW*

Figure 4.5-5: *Data is constantly collected inside the system during the measurement and transmitted by radio (left). Photo: LUBW*

of 15 to 19 °C, an air pressure range of 979 to 981 hPa and in a power range of 0 to 3,170 kW. The turbulence intensity (see Appendix A3) during the measurement was 15 %.

RESULTS: NARROW BAND LEVEL

Figure 4.5-6 shows the narrow band spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m with a resolution of 0.1 Hz. With the turbine turned on, clearly visible maxima can be seen in the infrasound range. The measured frequencies correspond to the passage frequency of a rotor blade (here approximately 0.6 Hz) and its harmonic overtones at 1.2 Hz, 1.8 Hz, 2.4 Hz, 3 Hz, etc. This concerns infrasound generated by the rotor due to its motion. The peaks disappear when the turbine is switched off. ***Figure 4.5-7*** shows the narrowband spectra of background noise and total noise at the measurement point MP4 at a distance of 650 m. At this location the discrete infrasound maxima (see measurement point MP1) are still detectable with the wind power plant turned on. The recognizable slightly higher levels at measurement point MP4, with frequencies lower than 5 Hz, cannot be attributed to turbine operation. The cause for

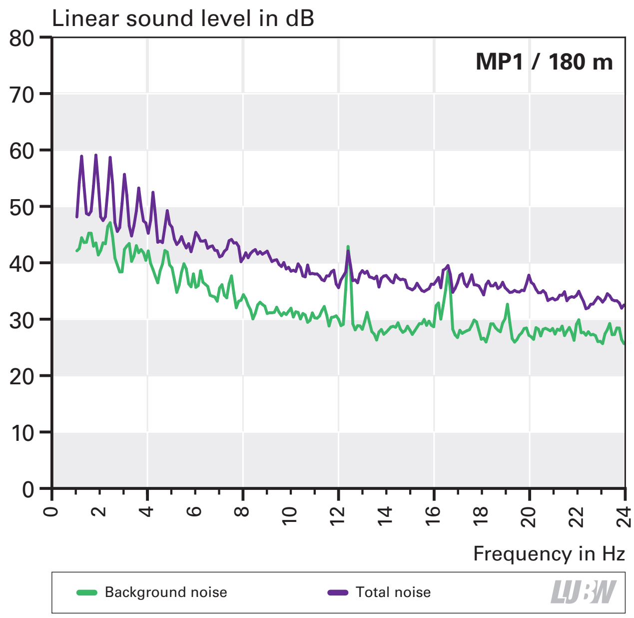

Figure 4.5-6: *Narrow band spectra of background noise and total noise in the vicinity of the wind turbine WT 4 for the frequency range of infrasound*

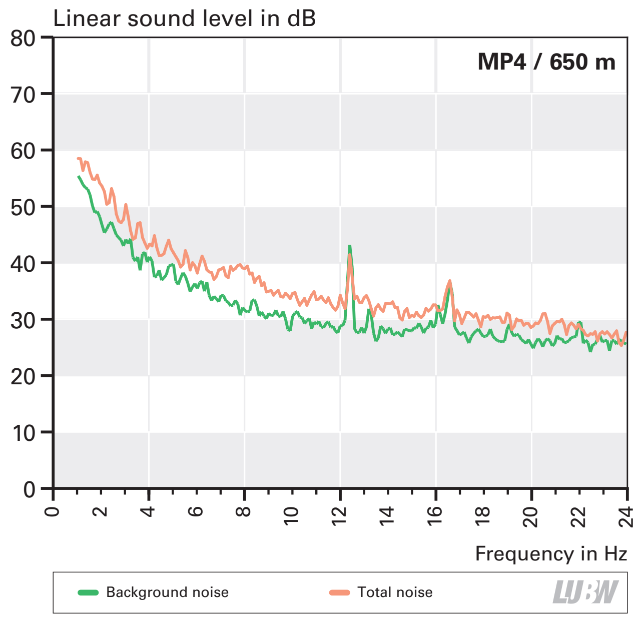

Figure 4.5-7: *Narrow band spectra of background noise and total noise in the far range of the wind turbine WT 4 for the frequency range of infrasound*

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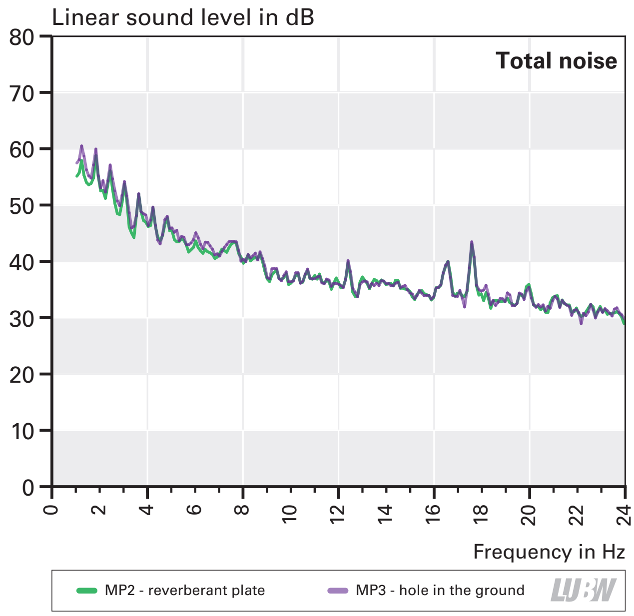


***Figure 4.5-8**: Narrowband spectra of the total noise at the measurement points MP2 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 4 for the range of infrasound. The distance from the turbine was 300 m*

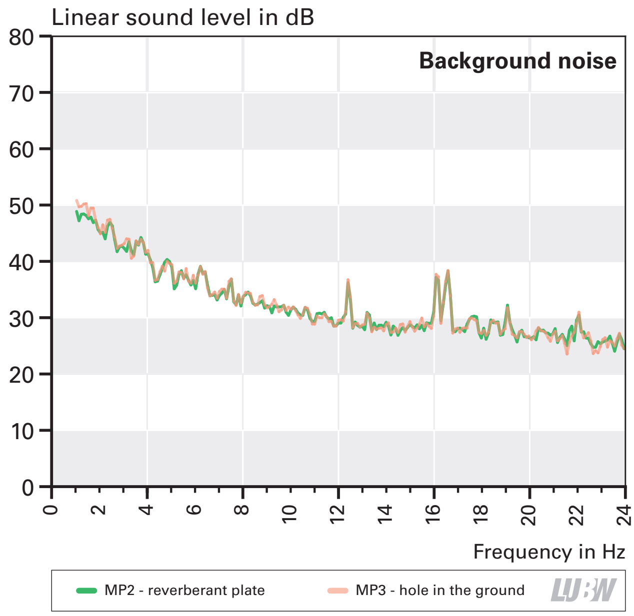


***Figure 4.5-9**: Narrowband spectra of the background noise at the measurement points MP2 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 4 for the range of infrasound. The distance from the turbine was 300 m.*

the up to 10 dB higher values is another background noise at the measurement point MP4 compared to the measurement point MP1. The wind speed was 5.5 m/s for both measurements.

The comparison of narrowband spectra for the two measurement points MP2 and MP3 in ***Figures 4.5-8 to 4.5-9*** shows that there is no significant difference between the two measurement points for the range of infrasound. The wind speed was 5.5 m/s respectively. It can therefore be assumed that below 20 Hz neither the absorption of the secondary wind screen nor the ground influences play a role. The increase in level towards lower frequencies was present in this measurement to an equal extent both with and without a hole in the ground. The expected reduction in the wind-induced background noise in the infrasound range cannot be observed in a direct comparison between the two measurement points. Further investigations regarding the issue of noise at the microphone induced by the wind were thus not deemed necessary.

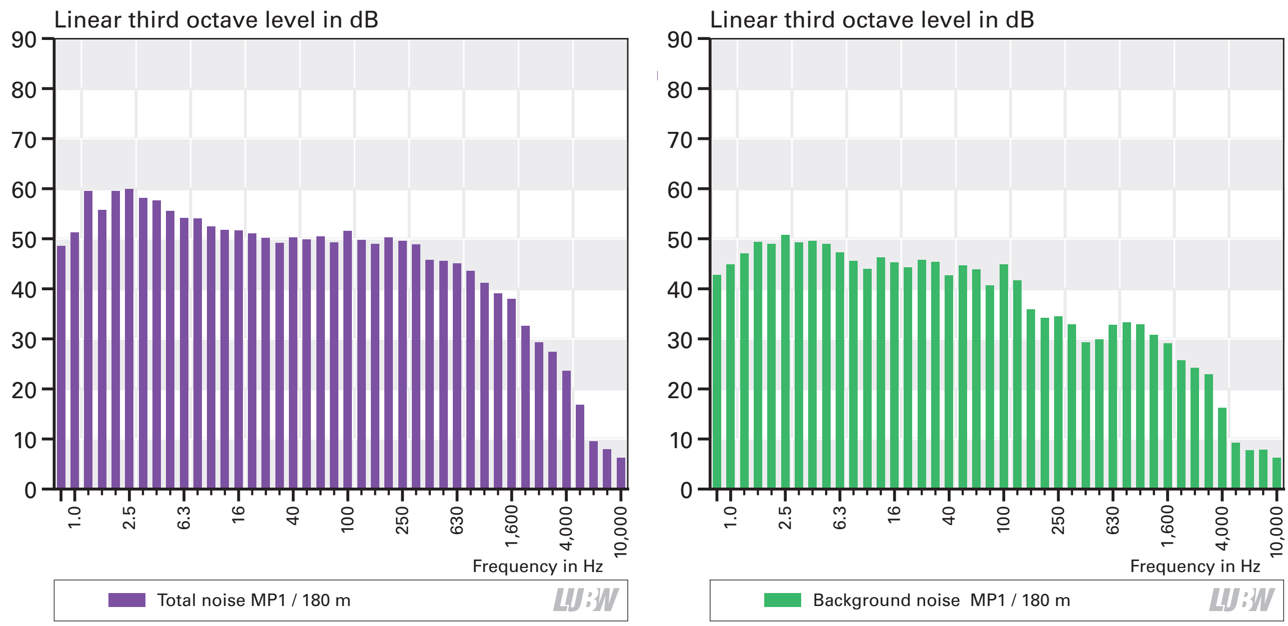


***Figure 4.5-10**: Third octave spectra of total noise and background noise in the vicinity of the wind turbine WT 4*

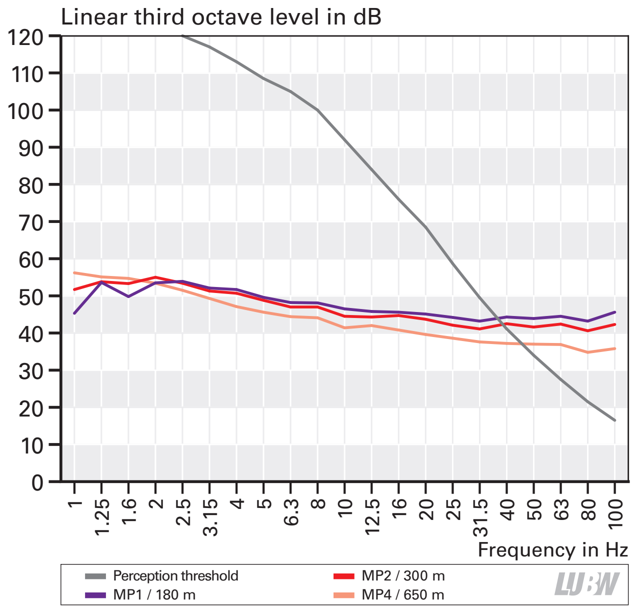


Figure 4.5-11*: Third octave spectra of total noise at the measurement points MP1 (180 m), MP2 (300 m) and MP4 (650 m) of WT 4, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.5-10 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 180 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.5 m/s. Here the level reduction through switching off the turbine is recognizable in a much broader spectral range.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.5-11 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP4 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 5.5 m/s. It must be kept in mind that the background noise of wind and vegetation are also included. These may vary at the respective measurement point. The measurement points MP2 and MP4 are further away from the turbine than MP1 (300 m and 650 m compared to 180 m). This is where somewhat lower values are also measured, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.5-12***. The three charts represent the relationships at the respective measurement points at the distances 180 m (top), 300 m (centre) and 650 m (bottom). Violet dots, which depict the lower value area, represent audible sound, expressed in dB(A). It can be seen clearly that the measured A levels are higher at a distance of 180 m (upper image) than at the measurement points at a distance of 300 m and 650 m from the turbine.

The red dots represent the G-weighted sound level when the wind turbine is switched on, the green dots when the turbine is switched off. The data shows that the G-weighted sound pressure level of the tested measurement points increases slightly during operation of the wind turbine with increasing wind speed. For the G-weighted sound pressure level of the background noise, no connection can be ascertained with the wind speed for the main part of the measuring period. However, the readings are also in a similar order with the turbine switched off due to strongly fluctuating wind conditions (gusts, turbulence). Lower levels were observed for the background noise merely for a late, roughly 30-minute measurement period from 8:50 p.m. onwards. During this period, the mean normalized wind speed was relatively constant at 5.5 m/s.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.5-13 shows the A and G-weighted level development between 4:00 p.m. and 9.00 p.m. for the distances of 180 m and 650 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. A level drop is also evident with the turbine switched off at measurement point MP3.

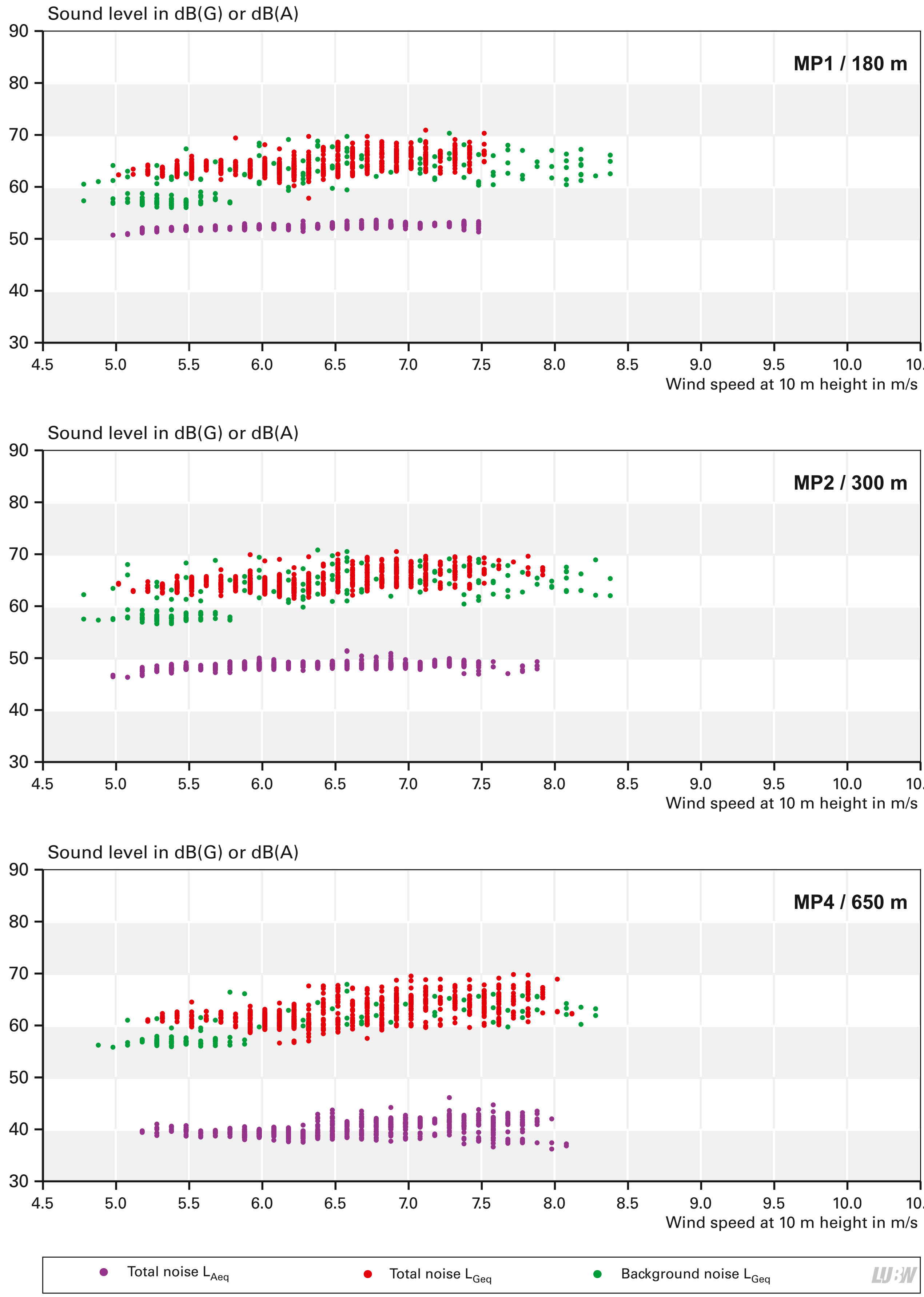


***Figure 4.5-12**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 4. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

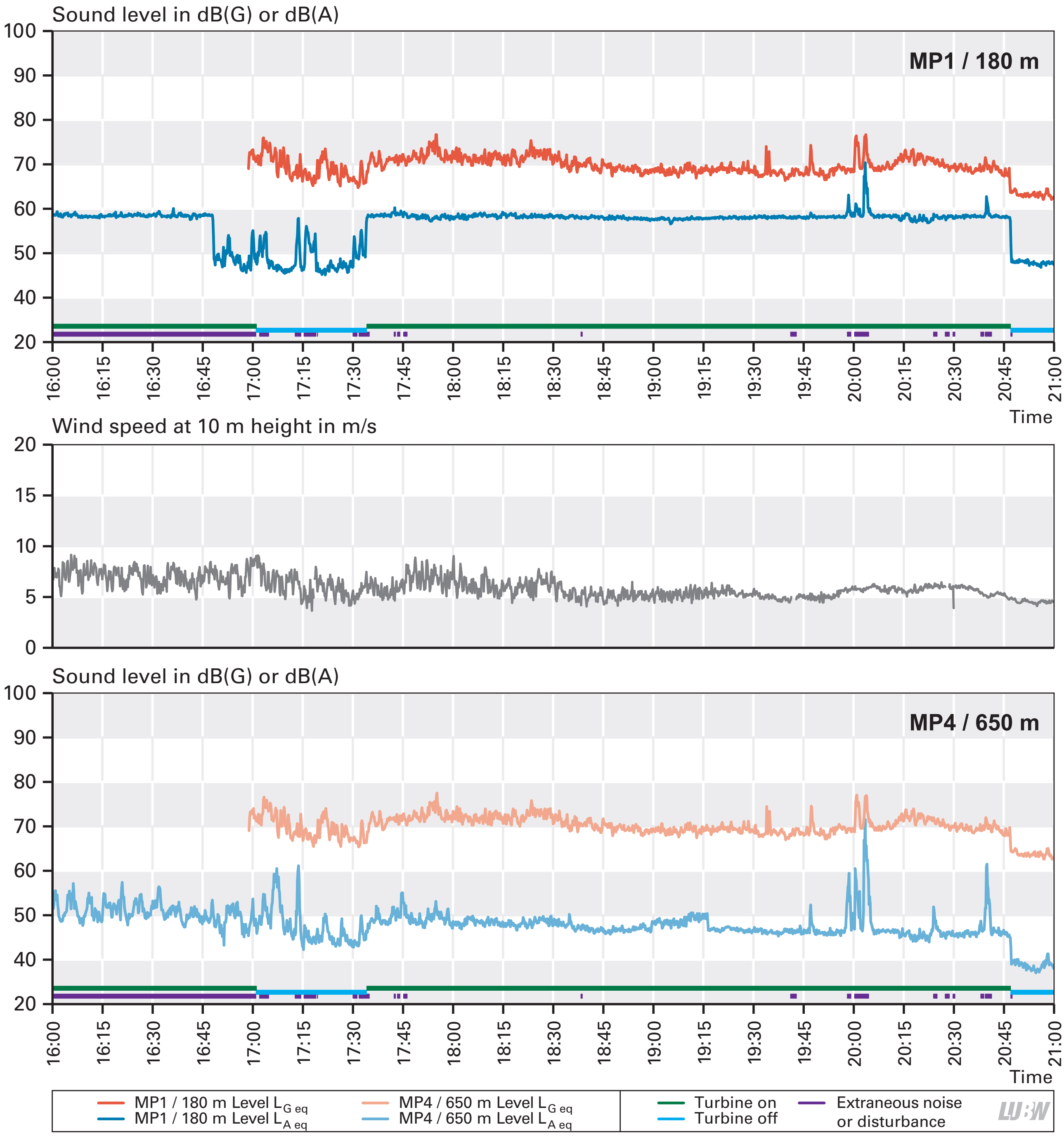


Figure 4.5-13*: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements at wind turbine WT 4*

4.6 Noise at wind turbine 5: Nordex N117 – 2.4 MW

BASIC CONDITIONS

The wind turbine 5 (WT 5) is a unit by the company Nordex, type N117/2400, with a nominal generator capacity of 2.4 MW (***Figure 4-3 and 4.6-1***). The rotor diameter is 117 m, the hub height above ground is 140.6 m.

The measured turbine is part of a wind farm with several wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The vicinity of the turbine consists of agricultural land. A dirt road is located in the immediate vicinity of the turbine, which is used only very seldom by agricultural and forestry vehicles. A district road is located about 400 meters south of the investigated wind power plant, and another road roughly 1,000 m east. During the measurement, no traffic noise was subjectively perceptible. A forest is located further away. The measurements were carried out on 13.01.2015 between 11:00 a.m. and 4:00 p.m. The microphone position of the measurement point MP1 was 185 meters from the turbine, the measurement point MP2 300 m and the measurement points MP3 and MP4 each 650 m from the turbine. All measurement points were located in a downwind direction in order to take into account a generally unfavourable situation (promotion of sound propagation through the wind). The measurement points MP3 and MP4 were immediately next to one another and served as a comparison. The microphone MP3 was provided with a primary wind screen and placed into an approx. 50 cm deep hole that was dug especially for that purpose. A secondary wind screen covered the hole flush. The parallel measurements were taken at the measurement points MP3 and MP4 in order to enable a comparison of the levels and allow conclusions to be made regarding wind-induced sound components arising at the microphone.

Figure 4.6-1: *Wind turbine WT 5 in surroundings used for agricultural purposes. In the foreground you can see the 10 m high wind measurement mast. Photo: Wölfel company*

The measurement was performed in a wind speed range of 5 to 12 m/s (measured at 10 m height), a temperature range of 10 to 13 °C, an air pressure range of 975 to 979 hPa and in a power range of 0 to 2,400 kW. The turbulence intensity (see Appendix A3) during the measurement was 13 %.

RESULTS: NARROW BAND LEVEL

Figures 4.6-2 to 4.6-5 show narrow band spectra of background noise and total noise for different measurement locations with a resolution of 0.1 Hz. The wind speed was 7.6 m/s during the measurement of the total noise and 6.9 m/s during the measurement of the background noise.

Figure 4.6-2 shows the results of measurement point MP1 at a distance of 185 m. With the turbine turned on, several discrete maxima can be seen in the infrasound range below 6 Hz. This concerns infrasound generated by the rotor due to its motion. The measured frequencies correspond to the passage frequency of a rotor blade of about 0.6 Hz and its harmonized overtones at 1.2 Hz, 1.7 Hz, 2.3 Hz, 2.9 Hz, 3.5 Hz, 3.9 Hz, etc. The peaks disappear when the turbine is switched off.

Figure 4.6-3 shows the narrow band spectra of background noise and overall noise at the measurement point MP4 at a distance of 650 m. At this distance, the infrasound maxima

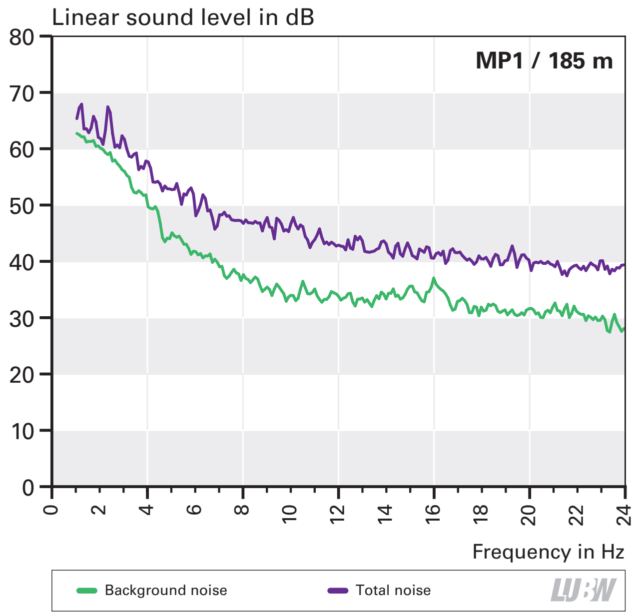


Figure 4.6-2: Narrow band spectra of background noise and total noise in the vicinity of wind turbine WT 5 for the frequency range of infrasound

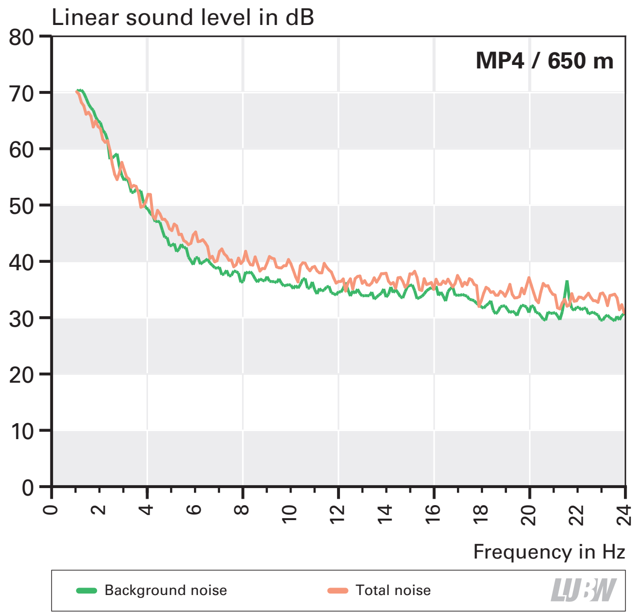


Figure 4.6-3: Narrow band spectra of background noise and total noise in the far range of wind turbine WT 5 for the frequency range of infrasound

of measurement point MP1 with the wind turbine switched on can no longer be distinguished. Between the states "turbine on" and "turbine off" there were only minor differences in infrasound for this measurement at a distance of 650 m. The infrasound here was primarily due to the sounds of wind and from the surroundings. The comparison of the narrowband spectra for the two measurement points MP3 (hole in the ground) and MP4 (reverberant plate) at a distance of 650 meters in ***Figures 4.6-4 to 4.6-5*** illustrates that in the infrasound range there is generally no significant difference between the two measurement points. Only at frequencies between 2 Hz and 8 Hz did the measurements in the hole in the ground show slightly higher levels. Neither the absorption of the secondary wind screen nor the ground influence appear to be of significance below 20 Hz. The increase in level towards lower

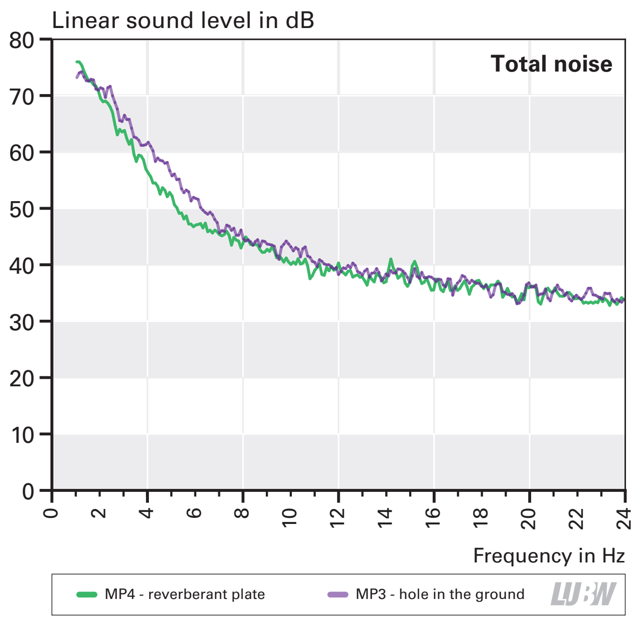


Figure 4.6-4: Narrowband spectra of the total noise at the measurement points MP4 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 5 for the range of infrasound. The distance from the turbine was 650 m.

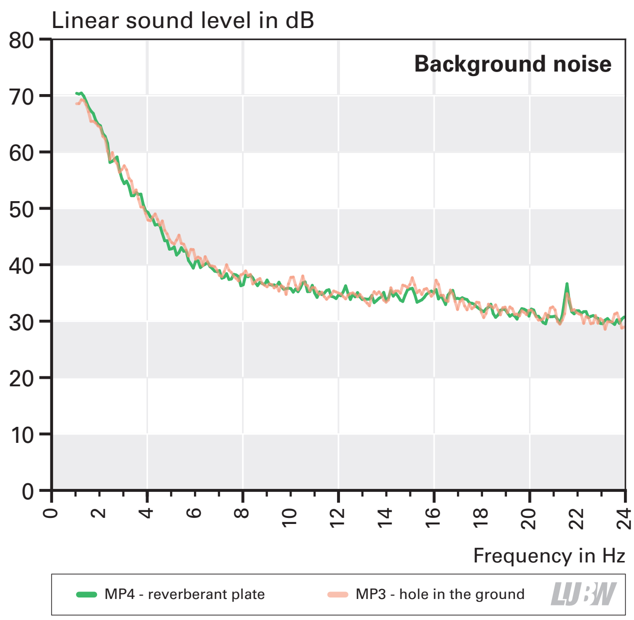
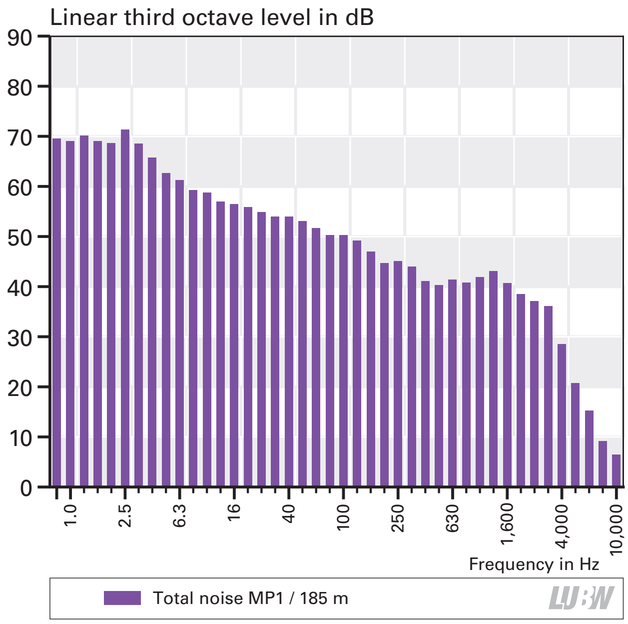


Figure 4.6-5: Narrowband spectra of the background noise at the measurement points MP4 (reverberant plate) and MP3 (hole in the ground) of the wind turbine WT 5 for the range of infrasound. The distance from the turbine was 650 m.



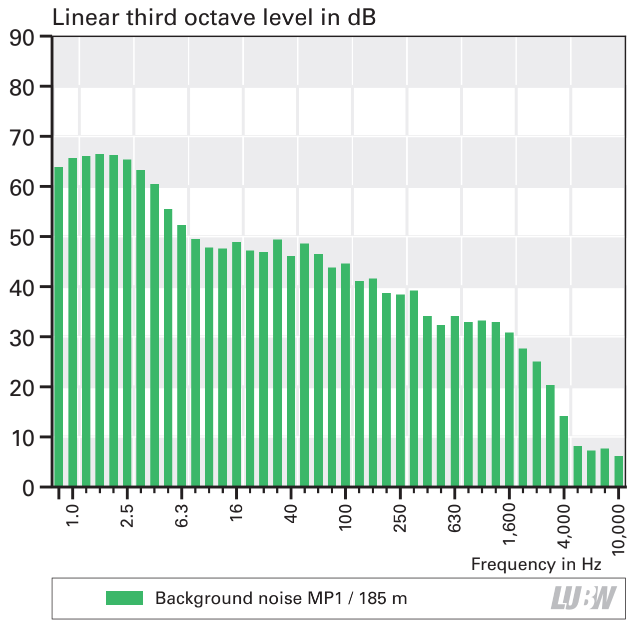


Figure 4.6-6: *Third octave spectra of total noise and background noise in the vicinity of wind turbine WT 5*

frequencies was present during this measurement with and without the hole in the ground. The expected reduction in the wind-induced background noise in the infrasound range cannot be observed in a direct comparison between the two measurement points (see also Section 4.5).

RESULTS: THIRD OCTAVE LEVEL

Figure 4.6-6 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 185 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.5 m/s. The influence of the turbine in a much broader spectral range can be recognised here.

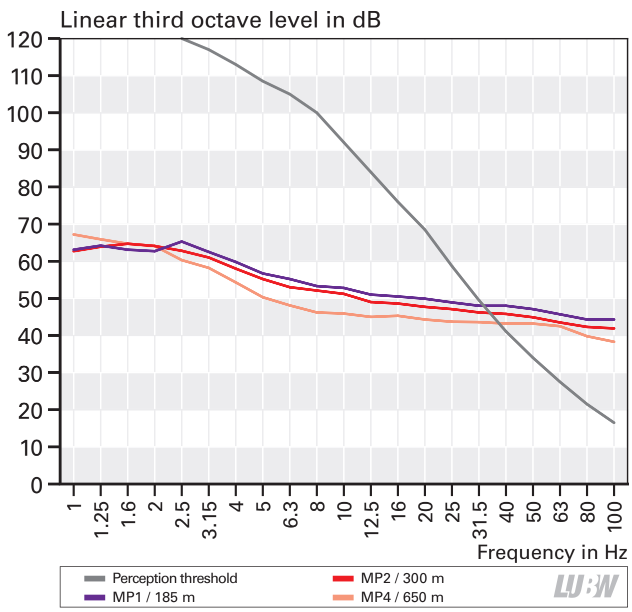


Figure 4.6-7: *Third octave spectra of total noise at the measurement points MP1 (185 m), MP2 (300 m) and MP4 (650 m) of WT 5, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.6-7 shows the third octave spectra of the total noise at the measurement points MP1, MP2 and MP4 for the frequency range from 1 Hz to 100 Hz along with the perception threshold in comparison. The wind speed was 7 m/s. It must be kept in mind that the background noise (wind, vegetation) is also included. This may vary at the respective measurement points. The measurement points MP2 and MP4 were further away from the turbine than measurement point MP1 (300 m and 650 m compared to 185 m). As expected, somewhat lower values were measured there, which becomes more apparent with increasing frequency. In the range of infrasound, the curves are well below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.6-8***. The three

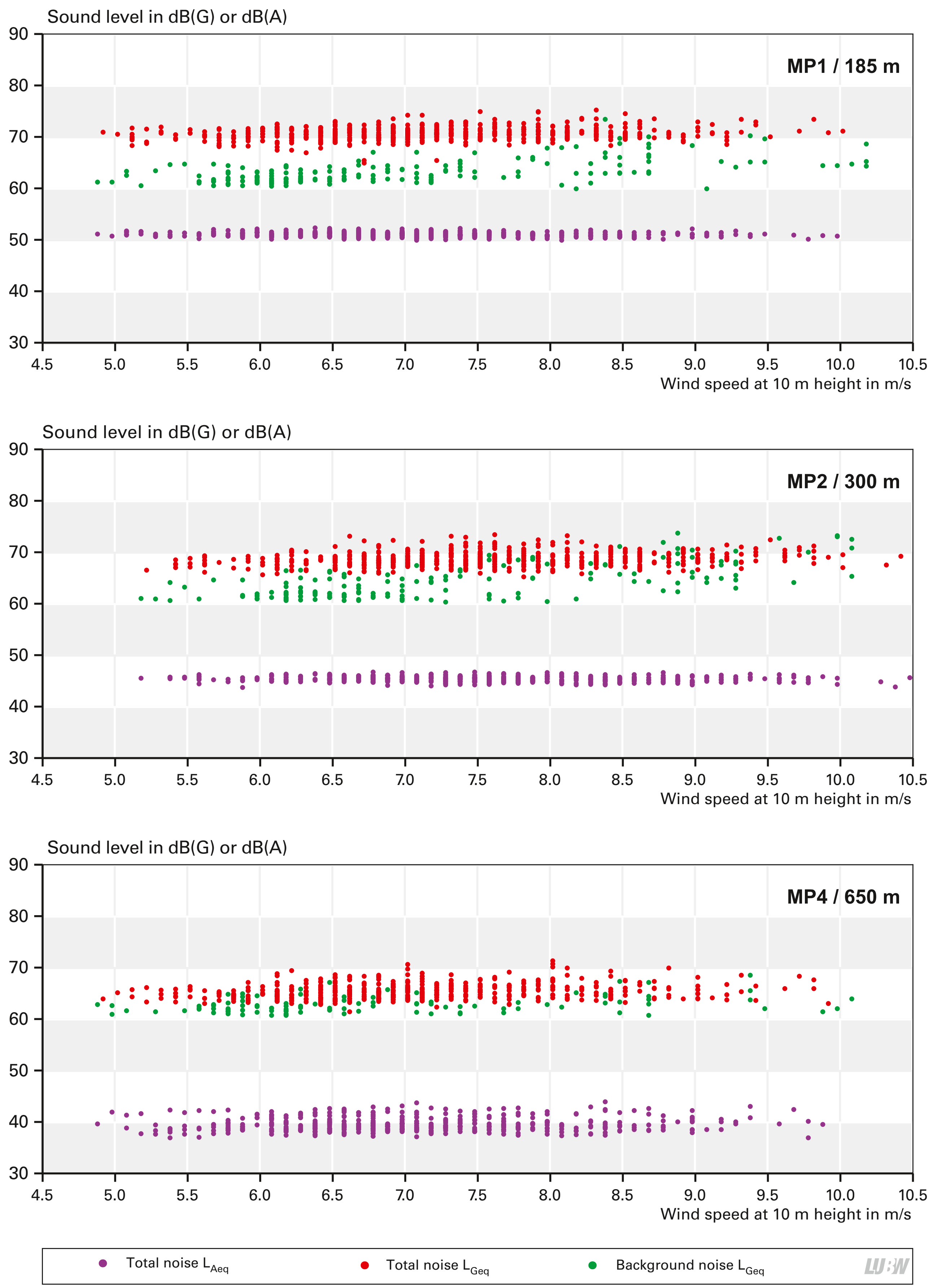


***Figure 4.6-8**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 5. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

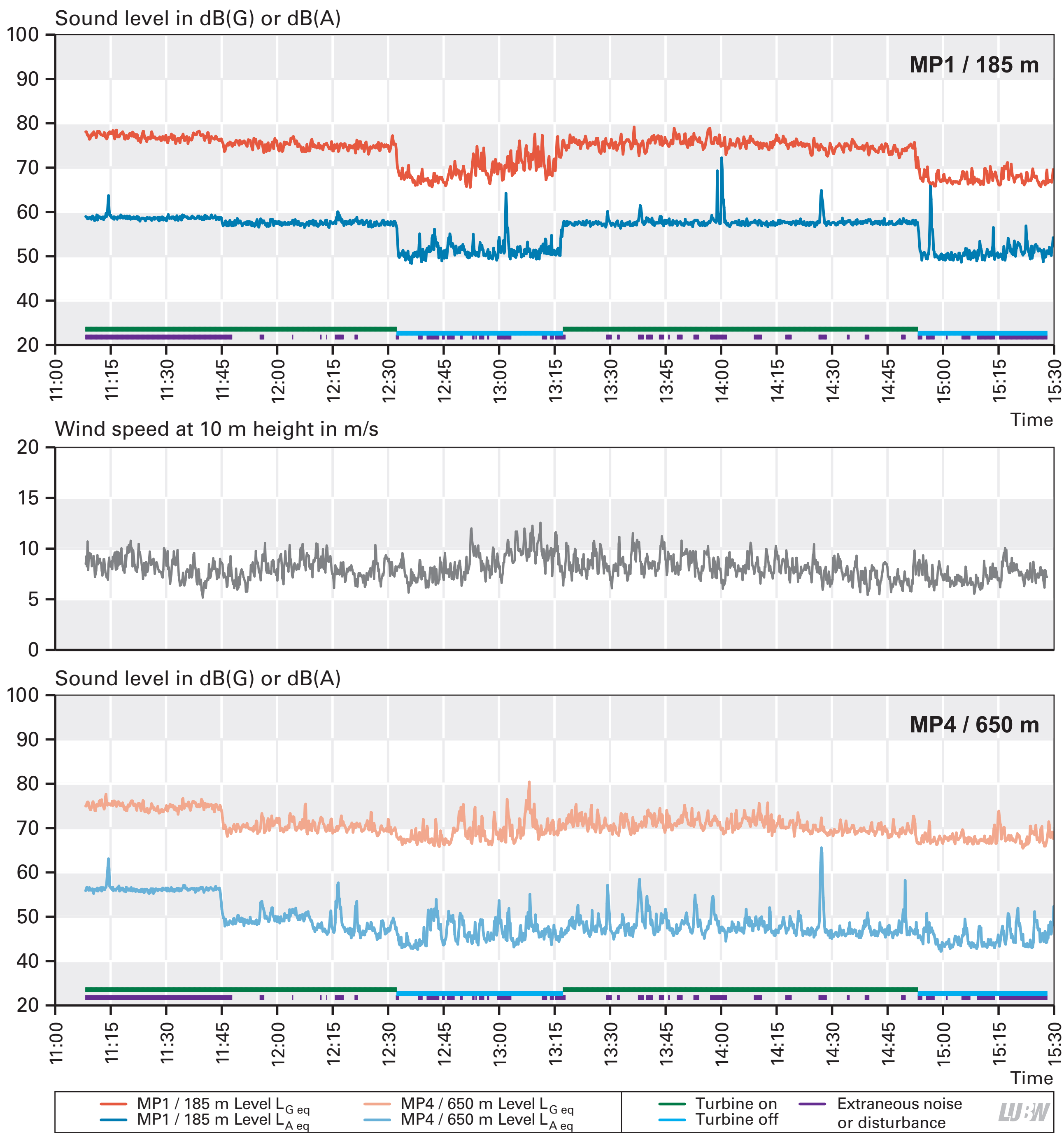


***Figure 4.6-9**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 5*

charts represent the relationships at the measurement points MP1 (185 m), MP2 (300 m) and MP4 (650 m).

The violet dots represent audible sound, expressed in dB(A). It is clearly visible that the measured A levels are higher close to the turbine than at the measurement points that are further away. The red dots represent the G-weighted sound level when the turbine is switched on, the green dots when the turbine is switched off. The figure shows that the G-weighted sound pressure levels at the measurement points examined during operation and standstill of the WT have no significant connection with the increase in wind speed. This fairly constant level curve can also be seen in the A-weighted level development. At measurement point MP1, a significantly increased mean G level can be seen during operation of the wind turbine compared to turbine standstill. As expected, the level difference between the states "turbine on" and "turbine off" decreases

Figure 4.7-1*: Wind turbine WT 6 in surroundings used for agricultural purposes. The measurement point MP1 with reverberant plate and dual wind screen can be seen in the foreground. Photo: Wölfel company*

with increasing distance. The A level also drops from values greater than 50 dB(A) at measurement point MP1 to values of around 40 dB(A) at measurement point MP4.

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.6-9 shows the A and G-weighted level developments between 11:00 a.m. and 5:30 p.m. for distances of 185 m and 650 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is recognisable through the considerably declining level developments. At measurement point MP4, a level drop with the turbine switched off due to the fluctuating background noise is only slightly recognisable.

4.7 Noise at wind turbine 6: Enercon E-101 – 3.05 MW

BASIC CONDITIONS

The wind turbine 6 (WT 6) is a unit by the company Enercon, type E-101 (***Figure 4-6***) with a nominal generator capacity of 3.05 MW. The rotor diameter is 101 m, the hub height above ground is 135.4 m.

The measured turbine is part of a wind farm with several wind turbines. The adjacent turbines were completely turned off during the measurement period in order to prevent extraneous noise. The nearest other turbine that was in operation during the measurement period was located at a distance of approx. 850 m and was subjectively not perceptible over the entire measuring period. The vicinity of the turbine consists primarily of agricultural land. A dirt road is located in the immediate vicinity of the turbine, which is used only very seldom by agricultural and forestry vehicles. A state road is located at a distance of approx. 480 m eastward of the examined wind power plant. During the measurement, only occasionally traffic noise was perceptible. The measurements were carried out on 15.01.2015 between 12:00 p.m. and 3:00 p.m. The position of the microphone at the measurement point MP1 was located at a distance of 192 m from the turbine; the measurement point MP2 at a distance of 305 m and the measurement point MP3 at a distance of 705 m. The measurement points were each in a downwind direction in order to take into account the generally most unfavourable situation (promotion of sound propagation through the wind). The measurement point MP1 and the measured turbine can be seen in ***Figure 4.7-1***.

The measurement was performed in a wind speed range of 2.8 mm/s to 9.9 m/s (measured at 10 m height), a temperature range of 6 °C to 7 °C, an air pressure range of 954 hPa to 956 hPa and in a power range of 0 to 3,050 kW. The turbulence intensity (see Appendix A3) during the measurement was 14 %.

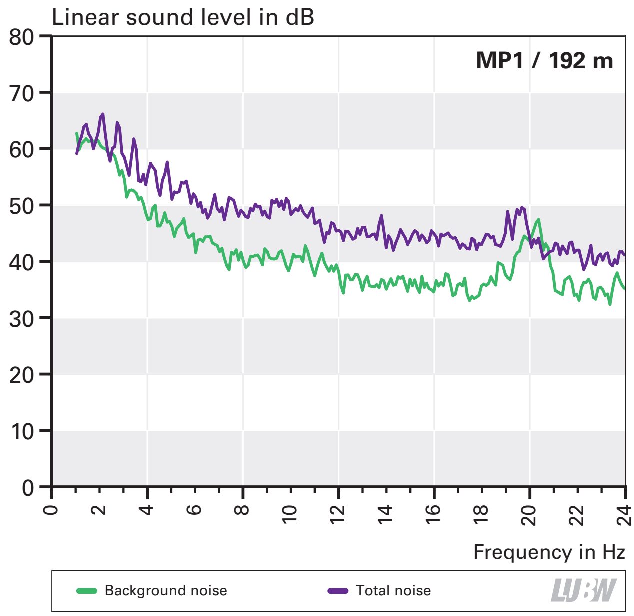


Figure 4.7-2: Narrow band spectra of background noise and total noise in the vicinity of wind turbine WT 6 for the frequency range of infrasound

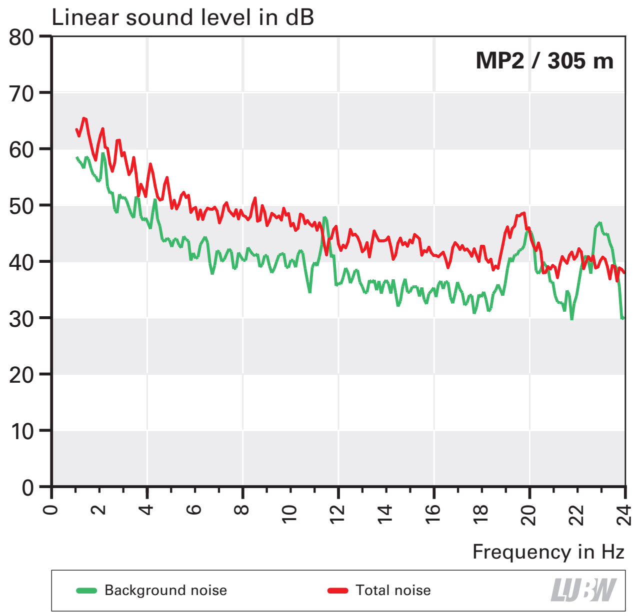


Figure 4.7-3: Narrow band spectra of background noise and total noise in the far range of wind turbine WT 6 for the frequency range of infrasound

RESULTS: NARROW BAND LEVEL

Figures 4.7-2 to 4.7-3 show the established narrow band spectra for the operation of WT 6 with a mean wind speed of approximately 5.6 m/s at a height of 10 m. Clearly visible maxima can be seen at the measurement points MP1 and MP2. The measured frequencies correspond to the passage frequency of a rotor blade (here approx. 0.7 Hz) and the harmonic overtones at 1.4 Hz, 2.1 Hz und 2.8 Hz. This concerns infrasound generated by the rotor due to its motion. The peaks disappear when the turbine is switched off. At the measurement point MP3 at a distance of 705 m (not pictured), the mentioned maxima no longer occur so clearly. The level maximum at approx. 20 Hz is striking, which is clearly visible at all measurement points. However, it is highly likely that this is not attributable to the wind turbine, as it is also evident in the background noise.

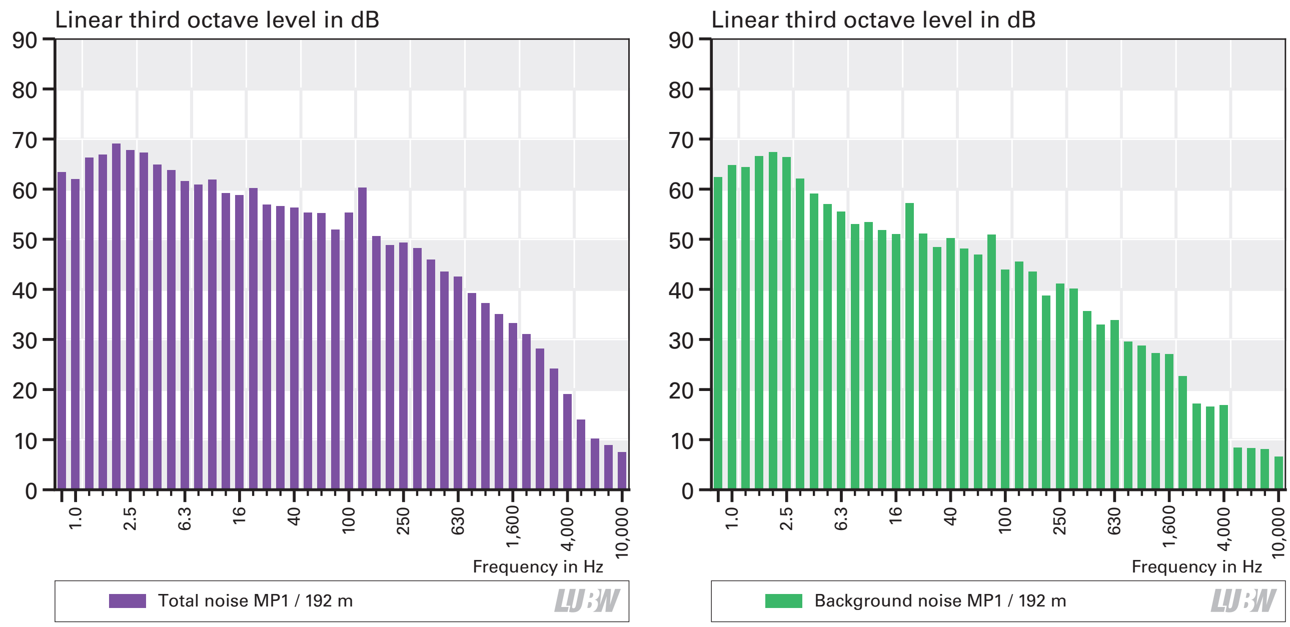


Figure 4.7-4: Third octave spectra of total noise and background noise in the vicinity of wind turbine WT 6

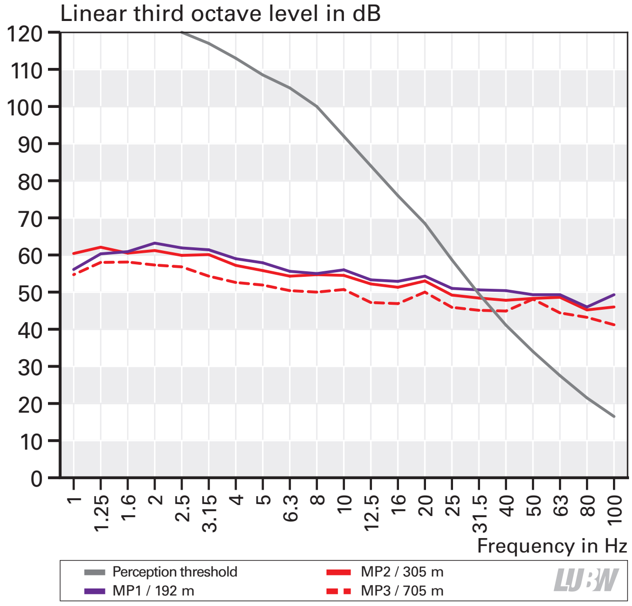


***Figure 4.7-5**: Third octave spectra of total noise at the measurement points MP1 (192 m), MP2 (305 m) and MP3 (705 m) of WT 6, with the perception threshold according to Table A3-1 in comparison. The measured values were corrected according to Section 4.1.*

RESULTS: THIRD OCTAVE LEVEL

Figure 4.7-4 shows the third octave spectra of background noise and overall noise at the measurement point MP1 at a distance of 192 m for the frequency range from 0.8 Hz to 10,000 Hz. The wind speed was 5.6 m/s. The level reduction through switching off the turbine in a clearly broader spectral range can be seen.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 4.7-5 shows a comparison of the three measurement points for the low-frequency range from 1 Hz to 100 Hz. It must be noted that the background noise (wind, vegetation) is also included. This may vary at the respective measurement point. The wind speed at 10 m height during the averaging period was on average 5.6 m/s. At all measurement points, the ascertained levels were below the perception threshold at frequencies lower than 30 Hz. The levels in the area of infrasound fell clearly below the perception threshold.

INFLUENCE OF WIND SPEED

In order to investigate the dependency of low-frequency emissions on wind speed, numerous readings were recorded and graphically depicted in ***Figure 4.7-6***. The three charts represent the relationships at the measurement points at the distances 192 m, 305 m and 705 m.

The violet dots, which depict the lower value area, represent audible sound, expressed in dB(A). It can be seen clearly that the measured A levels are higher at a distance of 192 m (upper image) than at the measurement points further away. The A level at first increases with increasing wind speed.

The red dots represent the G-weighted sound level when the wind turbine is switched on, the green dots when the turbine is switched off. Similarly to the A level, it can also be seen for the G level that – despite higher scattering – it somewhat increases with increasing wind speed, and then remains constant (measurement point MP1).

The image above shows that at MP1, i.e. in the near field at a distance of 192 m from the turbine, the G-weighted sound pressure level during operation of WT 6 is significantly higher than the background noise when the turbine is off. This is much less pronounced at a distance of 305 m (centre image).

LEVEL DEVELOPMENT DURING THE MEASUREMENT

Figure 4.7-7 shows the A and G-weighted level development between 12:40 p.m. and 2:40 p.m. for the distances of 192 m and 705 m. In addition, the operating conditions of the wind power plant (green = turbine on, light blue = turbine off) as well as periods of extraneous noise (violet) are shown. For the two level developments of measurement point MP1, the operational phase "turbine off" is easily recognisable through the considerably declining level developments. At measurement point MP3, a level drop with the turbine switched off due to the fluctuating background noise is hardly recognisable.

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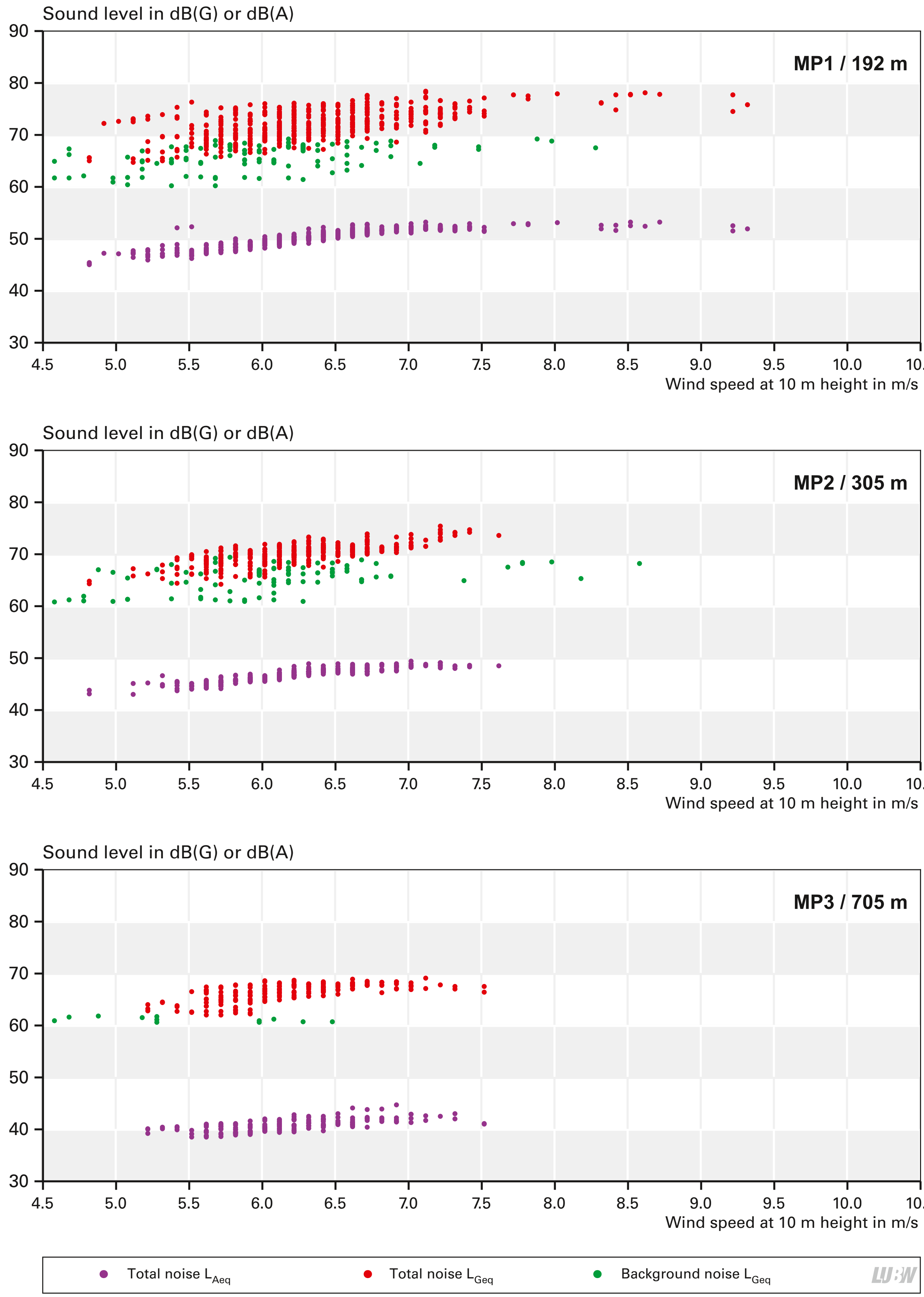

***Figure 4.7-6**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the wind turbine WT 6. The G levels when the turbine is switched on (red dots) and when the turbine is switched off (green dots) are shown, as are the A levels with the turbine switched on (violet dots).*

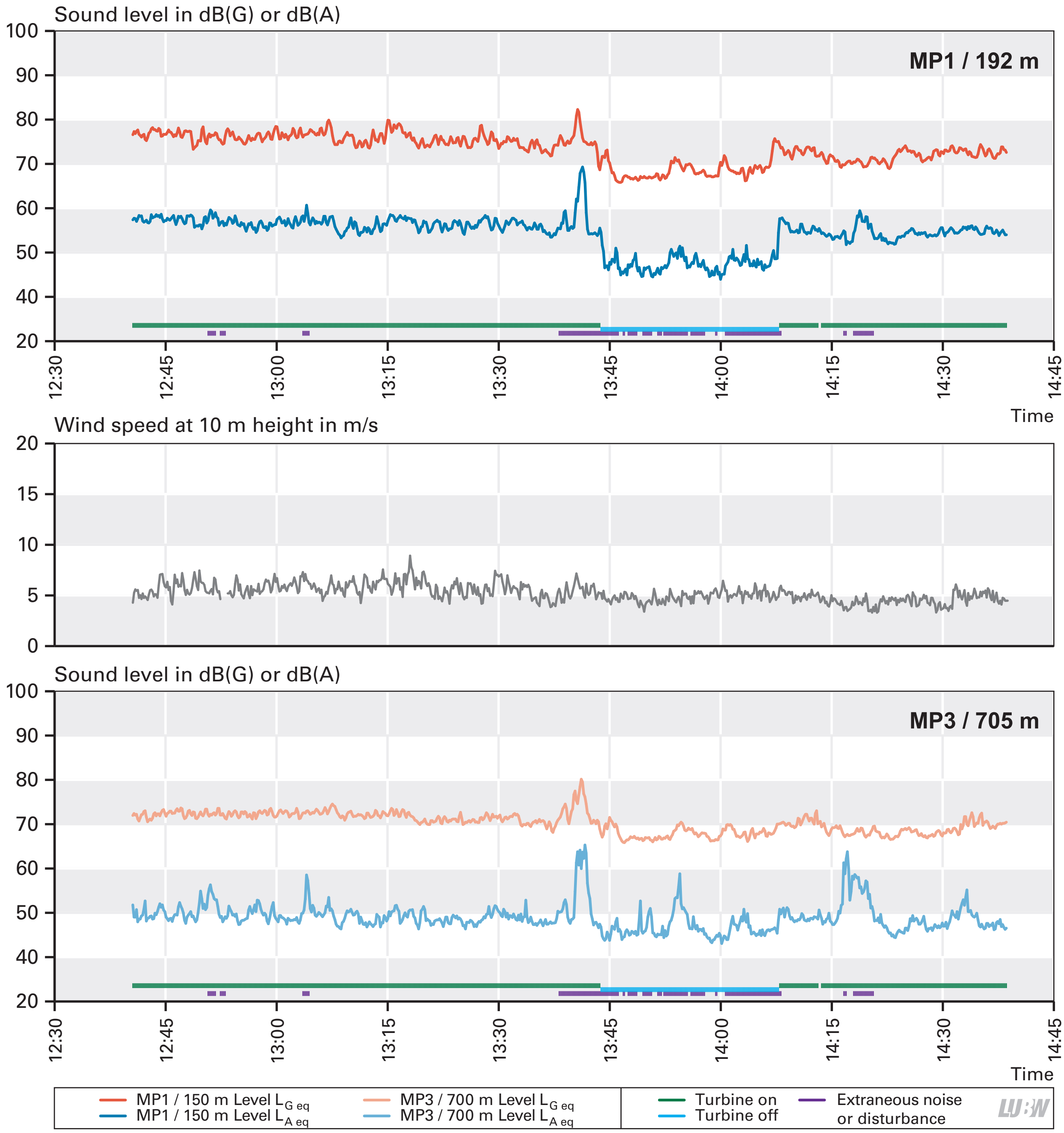

***Figure 4.7-7**: Chronological sequence of audible sound level (A level), infrasound level (G level), as well as the wind speed during the measurements of the wind turbine WT 6*

4.8 Vibrations at wind turbine 5: Nordex N117 – 2.4 MW

In order to determine a possible influence of the wind power plant on the surrounding area through vibration emissions, tremor measurements were carried out in addition to the sound assessments in the surrounding areas of wind turbine 5 (WT 5). The execution and analysis of the measurements was carried out in accordance with DIN 45669 [12] and DIN 4150 [13].

***Figure 4.8-1**: Vibration measurement point MP A at the tower foundation of WT 5. Photo: Wölfel company*

BASIC CONDITIONS

Wind turbine 5 (WT 5) is a unit by the company Nordex, type N117/2400, with a nominal generator capacity of 2.4 MW (see ***Figure 4.6-1***). The rotor diameter is 117 m, the hub height above ground is 140.6 m. The following is known about the building ground of the power plant: Up to a depth of 7 m there is cohesive ground (loam, weathering clay), which is judged to be not stable enough for the foundation of the power plant. Only after a depth of approx. 7 m is there Keuper rock, meaning that the foundation of the building structure or the load transfer has to be in this layer. It is not known whether this was accomplished with a pile foundation or a different procedure.

***Figure 4.8-2**: Vibration measurement point MP D on ground spike at a distance of 285 m from WT 5. Photo: Wölfel company*

The vibration measurement was carried out in all three spatial directions with the help of vibration sensors. The x axis was radially aligned to the tower, the y axis tangentially and z axis vertically aligned. Measurements were taken at the same time at the following locations:

- MP A directly at the tower near the outer wall of the wind turbine on concrete, see ***Figure 4.8-1***
- MP B at a distance of 32 m from the WT's exterior wall on a ground spike
- MP C at a distance of 64 m from the WT's exterior wall on a ground spike
- MP D at a distance of approx. 285 m from the WT's exterior wall on a ground spike, see ***Figure 4.8-2***

For the connection of the sensors by means of ground spikes to the ground, holes with a diameter of approximately 50 cm and a depth of 20 cm to 40 cm were dug into the ground.

The following operational states were registered during the measuring time:

- Operation of a wind turbine at wind speeds between approx. 6 and 12 m/s at a height of 10 m
- Switching off and subsequent restarting of the turbine
- Standstill of all wind power plants in the wind farm

During the measurement the wind turbine reached the maximum possible speeds starting from wind speeds of 6.6 m/s. Even at higher wind speeds no higher rotational speeds of the turbine are to be expected.

RESULTS

During the operation of the wind turbine, fluctuations in the signals were repeatedly seen, in particular at measurement point MP A directly by the tower. These can be attributed to individual gusts of wind. At the measurement points located farther away, these effects are less pronounced. A direct link between the changes in wind speed in the range of 6 to a maximum of 12 m/s and the vibrations in the ground cannot be seen. ***Table 4.8-1*** shows the ascer-

***Table 4.8-1**: Maximum values of the unweighted vibration velocities v in mm/s at the measurement points. The wind speeds measured at 10 m above ground level were between about 6 and 12 m/s.*

	MP A, at the tower		**MP B**, 32 m distance		**MP C**, 64 m distance		**MP D**, 285 m distance	
	z	x, y	z	x, y	z	x, y	z	x, y
Turbine on	0.5 - 1.0	0.30	0.03	0.08	0.02	0.04	< 0.01	0.01
Turbine off	0.04	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

tained maximum values of the unweighted vibration velocities v in mm/s for the different measurement points with uniform full load operation of the turbine. In the horizontal measurement directions the one with the highest value is stated; this was usually the x direction (radial, towards the tower).

Decreasing vibration velocity over the distance is shown graphically in ***Figure 4.8-3***. At the measurement point MP D at a distance of 285 m, the influence of the wind turbines is barely perceptible. For comparison, the spread calculated in accordance with [13] is also shown. When shutting down or restarting the turbine, the vibration level changes only slightly, see ***Figure 4.8-4***.

The evaluation of vibrational immissions with respect to possible exposure of people in buildings is carried out on the basis of DIN 4150 Part 2 [13]. The essential base parameter of this standard is the weighted vibration severity $KB_F(t)$. This is also an indication of the ability to sense vibrational effects. The perception threshold for most people lies in the area between $KB_F = 0.1$ and $KB_F = 0.2$. The KB_F value of 0.1 corresponds to an unweighted vibration velocity of approx. 0.15 to 0.30 mm/s. During the transition of tremors from the ground to building foundations there is usually a reduction of the vibration amplitudes. According to DIN 4150 Part 1, a factor of 0.5 should be taken. In the building itself, there may be an amplification, particularly if the excitation frequency is in the range of the ceiling's natural frequency. However, it is not expected that the effects established at the measurement point MP D could actually reach the level of the reference values according to DIN 4150 Part 2 in a building, since this would require an amplification by more than a factor of 20 within the building. At measurement point MP D at a distance of 285 m, mainly frequencies below 10 Hz were established, as shown in ***Figure 4.8-5***. In contrast, the natural frequencies for concrete ceilings in residential buildings are normally approx. 15 Hz to 35 Hz. For beamed ceilings, the natural frequencies are lower and can drop to approx. 10 Hz. Resonance excitation of the building ceilings can therefore not be expected.

CONCLUSION

The ground vibrations emanating from wind turbines can be detected by measurement. Already at a distance of less than 300 m from the turbine, they have dropped so far that they can no longer be differentiated from the permanently present background noise. No relevant vibrational effects can be expected at residential buildings.

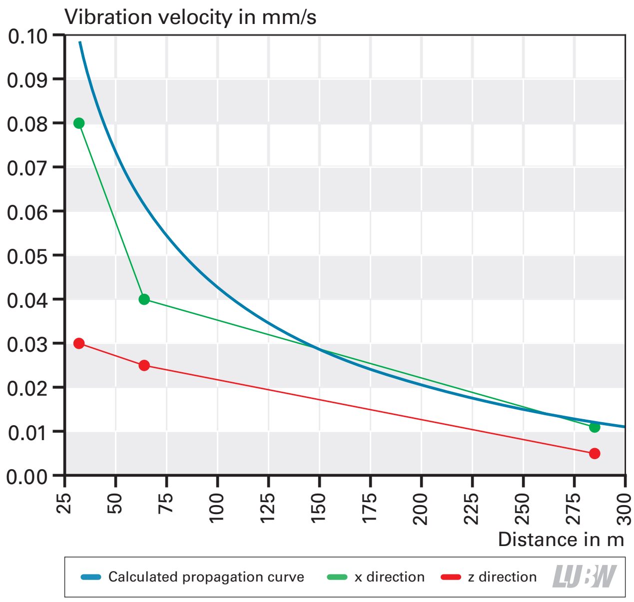

***Figure 4.8-3**: Comparison of prediction formula for [13] with the measured values*

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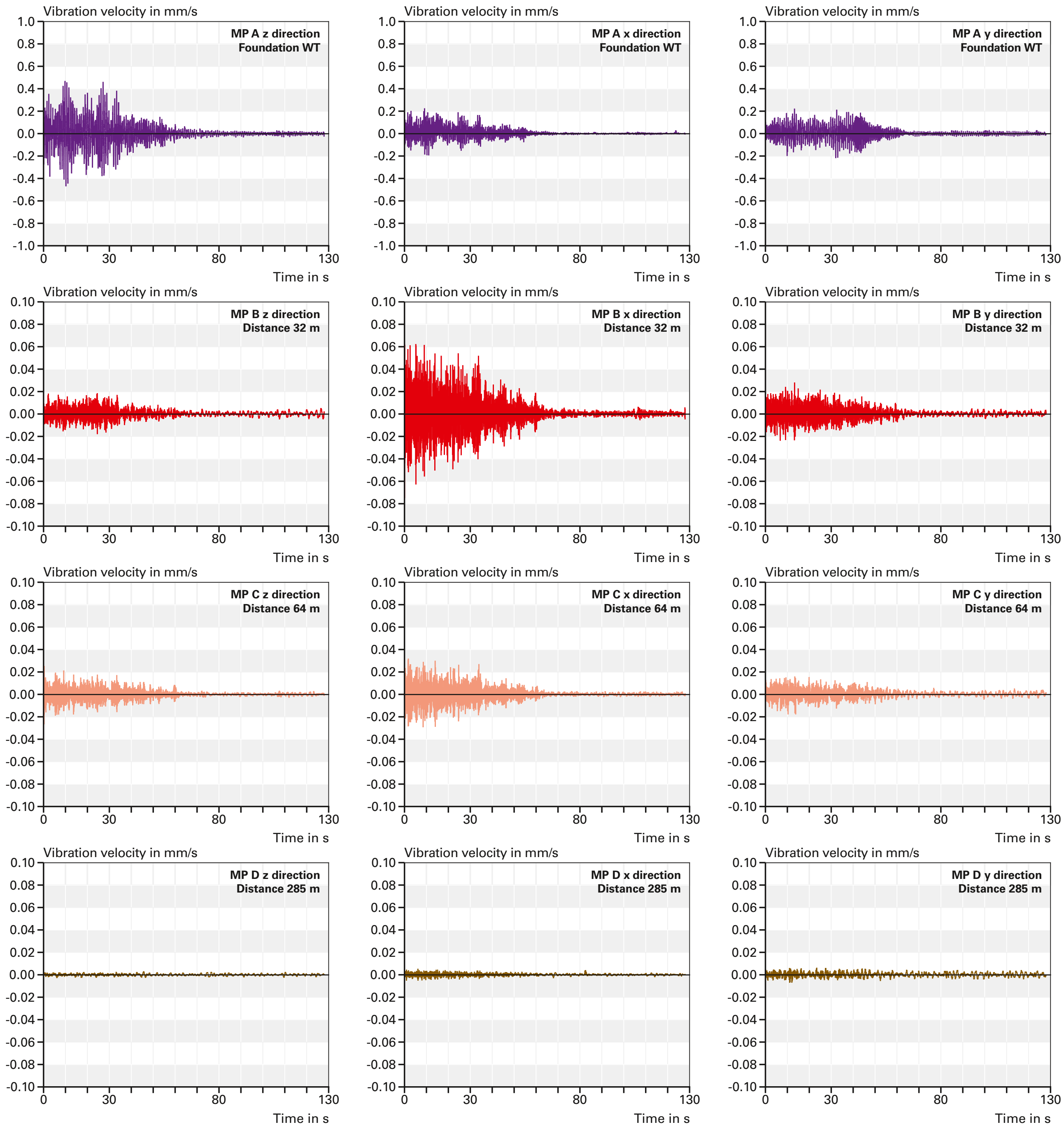

Figure 4.8-4: *Representation of the decreasing vibration after shutdown of the wind turbine 5 for all measurement points and directions. From top to bottom: Measurement points MP A to MP D; left to right: Spatial directions z, x and y. The shutdown of the turbine followed at 12:32 p.m. – Note the different scale of the vibration velocity at the measurement point MP A (foundation, top row).*

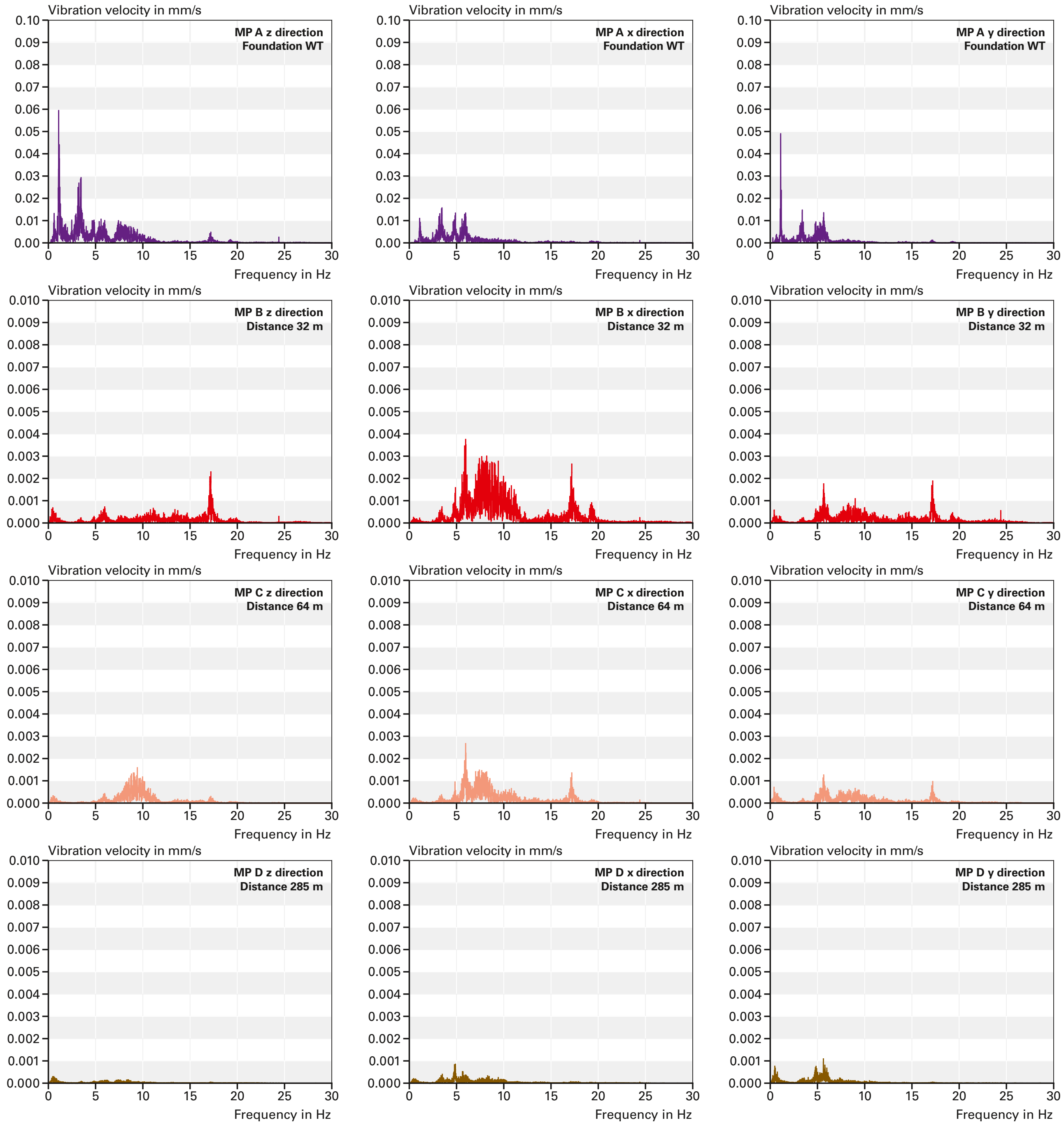

Figure 4.8-5: *Representation of the frequency spectrum of the vibrations with uniform operation of the wind turbine 5 for all measurement points and directions. The measurement was taken at 11:12 a.m. at a wind speed of approx. 8 m/s at a height of 10 m. From top to bottom: Measurement points MP A to MP D; left to right: Spatial directions z, x and y. – Note the different scale of the vibration velocity at the measurement point MP A (foundation, top row).*

4.9 Measurement results from literature

In the following a few previously available, publicly accessible measurement results about infrasound and low-frequency noise at wind turbines shall be briefly discussed. Overall, the amount of available worldwide publications on this issue is modest but not low. The publications presented here partially refer to many other references. In this selection we have aimed to introduce German-speaking publications (Mecklenburg-Western Pomerania, Bavaria) as well as important European (Denmark) and international (Australia) studies and measurement programmes. However, the report at hand is no literature study, meaning that a restriction is necessary.

MECKLENBURG-WESTERN POMERANIA

The company Kötter Consulting, Rheine, carried out emissions and immissions measurements in 2005 and 2009 on behalf of the Federal State of Mecklenburg-Western Pomerania, State Office for the Environment, Nature Conservation and Geotechnology (LUNG) at a wind farm that contained a total of 14 turbines. The report is publicly available [14]. In summary, the authors come to the following conclusions:

- "The results of the emission measurement [...] show that at frequencies in the infrasound range at f < 10 Hz, the individual operating states cannot be distinguished from one another. Moreover, the dispersion of the sound pressure level is high." See ***Figure 4.9-1***.
- "In terms of emissions, however, the different operating states in the low-frequency range (16 Hz < f < 60 Hz) are metrologically detectable, whereas at the immission location, the turbine noise is indistinguishable from background noise."
- "The results of immission measurements show [...] that the reference values for the evaluation of low-frequency noise according to Supplement 1 of DIN 45680 [4] [...] are also complied with."
- "In terms of immissions, no noteworthy difference is perceivable between the operating state ‚all WT on' and background noise. The readings are clearly below the hearing threshold level curve in the infrasound range." See ***Figure 4.9-2***.

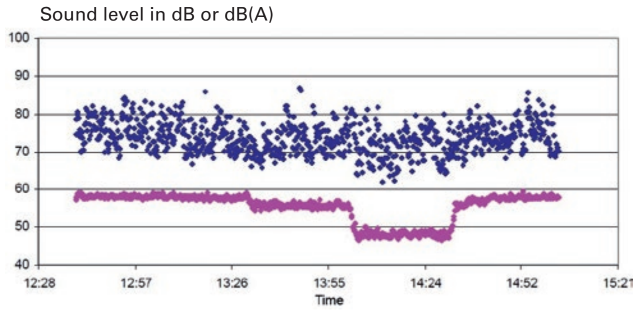

Figure 4.9-1: *Chronological sequence of level at the emission location (outside) near the turbine. The lower, magenta curve represents the sequence of the A-weighted audible noise level. The clearly identifiable gradual decrease in the sound level correlates with the various operating states (far left all turbines on, then two turbines off, then all turbines off). At the end, the A-weighted sound level increases again when all turbines are turned on (far right). Remarkably, the 8 Hz infrasound level hardly changes at all (blue, greater scattering of dots). The measurement report also includes illustrations for 20 Hz and 63 Hz; with these low frequencies, the operating conditions could be registered in the near field. Source: [14], Figure 9, page 24, details added.*

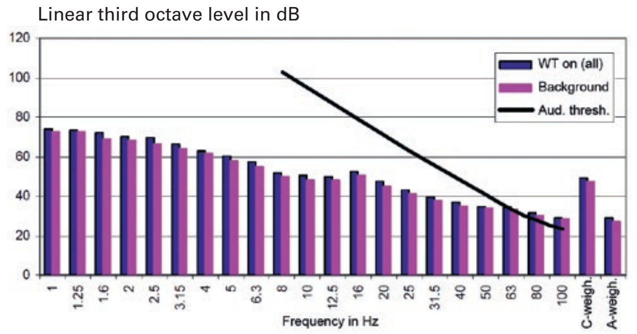

Figure 4.9-2: *Immission: Display of lower frequency levels subject to third octave frequency within a residential building at a distance of 600 m. No significant difference can be seen between the operating states "all WT on" and the background noise. The readings are clearly below the hearing threshold curve in the infrasound range. Source: [14], Figure 21, page 33*

BAVARIA

The Bavarian State Office for the Environment (LfU) carried out a long-term noise immission measurement from 1998 to 1999 at a 1 MW wind turbine of the type Nordex N54 in Wiggensbach near Kempten. ***Table 4.9-1*** and ***Figure 4.9-3*** show the main results. The study concludes that "the noise emissions of the wind turbine in the infrasound range are well below the perception threshold of humans and therefore lead to no burden". Furthermore, it was found that the infrasound caused by the wind is significantly stronger than the infrasound generated by the wind turbine alone [15] [16].

DENMARK

A Danish study from 2010 [17], in which data from almost 50 wind turbines with outputs between 80 kW and 3.6 MW was evaluated, comes to the following conclusion: "Wind power plants do certainly emit infrasound, but the levels are low when taking into account the human sensitivity to such frequencies. Even close up to the wind power plants, the sound pressure level is far below the normal auditory threshold, and the infrasound is therefore not seen as a problem for wind power plants of the same type and size as the ones examined" [15]. Further international publications on the issue are quoted in the study.

AUSTRALIA

In 2013 the Enviroment Protection Authorithy South Australia and the engineering company Resonate Acoustics published the study "Infrasound levels near windfarms and in other environments" [18]. The study includes results of measurements taken both outside as well as indoors. The measurement points were in close proximity to windparks and in regions without wind power plants.

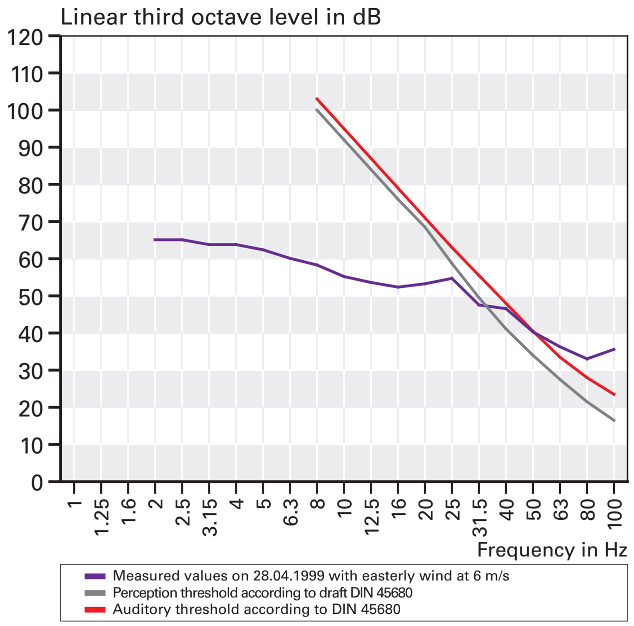

Figure 4.9-3*: The examined wind turbine causes sound waves that can be heard only above 40 Hz by a person standing on a balcony at a distance of 250 m. The infrasound range is not perceptible, since it lies clearly below the perception threshold. Source: [15]*

In summary, it was stated that the measured infrasound expositions, which were measured in close proximity to windfarms in residential buildings, correspond to the levels determined in comparable regions without wind power plants. The lowest infrasound levels determined in the measuring project were registered in a house standing in the proximity of a wind park.

The infrasound levels in close proximity to wind power plants are not higher than in other urban and rural regions, in which the contribution of wind power plants is negligible, compared to the background level of infrasound in those areas.

Table 4.9-1*: Infrasound level at a distance of 250 m from a 1 MW wind turbine with different wind velocities. Source: [15]*

Wind velocity		Linear third octave level in dB with a third octave centre frequency of 8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz
6 m/s	Breeze, the measured sound comes primarily from the wind turbine	58	55	54	52	53
15 m/s	Strong to stormy wind, the measured sound comes primarily from the wind	75	74	73	72	70

Quotation: "It is clear from the results that the infrasound levels measured at the two residential locations near wind farms (Location 8 near the Bluff Wind Farm and Location 9 near Clements Gap Wind Farm) are within the range of infrasound levels measured at comparable locations away from wind farms. Of particular note, the results at one of the houses near a wind farm (Location 8) are the lowest infrasound levels measured at any of the 11 locations included in this study. This study concludes that the level of infrasound at houses near the wind turbines assessed is no greater than that experienced in other urban and rural environments, and that the contribution of wind turbines to the measured infrasound levels is insignificant in comparison with the background level of infrasound in the environment". [18]

4.10 Conclusion of the measurements at wind turbines

- The low-frequency noise including infrasound measured in the vicinity of wind turbines consists of three parts: 1. Turbine noise; 2. Noise that results from the wind in the surrounding area; 3. Noise that is induced at the microphone by the wind. Wind always has to be considered as an interference factor (extraneous noise) when determining the turbine noise. The measured values are subject to a wide spread.

- The infrasound being emanated from wind turbines can generally be measured well in the direct vicinity. Below 8 Hz discrete lines appear in the frequency spectrum as expected, which are attributable to the constant movement of the individual rotor blades.

- At a distance of 700 m from the wind turbines, it was observed that when the turbine is switched on, the measured infrasound level did not increase notably or only increase to a limited extent. The infrasound was generated mainly by the wind and not by the wind turbines.

- The measured infrasound levels (G levels) at a distance of approx. 150 m from the turbine were between 55 and 80 dB(G) with the turbine running. With the turbine switched off, they were between 50 and 75 dB(G). At distances of 650 to 700 m, the G levels were between 55 and 75 dB(G) with the turbine switched on as well as off. A cause for the spread of the values is the strongly varying proportions of noise, which are caused by the wind (***Table 2-1***).

- For the measurements carried out even at close range, the infrasound levels in the vicinity of wind turbines – at distances between 150 and 300 m – were well below the threshold of what humans can perceive in accordance with DIN 45680 (2013 Draft) [5] or ***Table A3-1***.

- The vibrations caused by the wind turbine being examined were already minimal at a distance of less than 300 m. At distances as prescribed for reasons of noise pollution protection, no exposures that exceed the pervasive background noise are to be expected at residential buildings.

- The results of this measurement project comply with the results of similar investigations on a national and international level.

Table 4-11: *Tabular representation summing up the first measured values (infrasound and low-frequency noise) at wind turbines. The measured values were frequently subject to substantial fluctuations and always also contain wind noises. Since the measurements were carried out with a reverberant plate, a correction took place (see. Section 4.1).*

Wind turbine (WT)		Section	G-weighted level in dB(G) WT on / off	Infrasound third octave level ≤ 20 Hz in dB * WT on	Low-frequency third octave level 25-80 Hz in dB * WT on
WT 1	– 700 m – 150 m	4.2	55-75 / 50-75 65-75 / 50-70	– 55-70	– 50-55
WT 2	– 240 m – 120 m	4.3	60-75 / 60-75 60-80 / 60-75	– 60-75	– 50-55
WT 3	– 300 m – 180 m	4.4	55-80 / 50-75 55-75 / 50-75	– 50-70	– 45-50
WT 4	– 650 m – 180 m	4.5	50-65 / 50-65 55-65 / 50-65	– 45-55	– 40-45
WT 5	– 650 m – 185 m	4.6	60-70 / 55-65 60-70 / 55-65	– 50-65	– 45-50
WT 6	– 705 m – 192 m	4.7	55-65 / 55-60 60-75 / 55-65	– 55-65	– 45-50

* Linear third octave level in dB(Z)

5 Traffic

Within the context of the measurement project, not only wind turbines but also other sources of low-frequency sound incl. infrasound were to be examined. An obvious choice was to investigate the pretty-much ubiquitous road traffic. For this purpose, measurements was carried out at a road in Würzburg (by the company Wölfel) as well as at the federal motorway A5 south of Karlsruhe (by the LUBW). In addition, data from the inner-city continuous traffic noise measuring stations of the LUBW in Karlsruhe and Reutlingen was used, in order to assess the recorded data with respect to low-frequency noise incl. infrasound. The conditions were selected in such a way that neither wind noises in the vicinity nor wind-induced noises at the microphones arose, which can cause problems during the measurements at the wind turbines (see Section 4). The results represented in the following are therefore to be causally attributed to road traffic.

5.1 Inner-city roads – measurement in Würzburg

At the immission location of Rottendorfer Strasse in Würzburg it was possible to carry out the noise level measurements with a special focus on low-frequency noise and infrasound inside as well as outside of a residential building. The measurement point is predominantly in the direct sphere of influence of Rottendorfer Strasse, but also within the sphere of the federal road B 19, which leads from Bad Mergentheim to Würzburg, as well as the railway line Würzburg-Lauda (***Figure 5.1-1***). However, at the immission location, the noise from the road traffic on the Rottendorfer Strasse dominates (***Figure 5.1-2***), with an average traffic volume of 13,971 motor vehicles in 24 hours with a proportion of heavy goods traffic of approx. 3 % (data from the 2012 traffic survey).

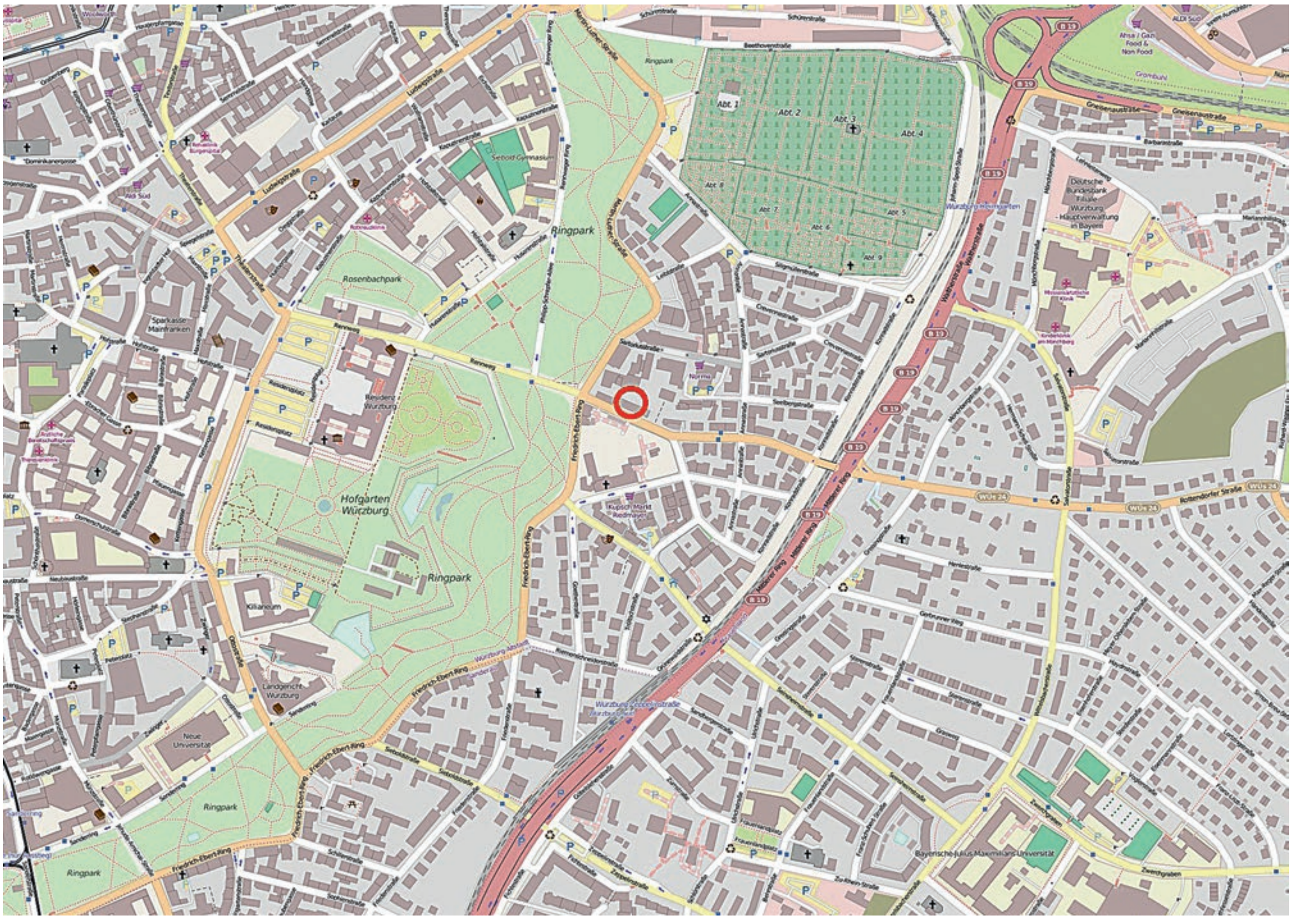

Figure 5.1-1*: Layout plan showing the immission location at Rottendorfer Strasse, Würzburg. Source: www.openstreetmap.org*

***Figure 5.1-2 a/b**: View along Rottendorfer Strasse in Würzburg. Photo: Wölfel company*

A situation as can be found in many places was specifically selected. At measurement points with very high volumes of traffic and the thus associated traffic noise, the audible noise level is prioritised; this can already lead to situations that are a nuisance and possibly also harmful environmental effects. The low-frequency noise, incl. its share of infrasound, eminating from the road traffic could be measured without any disturbing wind noises. The measured levels are characteristic for the noise situation in the residential area.

The sound pressure level up to a lower threshold frequency of 1 Hz was measured at one measurement point in the open and one measurement point in a residential building. For the evaluation of the low-frequency effects, evaluations according to DIN 45680 (2013 draft) [5] were carried out for the measurement point within the building.

The execution of the measurement took place at two measuring locations. Measurement point MP1 was selected in accordance with DIN 45645 (1996) [8] and – in the same manner as the measurements at the wind turbines – with reverberant plate on the ground of the balcony facing the road. A second measurement point MP2 was located within the building in accordance with DIN 45680 (March 1997) [4]. The measurement was carried out as an observed measurement. The fully furnished and inhabited flat was not used during the measuring time. The size of the room was approx. 7.6 m x 4.3 m x 2.5 m. An informatively comparative measurement was carried out at a third measurement point located directly on the façade at the height of the windows. The third octave levels on the façade in the range below 25 Hz are between 0 and 3 dB lower than the third octave level on the floor of the balcony. Within the range between 25 Hz and 80 Hz, the third octave levels directly at the façade are up to 6 dB lower than the third octave levels on the floor of the balcony. In the frequency range above 100 Hz, on the other hand, they are 0 to 3 dB higher than the third octave levels on the floor of the balcony. The measuring data presented here for the floor of the balcony was not subjected to level corrections according to Section 4.1.

The measurement period extended from Thursday afternoon, 04.07.2013, 3:00 p.m., to the early morning of the following Friday, 05.07.2013, 6:00 a.m. The measuring period was not during the school holidays and is representative for the burden of the immission location on a working day. The traffic volume is estimated as being comparable to the data of the traffic survey. During the measurement of traffic noise, the periods with significant external noise exposure (e.g. flight noise, animal sounds and noises by the measuring engineer) were marked and excluded from the analysis. The measurements were performed in a wind speed range of 0 to 4 m/s (a mean value of 0.5 m/s), a temperature range of 16.3 to 22.5 °C, and an air pressure range of 999 to 1,003 hPa.

RESULTS AT OUTDOOR MEASUREMENT POINT

As an example, third octave spectra for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are presented in ***Figure 5.1-3*** for the measurement point MP1 (outside the building). The outside daytime levels in the low-frequency range were up to 100 Hz above the hearing or perception threshold. A significant peak in the frequency range 25 Hz to 80 Hz can be seen in the third octave spectra, which is due to vehicle traffic. In the area of 25 Hz to 63 Hz, the levels exceed 70 dB, partially up to 75 dB. At night, values of up to 65 dB are reached. For the infrasound up to 20 Hz, the outdoor daytime levels were below the hearing or perception threshold between 45 and 65 dB. The specified frequencies refer to the third octave centre frequency.

Figure 5.1-4 shows the one hour average linear third octave level for the low-frequency range below 100 Hz compared to the perception threshold in accordance with DIN 45680 (2013 draft) [5]. For values below 8 Hz, this was amended [11], see also ***Table A3-1***. The correlation of the values with the traffic situation is clearly recognisable: The heavier road traffic between 4:00 p.m. to 5:00 p.m. leads to higher values both in the infrasound range as well as in the other low-frequency ranges. Depending on the traffic volume, the perception threshold is exceeded between 20 Hz and 32 Hz (third octave centre frequency).

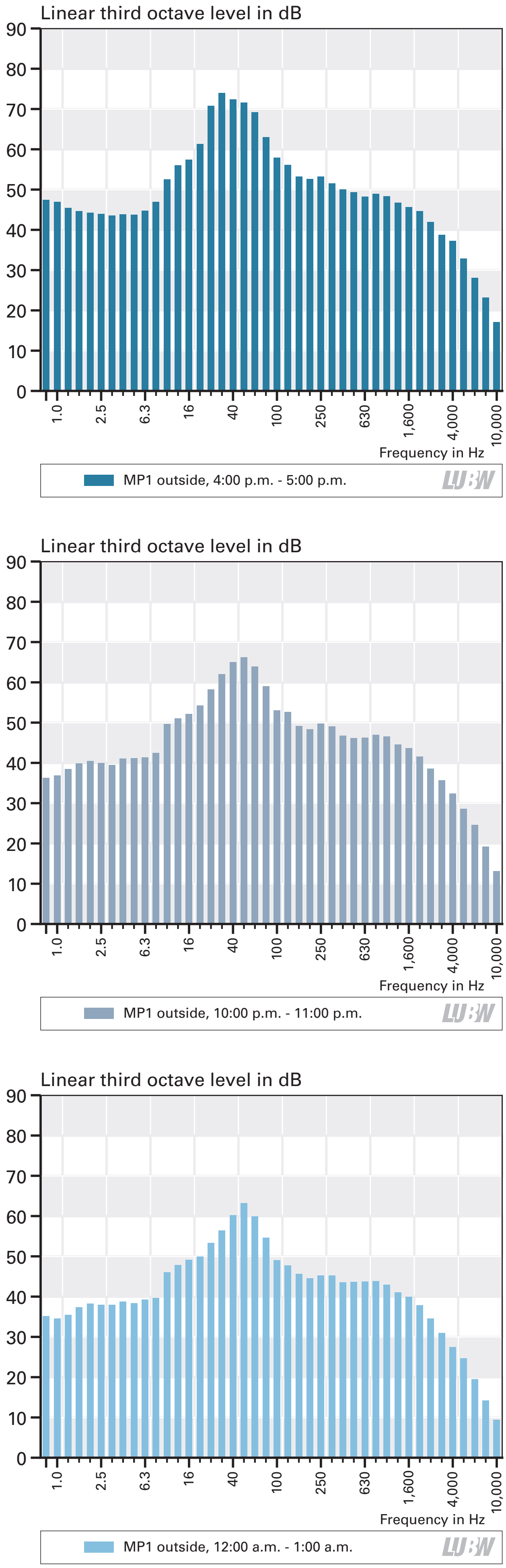

Figure 5.1-3*: Linear third octave spectra for the periods 4:00 p.m. - 5:00 p.m. (top), 10:00 p.m. - 11:00 p.m. (centre) and 12:00 a.m. - 1:00 a.m. (below) at the outside measurement point MP1. A significant peak in the frequency range 25 Hz to 80 Hz can be seen for the spectra, which is due to vehicle traffic.*

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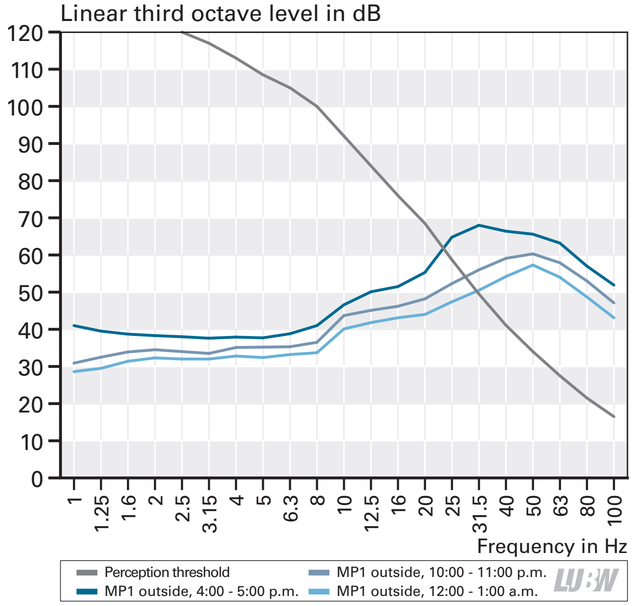


***Figure 5.1-4**: Comparison of the corrected linear third octave levels, determined at the measurement point MP1 (outside the building) for the averaging periods 4:00 - 5:00 p.m., 10:00 - 11:00 p.m., and 12:00 - 1:00 a.m. Furthermore, the perception threshold is also shown (see Section 4.1).*

The A and G-weighted sum level LAeq(t) and LGeq(t) recorded during the entire measuring period are shown in ***Figure 5.1-5***. While the A-weighting shows the audible sound as a single number value, the valuation focus of the G level is in the infrasound range. The curves show a significant bandwidth that is created by the variations of the sound influences. These variations are less pronounced for the G level. The relationship of the courses of the A and G levels can also be clearly seen. Both levels are significantly reduced at night, when there is less traffic. The G level reaches values of up to 80 dB (G) at daytime and minimum values of around 55 dB (G) at night, with strong fluctuations.

RESULTS AT INDOOR MEASUREMENT POINT

The third octave spectra for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are presented in ***Figure 5.1-6*** for the measurement point MP2 inside the building. The interior levels for infrasound up to 20 Hz are below the hearing or perception threshold (< 55 dB) at day and night. Above 32 Hz to 40 Hz (third octave centre frequency), the values of the linear third octave level are above the hearing or perception threshold (up to 55 dB). In narrowband spectra (not shown here) a number of discrete, prominent maxima were detected, which were attributable to natural frequencies of the room and excited natural frequencies of the building.

Figure 5.1-7 shows the one hour average linear third octave level for the low-frequency range below 100 Hz compared to the perception threshold in accordance with DIN 45680 [5]. This was amended for values below 8 Hz [11]. In general, a decrease in the level can be seen the later it gets. Why

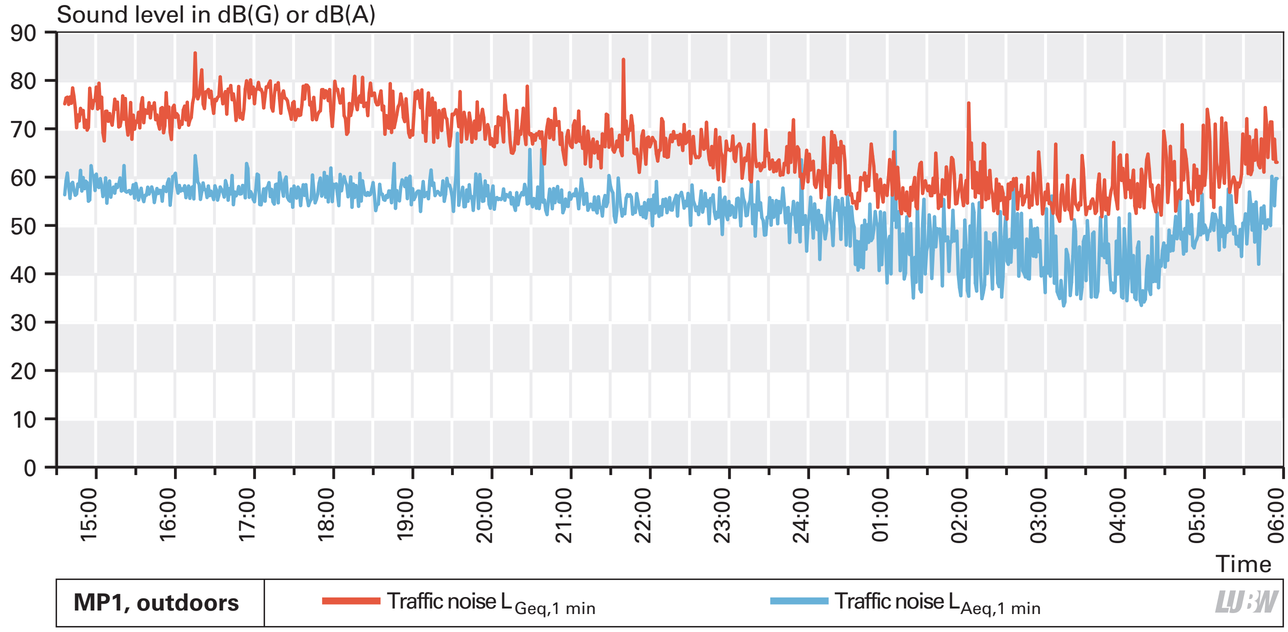
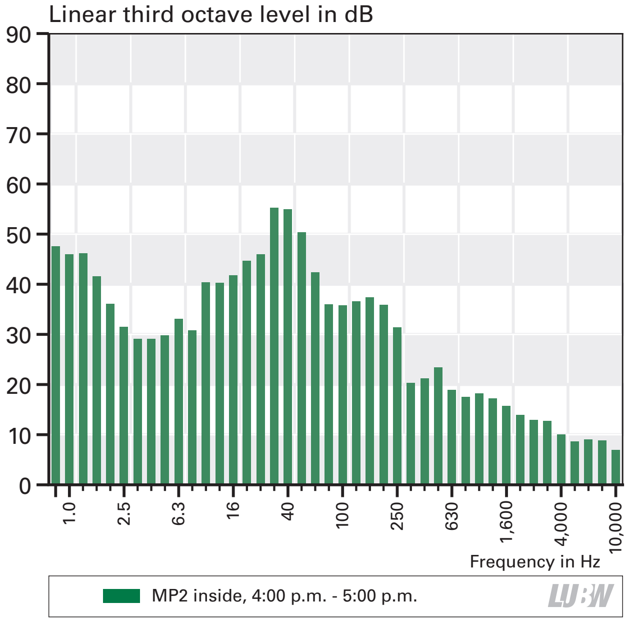
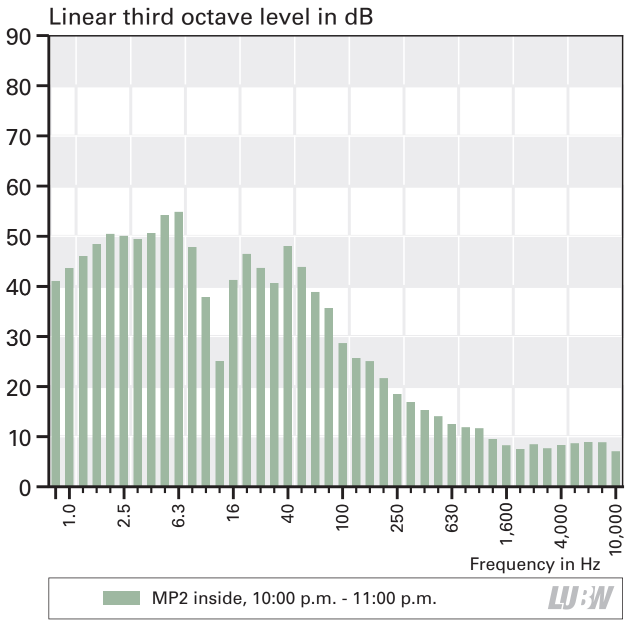


***Figure 5.1-5**: Distribution of the A-weighted sum level $L_{Aeq(t)}$ (blue) and the G-weighted sum level $L_{Geq(t)}$ (red) over the entire measurement period at the outdoor measurement point MP1*

the infrasound levels between 2 Hz and 8 Hz are higher at night is unclear. The G-weighted level during the time elapsed was between 40 dB(G) at night and 65 dB(G) at day.





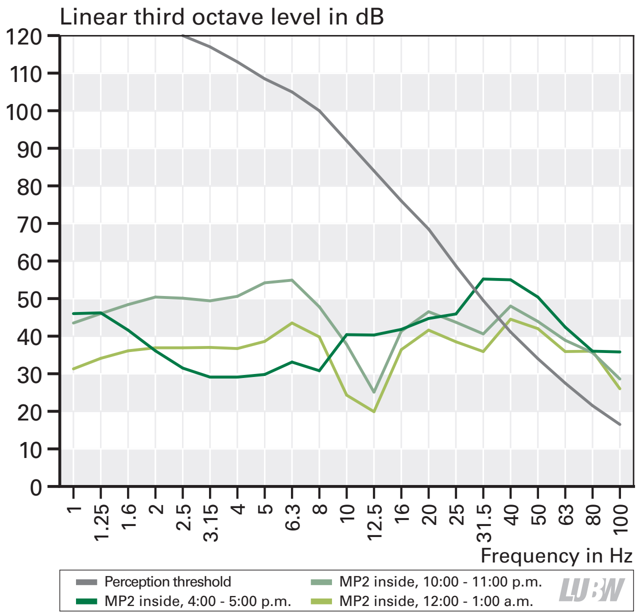


__Figure 5.1-7__ (top): Comparison of the third octave levels at the measurement point MP2 (indoors) for the averaging periods 4:00 - 5:00 p.m., 10:00 - 11:00 p.m. and 12:00 - 1:00 a.m. The perception threshold according to Table A3-1 is also shown.

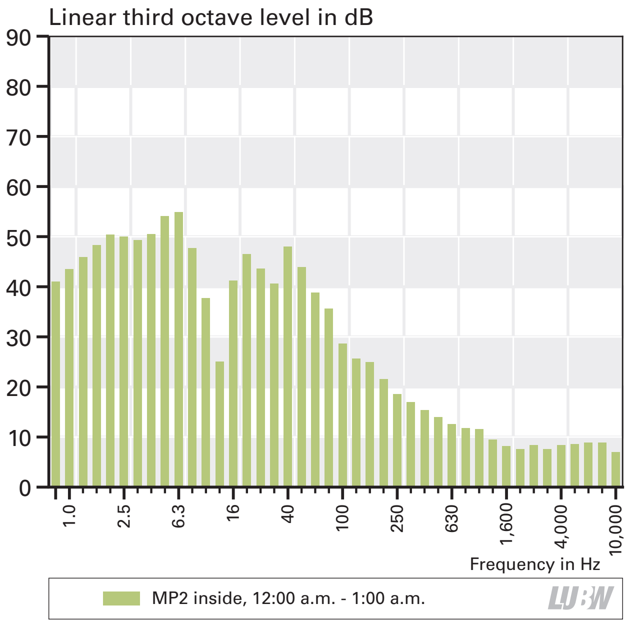


__Figure 5.1-6__ (left column): Linear third octave spectra for the time periods 4:00 - 5:00 p.m. (top), 10:00 - 11:00 p.m. (centre) and 12:00 - 1:00 a.m. (bottom) at the indoor measurement point MP2.

5.2 Inner-city roads – permanent measuring stations Karlsruhe and Reutlingen

Since November 2012, the LUBW has been running a stationary road traffic noise monitoring station in Karlsruhe (Reinhold-Frank Strasse), and a further one in Reutlingen (Lederstrasse-Ost) since March 2013. This is where average and maximum levels of total noise are measured with the use of high-quality sound level measurement devices, as well as meteorological parameters such as temperature, wind speed and precipitation. In addition, the traffic data (vehicle type, quantity and speed) are recorded. Both stations are in areas with relatively high volumes of traffic: In Karlsruhe, approximately 24,000 vehicles/24h, however with a partial standstill of traffic, and in Reutlingen approximately 50,000 vehicles/24h (as of 2011).

In Karlsruhe, the microphone is positioned close to the road, meaning that the recorded levels do not directly depict the concerns of the population living somewhat further away. The distance to residential buildings is less than 10 m (***Figure 5.2-1***). The location of the measuring station in Reutlingen allows immediate statements to be made about the noise pollution for the people affected (***Figure 5.2-2***). Further information is available on the website www.lubw.de/aktuelle-messwerte (home page). The annual reports by the LUBW for the traffic noise monitoring stations can be found under the heading "Auswertungen" (Reports).

Based on the measurement data of the road traffic noise measuring stations in Karlsruhe and Reutlingen, evaluations were made by us with regards to low-frequency noise (incl. infrasound). In the following ***Figures 5.2-3 and 5.2-4*** frequency-selective representations of the noise level from 6.3 Hz to 125 Hz (third octave centre frequency) can be found for the two stations. Averaging was carried out over 30 minutes and summarized. Here only those time periods have been considered in which the wind speeds were less than one meter per second. These were approx. 2,000 half-hour averages for Karlsruhe and about 1,900 for Reutlingen, including many night hours. This avoided the occurrence and subsequent measurement of noise in the vicinity caused by the wind, and also ensured that no sound induced by the wind occurred directly at the microphone. Both

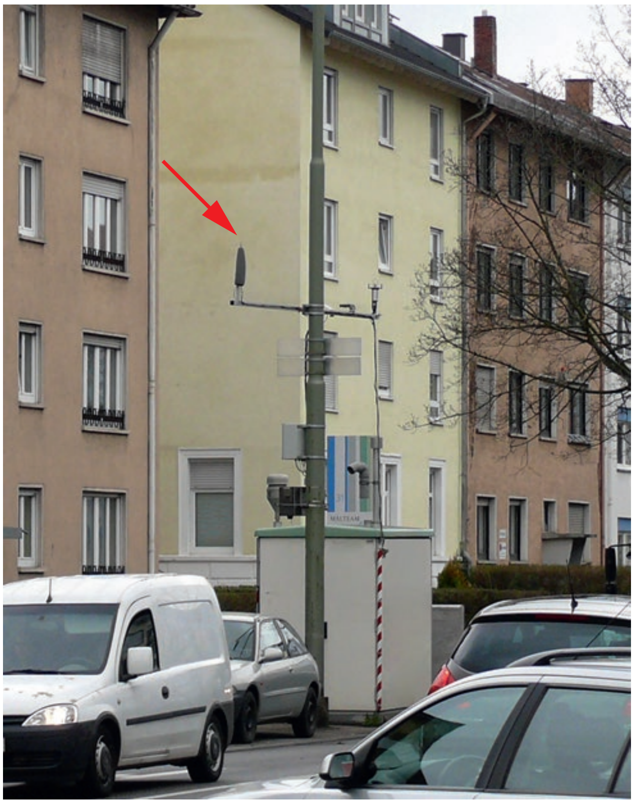


Figure 5.2-1: *LUBW measuring station for detecting road traffic noise in Karlsruhe, Reinhold-Frank-Strasse. The arrow shows the location of the microphone. Residential buildings visible in the background. Photo: LUBW*

Figure 5.2-2: *LUBW measuring station for detecting road traffic noise in Reutlingen, Lederstrasse. The arrow shows the location of the microphone. Photo: LUBW*

effects would have led to an increase in the level values at low frequencies and infrasound, as was the case during the measurements at the wind turbines.

To show the influence of traffic density, illustrations for higher and lower traffic volumes as well as for an average amount of traffic have been added (the exact data is given from the legend of ***Figure 5.2-3 and 5.2-4***). The proportion of heavy-goods traffic, based on the evaluated overall data, was 5 % in Karlsruhe and 11 % in Reutlingen.

Both evaluations show a striking increase between 31.5 Hz and 80 Hz above the perception threshold, which is attributable to motor vehicle traffic. Depending on traffic intensity, mean values of 72 dB (Karlsruhe) or 75 dB (Reutlingen) are reached. In the infrasound range (below 20 Hz) and below, the results of the measurements differ: This is where in Karlsruhe lower values are measured than in Reutlingen, which is probably due to different amounts of heavy-goods traffic, traffic volumes and speeds. In both cases, the third octave levels already exceed the perception threshold with a higher traffic volume between the 20 Hz and 25 Hz third. A similar result was at hand for the road measurement in Würzburg (Section 5.1, ***Figure 5.1-4***). The G-weighted sound levels were between 65 and 75 dB(G) in Karlsruhe and between 70 to 80 dB(G) in Reutlingen, see ***Table 5.2-1***.

5.3 Motorway – measurement near Malsch

The LUBW undertook sound measurements at the A5 (E52) motorway south of Karlsruhe near the town of Malsch on 26.06.2013 during the daytime between 1:00 p.m. and 3:00 p.m. The weather was sunny and practically windless. Wind-induced interfering noise at the microphone can therefore be ruled out. The distances of the microphone position to the middle of the centre strip of the motorway were 80 m, 260 m and 500 m (***Figure 5.3-1***). The measurement values at the measurement point at a distance of 500 m later had to be rejected due to the interference of the B3 main road and other interfering noise. Information on the used metrology can be found in Appendix A4.

The measurement results for the distances of 80 m and 260 m are graphically presented in ***Figure 5.3-2*** as a third

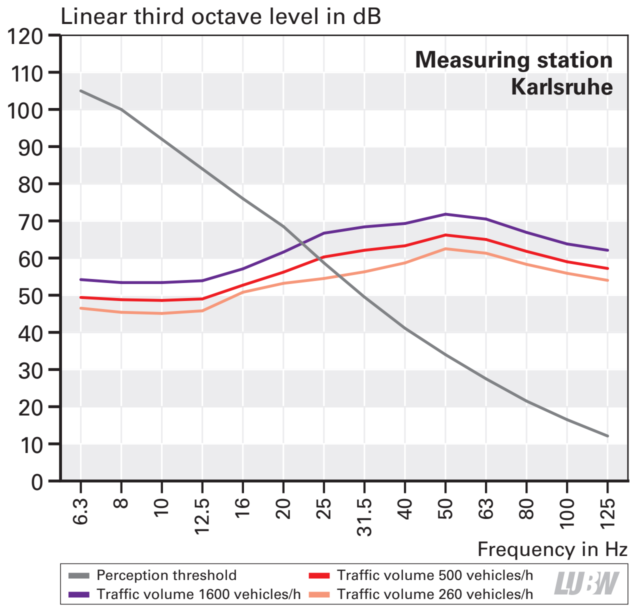


Figure 5.2-3*: Third octave spectra, measuring station Karlsruhe*

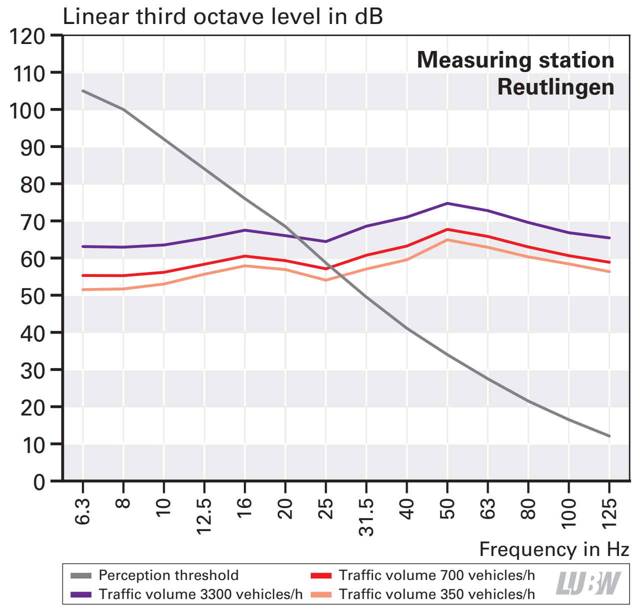


Figure 5.2-4*: Third octave spectra, measuring station Reutlingen*

Periods with zero wind or wind velocities below 1 m/s in the year 2013 were evaluated. Averages over 30 minutes each were formed and aggregated. The increased level in the range between the 31.5 Hz and 80 Hz thirds is caused by road traffic. The curves show the differences at various traffic volumes. Note: The representation begins at a frequency of 6.3 Hz (in other illustrations partly from 1 Hz.); this is due to the measuring technology. For comparison, the perception threshold according to Table A3-1 is shown.

***Table 5.2-1**: Summary of the measurement results for low-frequency noise (including parts of infrasound) at the traffic noise monitoring stations Reutlingen and Karlsruhe*

Source/situation	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB *	Low-frequency third octave levels 25-80 Hz in dB *
Traffic noise measuring station Karlsruhe traffic volume >1600 vehicles/h	75	53 to 62	67 to 72
Traffic noise measuring station Karlsruhe average traffic volume: 500 vehicles/h	65	48 to 57	60 to 67
Traffic noise measuring station Karlsruhe traffic volume < 260 vehicles/h	69	45 to 54	55 to 63
Traffic noise measuring station Reutlingen traffic volume > 3300 vehicles/h	80	63 to 68	64 to 75
Traffic noise measuring station Reutlingen average traffic volume: 700 vehicles/h	70	55 to 61	57 to 68
Traffic noise measuring station Reutlingen traffic volume < 350 vehicles/h	73	52 to 57	54 to 61

* Linear third octave level in dB(Z)

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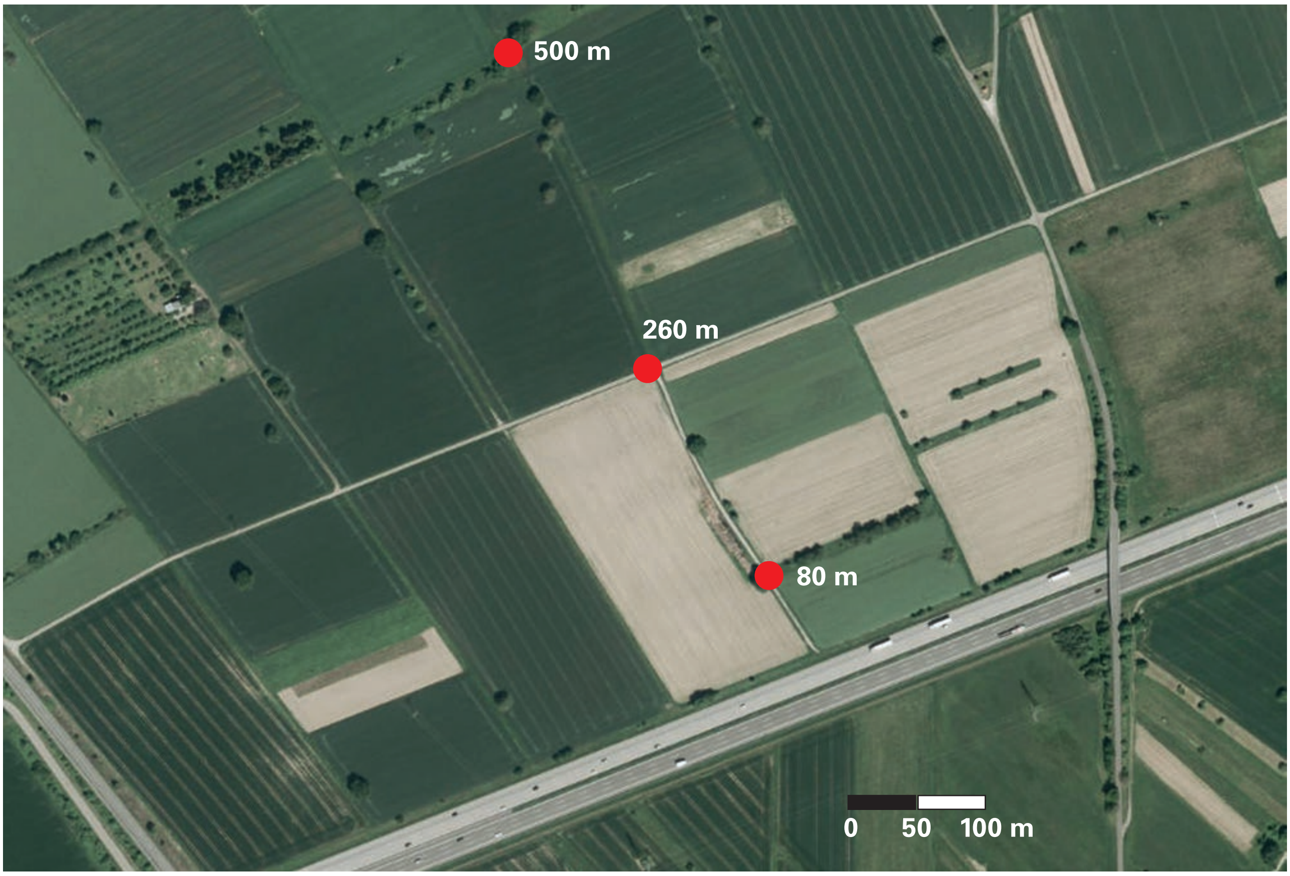


***Figure 5.3-1**: Location of the measurement points at the A5 motorway south of Karlsruhe near Malsch, indicating the distances between the microphone positions and the centre of the motorway. The town of Malsch is located outside of the picture at the bottom left. The B3 main road is located above the picture. Picture source: LUBW, LGL*

octave representation. The third octave levels in the infrasound range are at levels of around 60 dB and slightly below. In the low-frequency range, approximately between 40 Hz and 80 Hz, a slight peak can be seen. Here the measured values are significantly above the hearing threshold. The average traffic intensity is approximately 3,000 vehicles/h with a share of heavy-goods traffic of around 15 %. The G-weighted infrasound levels were around 75 dB(G) at a distance of 80 m and around 71 dB(G) at a distance of 260 m. Additional information concerning the G level can be found in Appendix A3.

5.4 Noise inside car while driving

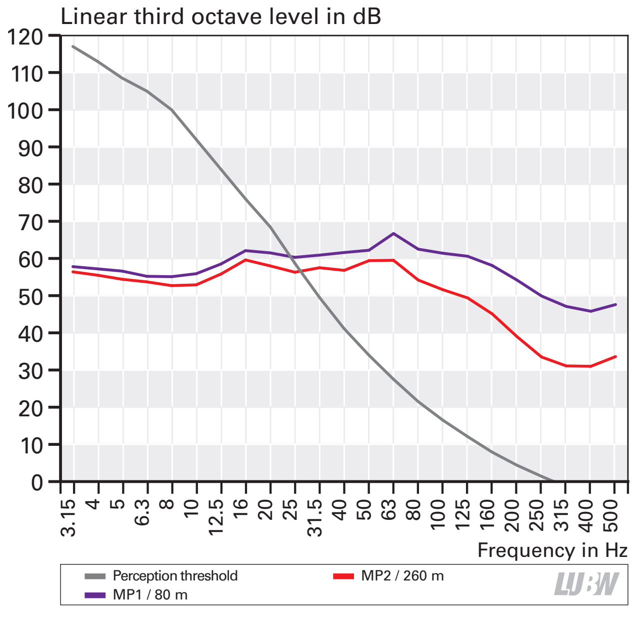
Below are the results of noise measurements carried out by the LUBW inside a moving car and a minibus on 06.09.2012. This is in fact no sound that occurs in the vicinity, i.e. no ambient noise or environmental noise in the strict sense. However, a lot of people are exposed to these sounds often and for longer periods of time, meaning that it surely makes sense to include such measurement values here. It became evident that relatively high levels in the infrasound range up to 20 Hz, as well as in the other low-frequency frequency range above 20 Hz occurred (***Firgure 5.4***, ***Table 5.4***). It must be noted that, with windows open, the levels that arise in the area of low frequencies incl. infrasound are so high that they are subjectively perceived as being painful. The values measured by us correspond to the respective specifications in literature (e.g. [19] [20]).

5.5 Conclusion of the road traffic measurements

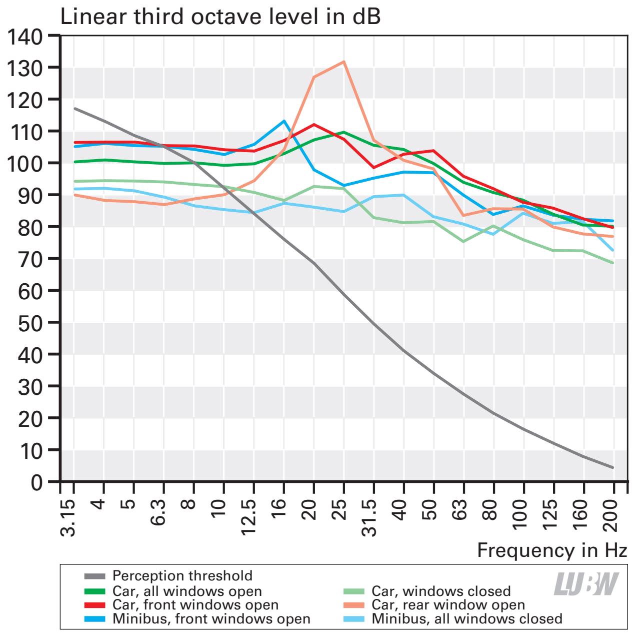
- It was possible to carry out the measurements for the low-frequency noise incl. infrasound resulting from road traffic without interfering wind noise. Unlike in the case of wind turbines, the recorded levels occur in the direct vicinity of residential buildings.

- As expected, it could be observed that the level of low-frequency noise including infrasound dropped at night. A good correlation with the traffic volume was also determined: The more the traffic, the higher the sound levels of low-frequency noise including infrasound.

- The Infrasound levels of traffic reach a maximum of 70 dB (unweighted) in individual thirds with respect to residential buildings in the vicinity. The G-weighted level



Firgure 5.3-2*: Frequency-dependent representation (linear third octave level) of a measurement at the motorway A5. As a comparison, the perception threshold according to Table A3-1 was also included. Note: The representation begins at a frequency of 3.15 Hz (in other illustrations partly from 1 Hz or 6.3 Hz). This is due to the measuring technology used.*



Firgure 5.4*: Low-frequency sound (averaging level) in the inside of car and minibus driving at approx. 130 km/h in comparison to the perception threshold according to Table A3-1*

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***Table 5.4**: Infrasound level inside a passenger car or minibus while driving at 130 km/h*

Source	G-weighted level in dB(G)	Infrasound third octave level between 3.2 und 20 Hz in dB *
Interior noise in passenger car, all windows closed	105	88 to 94
Interior noise in passenger car, rear window open	139	87 to 127
Interior noise in minibus, all windows closed	100	85 to 93
Interior noise in minibus, side windows open	122	98 to 113

* Linear third octave level in dB(Z)

is in the range between 55 and 80 dB(G). This roughly corresponds to values found in literature for sea surf (***Table 2-1***).

- For road traffic, increased levels were detected in the frequency spectra in the range of between roughly 30 Hz and 80 Hz. Low-frequency noise in this area lies significantly above the hearing threshold and seems to be more relevant for an assessment than the infrasound level up to 20 Hz. The values in this low-frequency frequency range are significantly higher for the observed situations of road traffic than in the areas surrounding wind turbines (***Table 2-1***).

- The highest levels in the context of the measurement project were measured in the interior of a car travelling at 130 km/h. Even though these are not immission levels that occur in the free environment, they are an everyday situation that many people are frequently subjected to for a longer period of time. The measured values for both the infrasound as well as the other low-frequency areas are higher by several orders of magnitude than the values usually measured in road traffic or at wind turbines.

6 Urban background

The Friedrichsplatz in Karlsruhe was chose for the measurement of infrasound and low-frequency noise at day and night in an urban background. It is located in the heart of the city. The Friedrichsplatz is a rather quiet square located directly by the natural history museum. Benches, landscaped flower beds and a fountain invite passersby to linger and stop for a short break (***Figure 6-1***). The square extends for about 125 m from north to south and 100 m from east to west. The Erbprinzenstrasse crosses the Friedrichsplatz as a bicycle road. In a westerly and easterly direction are the Ritterstrasse and Lammstrasse respectively, with very slowly driving traffic. In the south, the square is limited by the natural history museum of Karlsruhe. To the west lies the Church of St. Stephan with forecourt. Apart from that, the Friedrichsplatz is surrounded by offices and commercial buildings, as well as a number of individual apartments. The next somewhat busier road is situated about 250 m to the south, shielded behind the natural history museum and the Nymphengarten (Kriegstrasse, B 10). Tram lines are located at a distance of several hundred metres, partially behind several blocks of buildings (***Figure 6-2***), and a construction site is located in a north-westerly direction.

The measurements were carried out simultaneously at three measurement points. The location of the measurement points is shown in the aerial view in ***Figure 6-3***. Measurement point MP1 was chosen in the inside of a building adjacent to the Friedrichsplatz (meeting room of the education authority of Karlsruhe). A second measurement point MP2 was placed on the ground of the Friedrichsplatz, a third measurement point MP3 on the roof of the museum of natural history (***Figures 6-4 to 6-6***). MP2 and MP3 were positioned on a reverberant plate.

The measurements were carried out from Friday, 20.09.2013, 3:00 p.m. to Saturday, 21.09.2013, 2:00 a.m. Preliminary

Figure 6-1*: Friedrichsplatz in Karlsruhe, looking south at the natural history museum. Photo: LUBW*

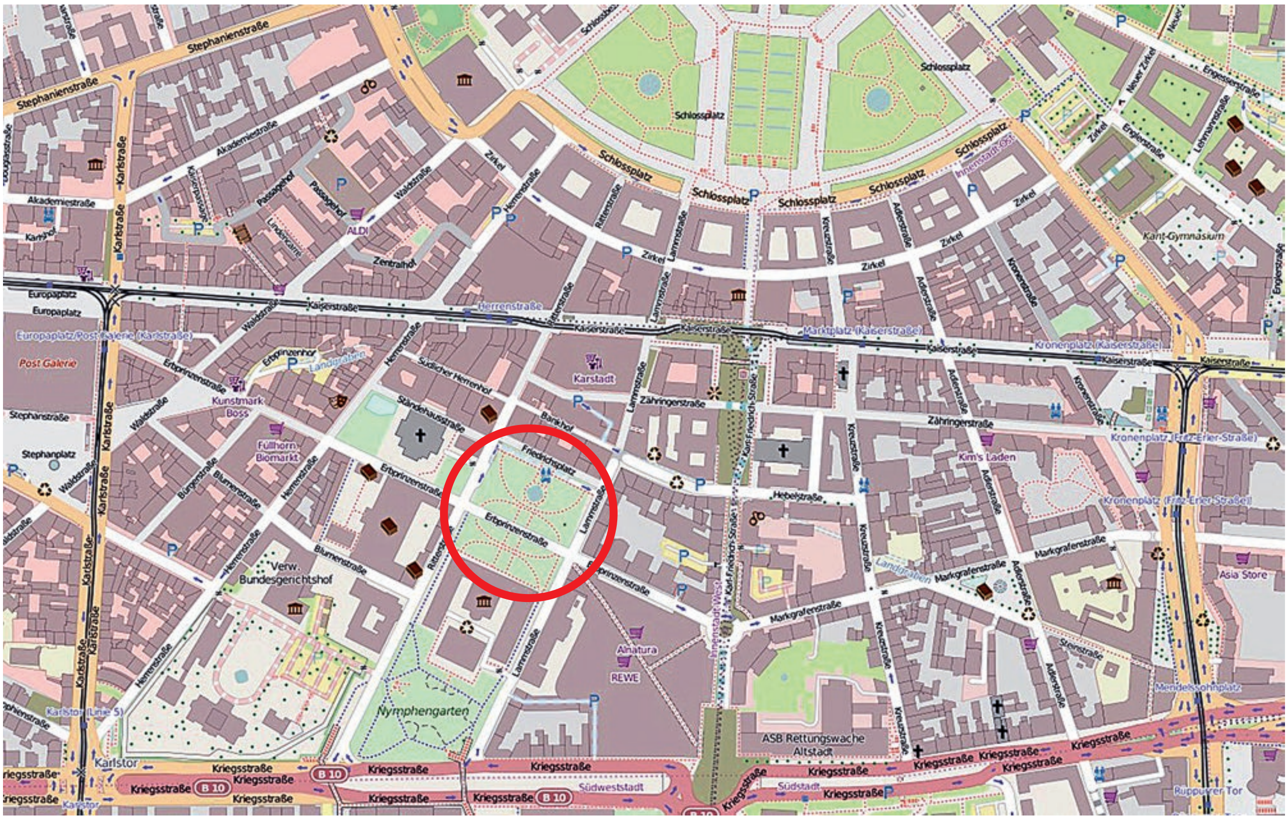

Figure 6-2: *City map of Karlsruhe with Friedrichsplatz (red circle) and the tram lines in the vicinity (dark and dashed lines). Source: www.OpenStreetMap.org*

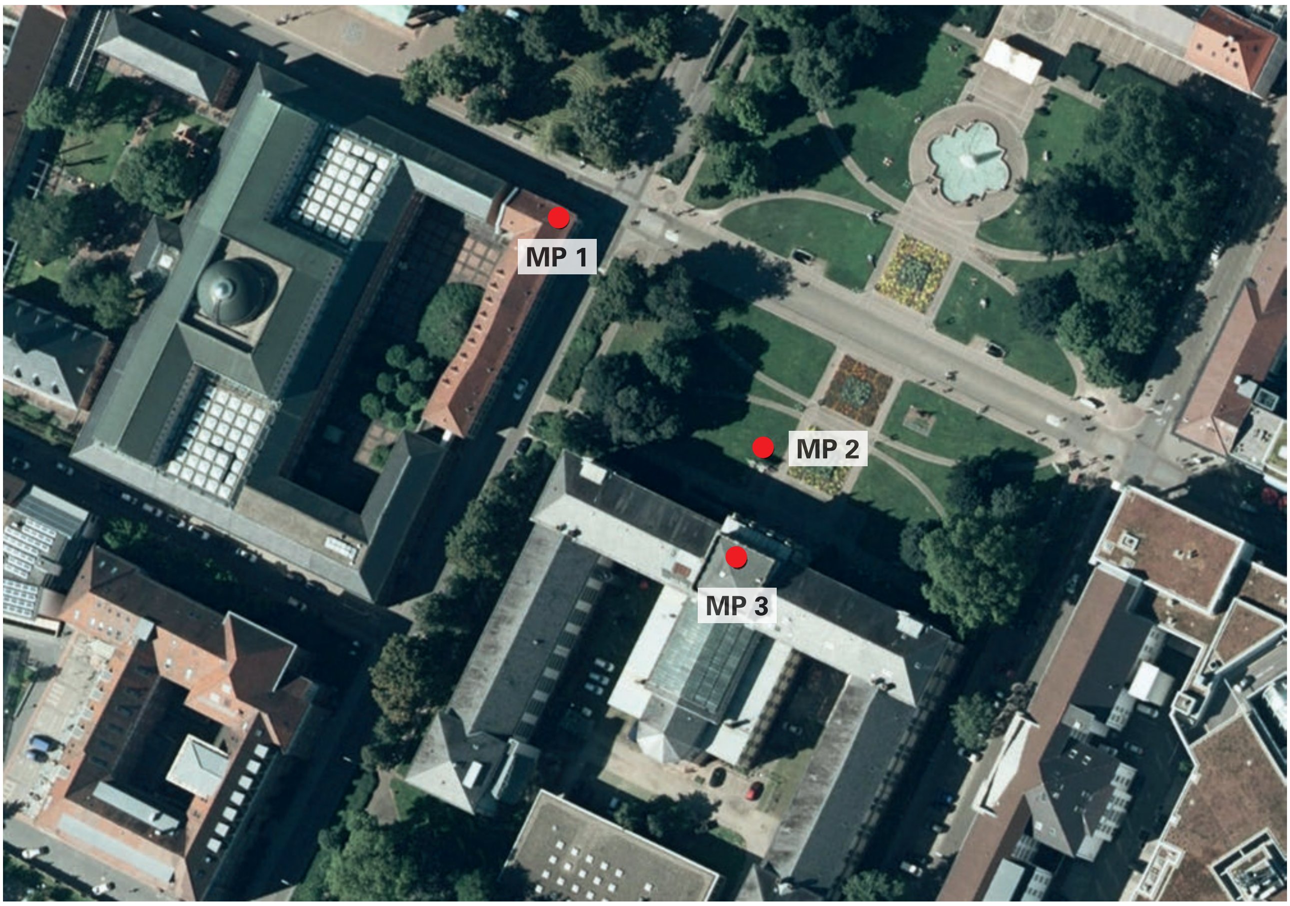

Figure 6-3: *Oriented aerial view of Karlsruhe Friedrichsplatz. Location of the three measurement points MP1 (meeting room of education authority), MP2 (on Friedrichsplatz) and MP3 (roof of museum of natural history). Source: LUBW, LGL*

measurements were taken by the LUBW on 26.06.2013. The measurements should enable conclusions to be made about the situation at day and at night. The volume of traffic (cars, pedestrians, cyclists) was typical for this site in the given weather conditions. In summer nights or during events, higher volumes will surely be the case.

Note: While the infrasound and low-frequency noise measured in the vicinity of operating wind turbines always contains a proportion of wind (and possibly also a share that is induced by the wind at the microphone), the conditions are much more favourable for the measurement of inner city noise. Here these effects related to the wind play virtually no role. The infrasound and low-frequency noise could be measured largely without any disturbing wind noise. Only on the roof of the museum of natural history did wind noise occur from time to time. For more information see page 73.

RESULTS

The measured third octave spectra for the three measurement points, each for the time periods 4:00 p.m. - 5:00 p.m., 10:00 p.m. - 11:00 p.m. and 12:00 a.m. - 1:00 a.m. are shown in ***Figure 6-8*** and are explained in the following:

At the measurement point MP1 (education authority, indoor measurement), third octave levels between just under 20 dB to 45 dB were measured in the infrasound area below 20 Hz. The values are all below the perception threshold. It is clearly visible that the infrasound levels drop at night by about 10 dB. In the further low frequency range a significant rise from 25 Hz to 63 Hz can be found, which is probably due to traffic noise and electrically powered equipment (the building was not without electrical power). All in all, the lowest levels are found at the indoor measurement at MP1 as a result of the absorption through the building envelope. The results of the indoor measurement were evaluated according to DIN 45680 (1997) [4],

Figure 6-4*: Setup of the measurement point MP1, indoor measurement at the education authority of Karlsruhe. Photo: LUBW*

Figure 6-5*: Measurement point MP2 on the Friedrichsplatz in front of the natural history museum Karlsruhe. Photo: LUBW*

Figure 6-6*: Microphone position at measurement point MP3 (roof of museum) with view over Karlsruhe. The meteorology was also determined at MP3. Photo: LUBW*

Figure 6-7*: View from measurement point MP3 (roof of museum) looking north over Karlsruhe. The floodlights of the KSC stadium in the Wildpark can be seen. Photo: LUBW*

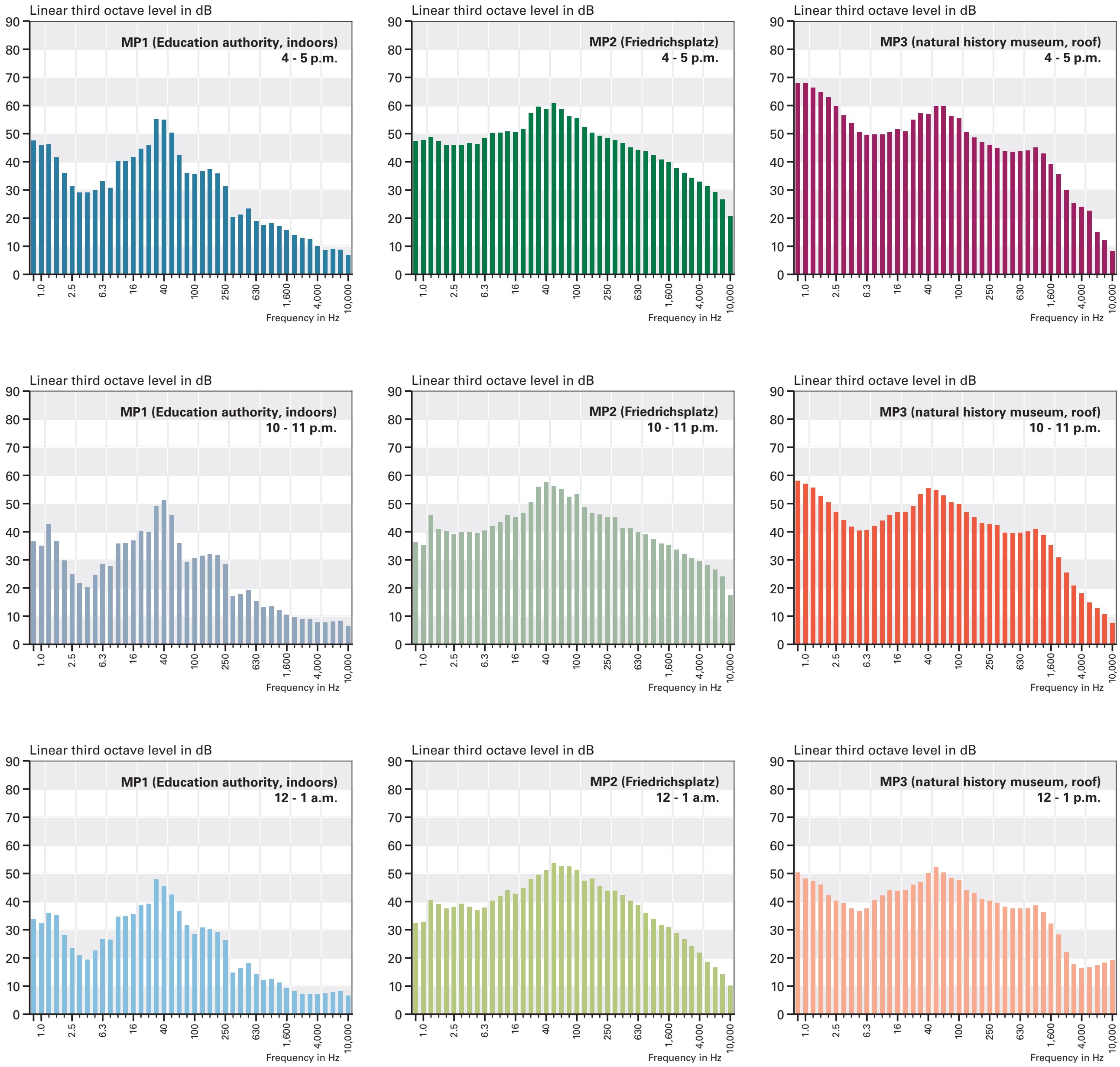

***Figure 6-8**: Measured third octave spectra for the three measurement points at different times of the day and at night. Left column: Measurement point MP1 (education authority, indoors); centre column: Measurement point MP2 (Friedrichsplatz); right column: Measurement point MP3 (natural history museum, roof). For explanations see text.*

even if the scope of this standard does not cover road traffic noise. Time periods with substantial influence of background noise at measurement point MP1 were excluded from the evaluation. The following periods of time were chosen: For the night period (10:00 p.m. - 11:00 p.m., loudest hour), as well as in accordance with the procedure of DIN 45680 (1997) [4] for the day period (4:00 p.m. - 5:00 p.m., loudest hour) as well as informatively for the night hour from 12:00 a.m. - 1:00 a.m. The reference values taken from the supplement sheet "Beiblatt 1" for above-stated norm (these are formally only valid for the operation of industrial plants) were exceeded in the daytime as well as night time periods. There were no clearly protruding single tones. For informative purposes, the measurement data was also evaluated according to the revised draft of DIN 45680 (2013) [5]. The reference values taken as a comparison (these are formally only valid for the operation of industrial plants) were exceeded in the daytime as well as night time periods.

The data of the measurement points MP2 and MP3 was respectively corrected according to Section 4.1 (reverberant plate). At the measurement point MP2 (Friedrichsplatz in front of the museum), third octave levels between

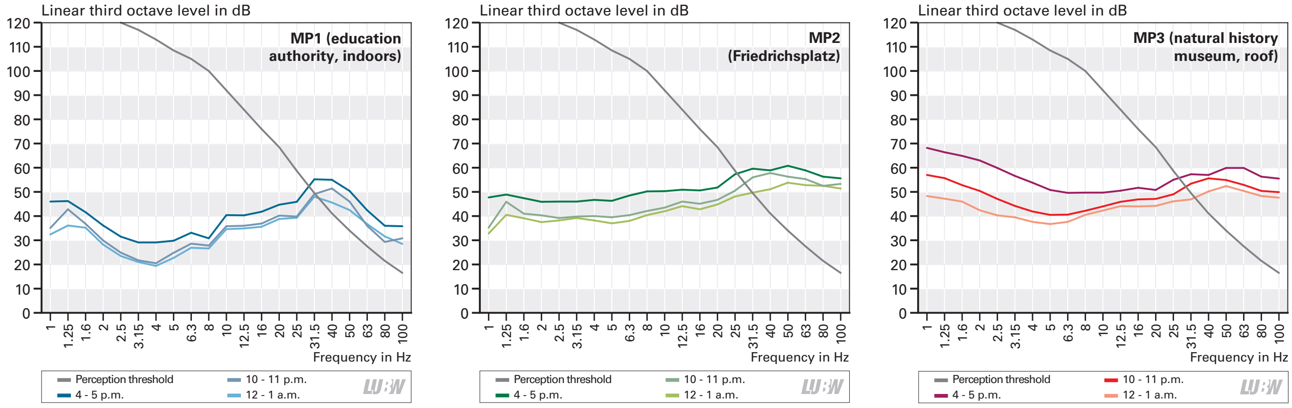

***Figure 6-9**: Comparative frequency-dependent representation of the third octave sound level for the three measurement points at different times of the day and at night. The results for MP2 and MP3 have been corrected (reverberant plate, see Section 4.1). The perception threshold was also shown as a means of orientation. Left: measurement point MP1 (education authority, indoors); Centre: measurement point MP2 (Friedrichsplatz); right: measurement point MP3 (natural history museum, roof).*

just under 35 dB and a little over 50 dB were measured in the infrasound range up to 20 Hz. Here too, a decrease of the infrasound can be recognised later at night. In the low-frequency range, an excessive increase can also be seen, which can be attributed to the road traffic. This is where levels above 55 dB are also reached at night in the range of 32 Hz to 80 Hz, which is above the perception or hearing threshold. An interesting effect can be seen for the 1.25 Hz third, which, for example, clearly stands out in the third octave spectrum for MP2 between 10:00 p.m. and 11:00 p.m. This concerns a natural frequency of the Friedrichsplatz, which is largely surrounded by buildings (half a wavelength corresponds to merely the extent of the square). This effect can be analysed further in the narrow band spectrum (not shown here).

At the measurement point MP3 (museum roof), similar conditions as for MP2 can be seen – with two differences: For the infrasound below 5 Hz, an excessive increase can be seen, which here is attributed to the somewhat increased wind speed on the roof and the corresponding wind effects. An increase arising in the range above 500 Hz can at least partially be attributed to the rolling noises of cars on roads located further away, such as the B 10 (Kriegstrasse). These were noticeable on the roof, but were otherwise screened off. In the evening, it was possible to get a direct view of the KSC football club's Wildpark stadium, where a match was taking place (***Figure 6-7***).

In a further analysis of the narrow band spectra (not listed here), some individually protruding lines could be detected at some frequencies. However, these could not all be associated with specific sources.

In ***Figure 6-9*** the developments of the linear third octave levels in the range from 1 Hz to 100 Hz are presented for the measurement points MP1 to MP3 in comparison to the perception threshold (according to draft of DIN 45 680 [5]; below 8 Hz supplemented by literature values [11]). See also ***Table A3-1***. The results for MP2 and MP3 were corrected, as shown in Section 4.1, due to the use of a reverberant plate.

Figure 6-10 shows the course of the A-weighted and G-weighted sound level during the measurement at the measurement point MP2 (Friedrichsplatz). It can be clearly seen that the G level, which represents the low-frequency noise including infrasound, slowly and steadily decreases in the evening hours. The G levels at the measurement point MP1 (indoors) were mostly between 45 dB(G) and 60 dB(G) during the measuring period, and at times even above that. At the measurement points MP2 (Friedrichsplatz) and MP3 (roof), the values were mostly between 55 dB(G) and 65 dB(G), and partially reached levels above 70 dB(G).

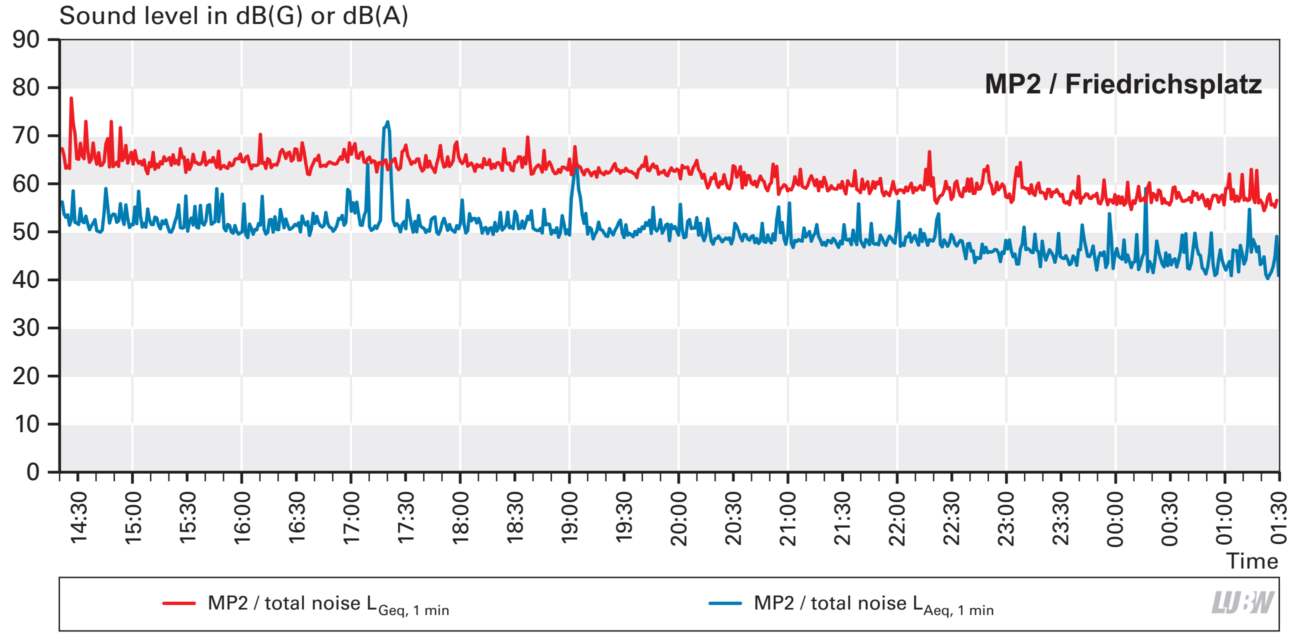

***Figure 6-10**: Course of the A and G-weighted sum level $L_{Aeq}(t)$ und $L_{Geq}(t)$ at the measurement point MP2 (Friedrichsplatz) in the time period 20.09.2013, approx. 2:30 p.m. to 21.09.2013, 1:30 a.m.*

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7 Sources of noise in residential buildings

Life in the modern household is characterized by the use of technical devices, which are used to facilitate everyday life. The locations of the devices are normally chosen on the basis of the existing supply connections for electricity, water or gas. When doing so, people also generally pay attention to ensuring a preferably trouble-free use of the living quarters. Devices such as fridges or ventilation systems are permanently or intermittently in operation, while other devices such as vacuum cleaners or electronic tools are used only briefly. During operation, every technical device emits characteristic sounds. Depending on the source, different sound patterns can also be caused by different operating modes.

With the help of manufacturer‘s instructions, buyers can inform themselves about the expected noise levels prior to the acquisition of technical devices. However, the data sheets often only specify the A-weighted levels. These provide no indications of how the sound spreads across different frequencies.

In order to also be able to present low-frequency noise that may occur in a living environment in a comparative manner, the LUBW carried out sound level measurements in a residential building in the city centre of Tübingen. The apartment building in half-timbered construction style dates from the second half of the 19th century. The compartments of the walls are made of sandstone and the wood-beamed ceilings are filled with clay. The ceilings and walls are additionally covered with a 3-4 cm thick layer of lime plaster. In the course of renovation work during the last few years, the worksite sandstone slabs or tiles were moved onto a layer of reinforced cement screed in some areas, such as in the bathrooms. The building is located in a restricted traffic area; the next multilane roads are about 150 m away. Any traffic noise emanating from there is largely shielded by the building density of Tübingen city centre. The acoustic situation around the building is significantly characterized by the communication noise of passers-by.

The measurements on 04.08.2015 registered two washing machines from various manufacturers, one refrigerator, one oil heating and one gas heating. For detailed information on the used measuring instrumentation please refer to Appendix A4.

7.1 Washing machine

The washing machines were located in two apartments on the 1st and 2nd floor of the house. The measurements were each taken at a measurement point MP1 at close range within the room of the installation itself, as well as at a measurement point MP2 in a separate room. When measuring washing machine 1 on the 1st floor, the measurement point MP1 in the middle of the room was approx. 0.5 m from the washing machine. Measurement point MP2 was located approx. 3 m vertically above MP1 on the 2nd floor. Washing machine 2 was located on the 2nd floor. Here measurement point MP1 was also positioned in the middle of the room approx. 0.5 m from the washing machine, while measurement point MP2 in the adjoining room – separated by a wall – was positioned approx. 5 m away.

RESULTS

The measurements of the two washing machines took place in the period from 10:50 a.m. to 11:30 a.m. Periods with extraneous noise effects were excluded from the evaluation.

With washing machine 1 in operation, third octave levels between 44 dB and 76 dB in the infrasound range under 20 Hz were measured at measurement point MP1 (***Figure 7.1-1***). The highest levels occurred during the spin cycle and the lowest ones during the wash cycle. At measurement point MP2, third octave levels of 29 dB to 60 dB occurred below 20 Hz during the measurement of washing machine 1. Here, too, the higher levels were registered during the spin cycle.

At washing machine 2, the third octave levels at measurement point MP1 in the infrasound range below 20 Hz were between 35 dB and 70 dB (***Figure 7.1-2***). Here too, the highest third octave levels were registered in the spin cycle. The measurements at measurement point MP2 showed third octave levels between 26 dB and 71 dB in the same frequency range.

The curves for the individual modes of operation of the two measured washing machines are almost parallel for the measurement points MP1 and MP2 in the infrasound range below 20 Hz. In contrast, it can be seen that above 20 Hz the difference between the third octave levels measured at both measurement points increases with increasing frequency. This can be attributed to the sound insulation effect of the building components (ceiling or wall). The building components reduce the higher-frequency sound to a significantly higher degree than is the case in the infrasound range.

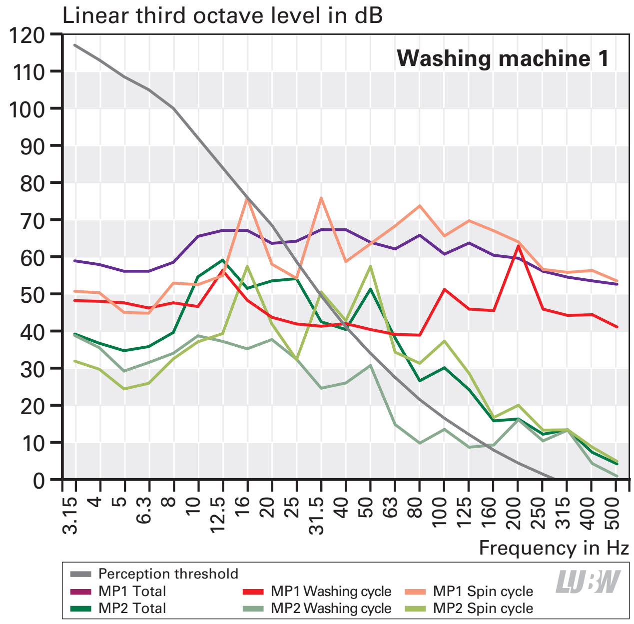

Figure 7.1-1*: Third octave noise level of washing machine 1 at measurement points MP1 and MP2 for different operating states, with perception threshold according to Table A3-1 for comparison. "Total": Average level over the entire wash cycle.*

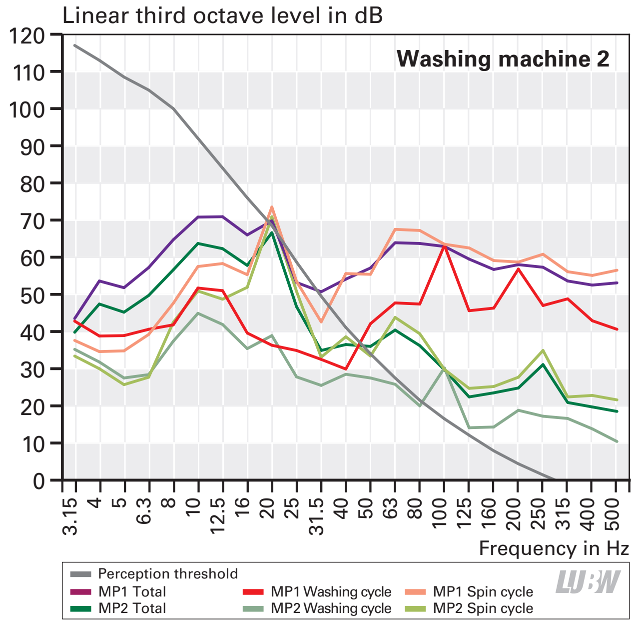

Figure 7.1-2*: Third octave noise level of washing machine 2 at measurement points MP1 and MP2 for different operating states, with perception threshold according to Table A3-1 for comparison. "Total": Average level over the entire wash cycle.*

The single tone at 16 Hz (washing machine 1) as well as 20 Hz (washing machine 2) are caused by the respective rotational speed during the spin cycle. The 16 Hz third octave correlates with 960 rpm, the 20 Hz third octave with 1,200 rpm. The additionally emerging single tone at washing machine 1 at about 31.5 Hz is a harmonic overtone of the 16 Hz third octave. Depending on the operating mode, single third octave levels can reach the perception threshold according to ***Table A3-1*** between roughly 16 Hz and 20 Hz; above 50 Hz the third octave levels are generally in the audible range.

7.2 Heating and refrigerator

The two heating units measured were an oil boiler in the basement with pressurised atomiser burner on the one hand, and a gas water heater installed on a wall in the bathroom of the 2nd floor on the other. The fridge was located on the 2nd floor in a corner of the kitchen. The measurements of these noise sources were each carried out at a measurement point at a distance of about 0.5 m.

RESULTS

The third octave spectra during operation of the two heating systems as well as the refrigerator in the period from 11:40 a.m. to 1:30 p.m. were measured using technical measuring equipment. The results of the measurements are shown in ***Figure 7.2-1***. As was the case for the other measurements, extraneous noise, e.g. caused by measuring staff or passers-by outside, was excluded from the assessment.

Levels of approx. 55 dB to 70 dB were measured at the oil heating in the infrasound range below the 20 Hz third octave. In the low-frequency range between 20 Hz and 80 Hz, the third octave levels are between 55 dB and 60 dB. A single tone with a third level of 74 dB is recognisable at 100 Hz. Levels between 40 dB and 50 dB were measured at the gas water heater in the infrasound range below 20 Hz. In the low-frequency range between 20 Hz and 80 Hz, the third octave levels measured at the gas heating are between 40 dB and 50 dB. The difference between the levels measured at the oil heating and the gas water heater in the low-frequency range is between 10 dB and 40 dB.

The fridge measured in the kitchen of the 2nd floor delivered third octave levels of between 32 dB and 50 dB in the infrasound range. Third octave levels between 17 dB and 50 dB were measured at the refrigerator between 20 Hz and 80 Hz. While the third octave spectrum of the oil heating clearly sets itself apart from the other measured units through higher levels, the third octave spectra of the gas water heater and the refrigerator are very similar.

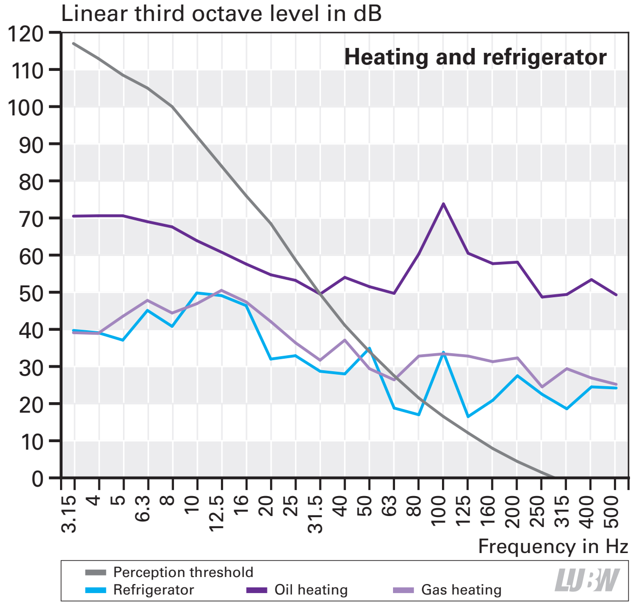

Figure 7.2-1: *Third octave sound level of the noise from oil heating, gas heating and refrigerator at a distance of 0.5 m from the unit, with perception threshold according to Table A3-1 for comparison*

SUMMARY

During the measurements in the residential building, the highest levels at washing machines were recorded during the spin cycle. Tonalities in individual third octaves correlate with the rotational speed of the drum of the washing machine during the spin cycle. As expected, building components dampen higher frequency noise components more than at low frequencies. The perceptual threshold according to ***Table A3-1*** was reached for the washing machines in the frequency range above 16 Hz and 20 Hz respectively. With the other devices, the infrasound level did not reach this threshold.

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8 Natural sources

8.1 Rural environment

In order to make statements about how much infrasound is caused by wind in the great outdoors, sound level measurements were carried out within the framework of the measuring programme on 09.05.2015 with strong winds in an open field (measurement point MP1), on the edge of a forest (measurement point MP2) and in a forest (measurement point MP3). The three points were aligned downwind of each other, starting with MP1. As with the wind power plants, the sound level measurements were carried out on a reverberant plate with a primary and secondary wind screen. At the same time, the wind speed was measured at 10 m height (open field) at the measurement point MP1. ***Figures 8.1-1 to 8.1-3*** provide an impression of the positioning of the measurement points. The measurement point MP1 lies approx. 130 m from the edge of forest.

The evaluation was carried out for the frequency range between 1 Hz and 10 kHz. The procedure corresponded to the analysis of the measurements at wind power plants, as described in Section 4. Two time periods were examined per measurement point at different wind speeds (6 m/s and 10 m/s at the measurement point MP1, open field), within which the wind blew evenly if possible. As a result, two situations with widely differing environmental conditions were recorded. Due to the spatial situation at the measurement points MP2 (edge of forest) and MP3 (forest) it can be assumed that at the same given point in time the wind speed is lower there than at the measurement point MP1 (open field).

RESULTS: NARROW BAND LEVEL

Figure 8.1-4 shows the narrow-band spectra determined from the audio signals at an average wind speed of approx. 6 m/s and 10 m/s at a height of 10 m (measured at the measurement point MP1). The three charts in the left column enable a comparison of measurement results for the two wind speeds at each measurement point. The two graphs in the right column show the sound levels that were recorded at the three measurement points for each of the wind speeds 6 m/s and 10 m/s. It can be seen clearly how the le-

***Figure 8.1-1**: Measurement point MP1 on open field (left) and meteorology mast (right), looking in direction of forest. Photo: Wölfel company*

***Figure 8.1-2**: Measurement point MP2, edge of the forest. Photo: Wölfel company*

***Figure 8.1-3**: Measurement point MP3 in the forest, approx. 90 m from measurement point MP2. Photo: Wölfel company*

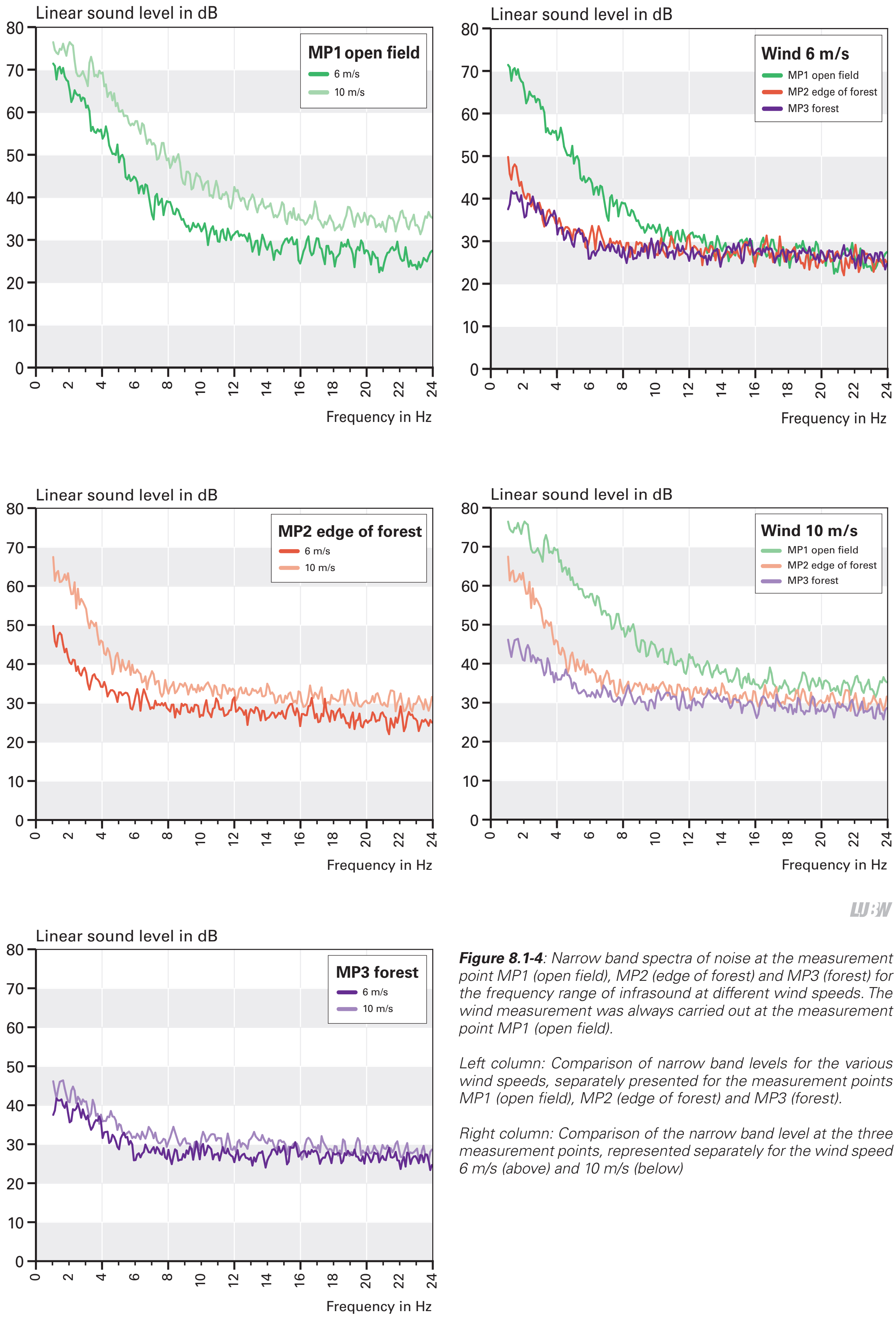

***Figure 8.1-4**: Narrow band spectra of noise at the measurement point MP1 (open field), MP2 (edge of forest) and MP3 (forest) for the frequency range of infrasound at different wind speeds. The wind measurement was always carried out at the measurement point MP1 (open field).*

Left column: Comparison of narrow band levels for the various wind speeds, separately presented for the measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest).

Right column: Comparison of the narrow band level at the three measurement points, represented separately for the wind speed 6 m/s (above) and 10 m/s (below)

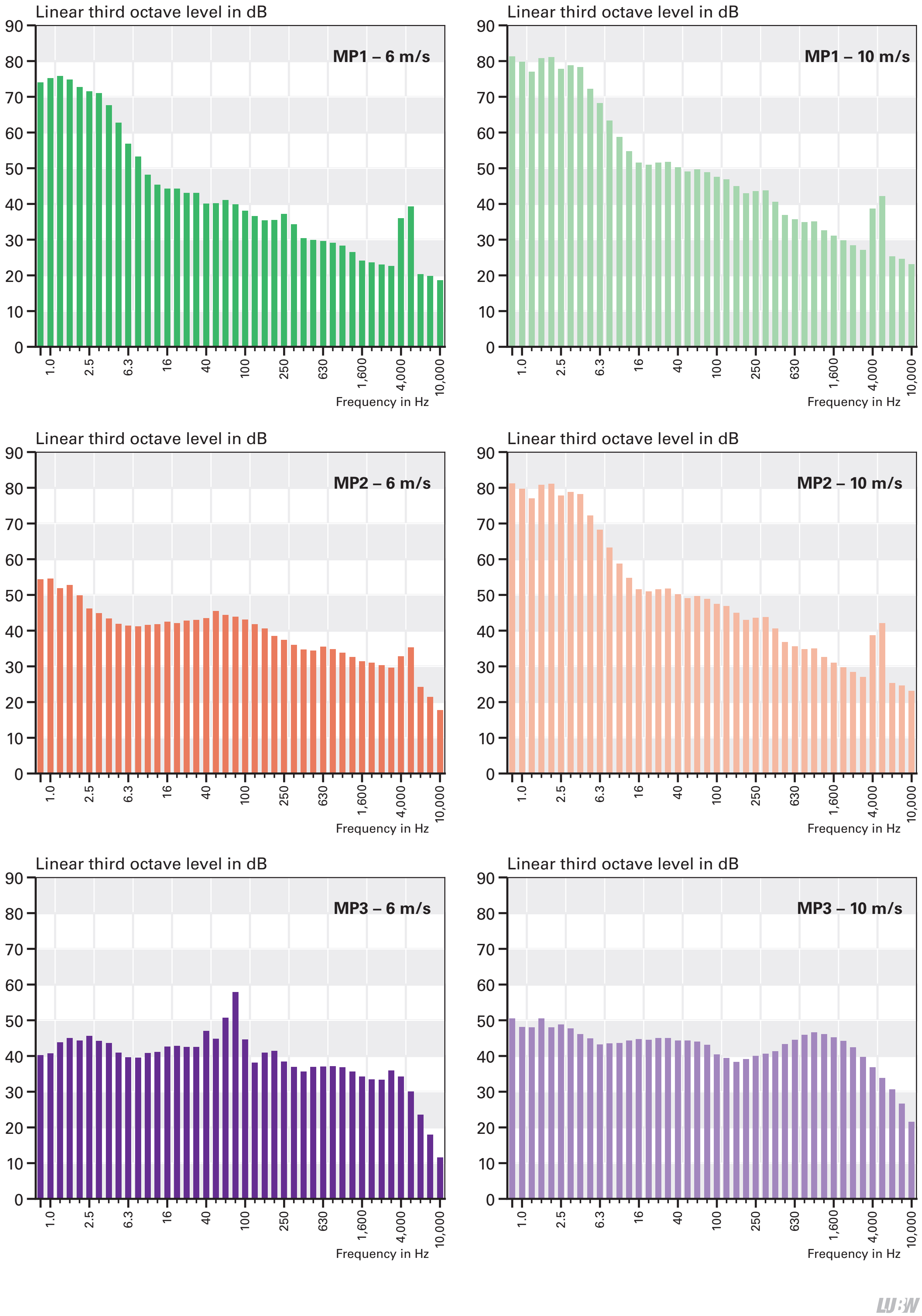

Figure 8.1-5*: Third octave spectra of the background noise at the measurement point MP1 (open field), MP2 (edge of forest), and MP3 (forest). Left column: Wind speed 6 m/s; right column: Wind speed 10 m/s. The wind measurement was always carried out at the measurement point MP1 (open field).*

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vels depend on the measuring position and the wind speed. On an open field, the levels are about 10 to 15 dB higher at a wind speed of 10 m/s than at a wind speed of 6 m/s. At the edge of the forest, this difference is somewhat weaker for frequencies above roughly 5 Hz. The difference is only 5 to 10 dB. In the forest, the difference is 5 dB or less. The spread of the measured values between the three measurement points falls from roughly 30 dB at the lowest end of the spectrum to 0 to 5 dB at the upper end, depending on the wind speed. Noteworthy level differences between the edge of the forest and the forest occur only below 10 Hz. The differences in level between open field and forest, on the other hand, become less only above 20 Hz.

RESULTS: THIRD OCTAVE LEVEL

The third octave spectra of the background noise at all three measurement points for the frequency range from 0.8 Hz to 10,000 Hz are presented in ***Figure 8.1-5***. The wind speed was 6 m/s (left column) and 10 m/s (right column). On the open field, the low frequencies are predominant in the spectrum; at the edge of the forest and even more so in the forest, however, a shift to higher frequencies can be seen. While the wind becomes less the closer it gets to the forest, and less wind noise is therefore induced at the microphone, the noise from the leaves in the forest increases considerably. The peak values at about 4,000 Hz are due to the chirring of crickets and chirping of birds.

COMPARISON WITH THE PERCEPTION THRESHOLD

Figure 8.1-6 shows the third octave spectra of the total noise at the measurement points field, edge of forest and forest for the frequency range from 1 Hz to 100 Hz along with the perception threshold for comparison. The wind speed was 10 m/s. In the range of infrasound, the curves are well below the perception threshold.

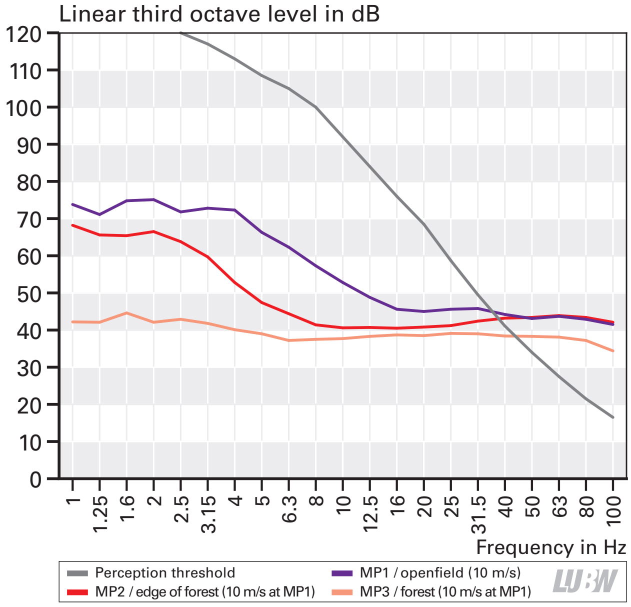

Figure 8.1-6: *Comparison of the third octave spectra of the total noise at the measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest) with the perception threshold according to Table A3-1. The measured values were corrected in accordance with Section 4.1.*

INFLUENCE OF WIND SPEED

The data in ***Figure 8.1-7*** shows that both the audible sound level (A level) and the infrasound level (G level) increase with increasing wind speed. Worth noting is the decrease in level of the G-weighted level from the measurement point MP1 (open field) in the direction of the measurement point MP3 (forest). This correlates with the decreasing wind speed when moving from the open field towards the forest. Wind-induced effects on the microphone can be generally ruled out (see Section 4.5 and 4.6, measurement in hole in the ground). The A-weighted level increases the closer you get to the forest, which can be attributed to the rustling of leaves, which is reflected in the A level.

Table 8.1-1: *Infra sound in a rural location at the three measurement points at different wind speeds*

Measurement point	G-weighted level in dB(G) Wind 6 / 10 m/s	Infrasound third octave level ≤ 20 Hz in dB * Wind 6 / 10 m/s
MP1 open field, 130 m from forest	50-65 / 55-65	40-70 / 45-75
MP2 edge of forest	50-60 / 50-60	35-50 / 45-75
MP3 forest	50-60 / 50-60	35-40 / 40-45

* Linear third octave level in dB(Z)

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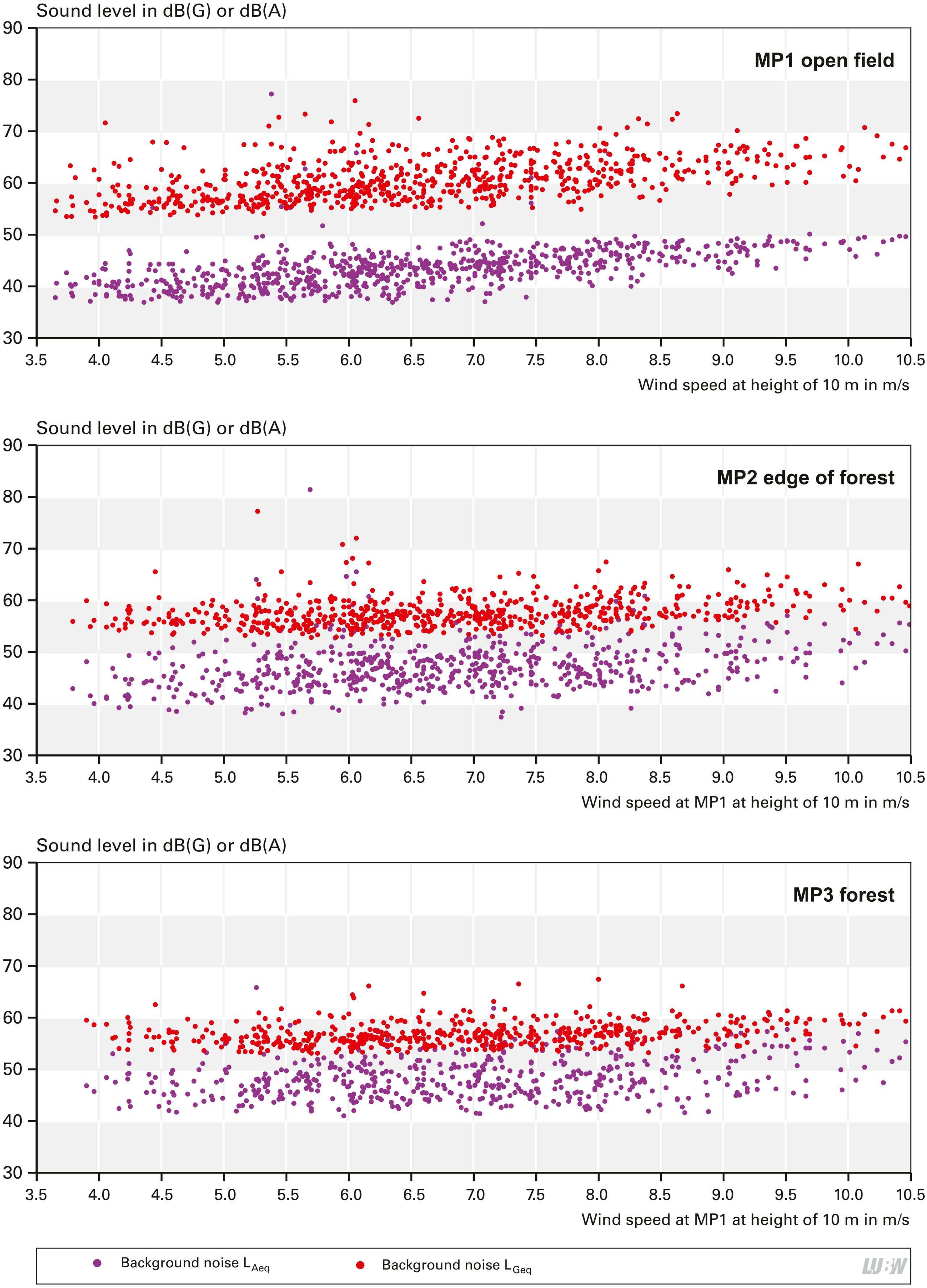

***Figure 8.1-7**: Audible sound level (A level) and infrasound level (G level) depending on the wind speed for the three measurement points MP1 (open field), MP2 (edge of forest) and MP3 (forest). The G levels (red dots) and the A levels (violet dots) are shown. The wind measurement was always carried out at the measurement point MP1 (open field).*

CONCLUSION

The infrasound shows a strong dependence on the measuring position. The linear levels in the narrow-band spectrum measured in the open field were up to 30 dB higher than the levels measured in the forest (***Table 8.1-1***). The differences are not as pronounced above 16 Hz, but a tendency towards higher levels can be seen in the open field compared to the forest at low frequencies. Higher levels were measured for A-weighted audible sound in the forest, which is attributable to the rustling of leaves.

8.2 Sea surf

In addition to wind noise, sea surf is a widespread natural source of low-frequency noise and infrasound. The LUBW was not able to take its own measurements at the coast within the framework of this project. Therefore, currently published values shall be drawn upon in order to provide an order of magnitude. In 2012 TURNBULL, TURNER and WALSH published metrics for sea surf as a natural source of infrasound [21]. Accordingly, the G-weighted infrasound level on a beach was 75 dB(G) at a distance of 25 m from the waterline, 69 dB(G) at a distance of 250 m from a cliff, and 57 dB(G) at a distance of 8 km from the coast (***Table 8.2-1***). Near the coast, the third octave levels at different frequencies below 20 Hz were in the range of 53 dB to 70 dB (***Figure 8.2-1***).

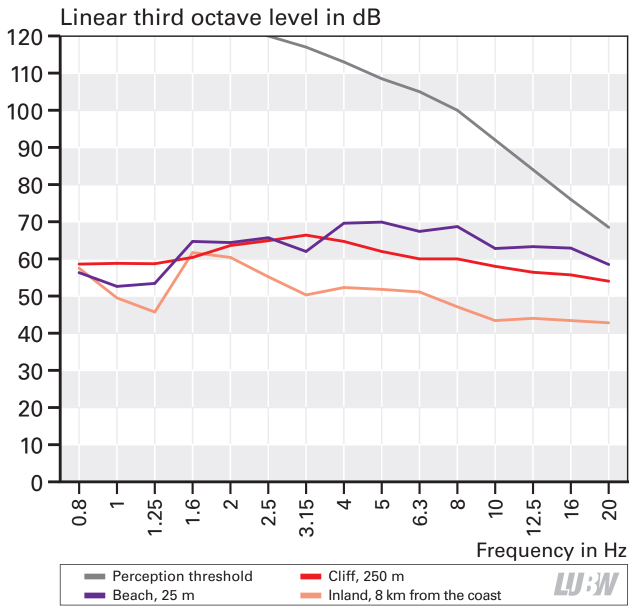

Figure 8.2-1*: Third octave spectra of the total noise of surf, different boundary conditions according to [21], perception threshold according to Table A3-1 for comparison*

Table 8.2-1*: Infrasound levels of sea surf for different boundary conditions*

Source	G-weighted level in dB(G)	Infrasound third octave level ≤ 20 Hz in dB *
Beach, 25 m from the waterline	75	53 to 70
Cliff, at distance of 250 m	69	54 to 65
Inland, 8 km from the coast	57	43 to 63

* Linear third octave level in dB(Z)

9 Design of a long-term measuring station for low-frequency noise

9.1 Task

An integral part of the measurement project "Low-frequency noise incl. infrasound from wind turbines and other sources" was the setup of a feasibility concept for a self-sufficient long-term measuring station with which to measure and document the noise situation at wind turbines. In particular, low-frequency effects were to be taken into account. When designing the concept, it was assumed that such a measuring station is to be used primarily in the context of monitoring measurements or in connection with complaint cases. Furthermore, the long-term measuring station should also provide a possibility to carry out special studies, e.g. for the determination of infrasound or sound modulations or before/after analyses. The following specifications had to be taken into account:

- DIN EN 61400-11 "Windenergieanlagen – Teil 11: Schallmessverfahren" (2013) [6]
- Technical guidelines for wind turbines, part 1, revision 18 (as of 01.02.2008, issued by FGW Fördergesellschaft Windenergie e.V.) [7]
- Technical instructions on noise abatement – "TA Lärm" (1998) [10]
- DIN 45680 "Messung von Bewertung tieffrequenter Geräuscheinwirkungen in der Nachbarschaft" (1997) [4] as well as DIN 45680 "Messung und Beurteilung tieffrequenter Geräuschimmissionen" (2013 draft) [5].

In addition, a mains voltage-independent operation of the measuring station should be ensured for a period of two to four weeks.

9.2 Concept

The design of the measuring station was to include in particular the technical equipment, the evaluation of the measured data as well as the evaluation of the results in the context of immission protection. In principle, the projected long-term measuring station is divided into the following functional modules:

- Unit for detecting the operating parameters of the wind turbine
- Meteorology measuring unit
- Noise measuring unit
- Device monitoring (remote control unit)
- Data centre (database and data analysis)

If the task requires it, the long-term measuring station could contain several similar measurement units. The basic design of a possible long-term measuring station is shown in ***Figure 9.2-1*** dargestellt.

9.3 Individual modules for data acquisition

FACILITY AND OPERATING PARAMETERS

Approximate statements regarding the operating state of a wind power plant can be derived from wind data determined near the measuring location. However, this does not apply for special operating modes of the system (e.g. low noise operation, system downtime in case of insufficient wind conditions).

Reliable results for the current performance of a wind turbine require the continuous determination of the actual turbine and operating parameters such as system power, rotor speed, nacelle angle, blade angle, wind speed and wind direction. Typically, the system operator already records these parameters as part of standard procedure. However, taking over such data from the operator into the collective of the data determined by the long-term measuring station is often difficult, if not impossible, in practice. It is therefore much more reliable, yet more bothersome, to record the turbine operation data on one's own measuring system. In order to do so, the turbine signals would have to be decoupled from the turbine control system of the wind

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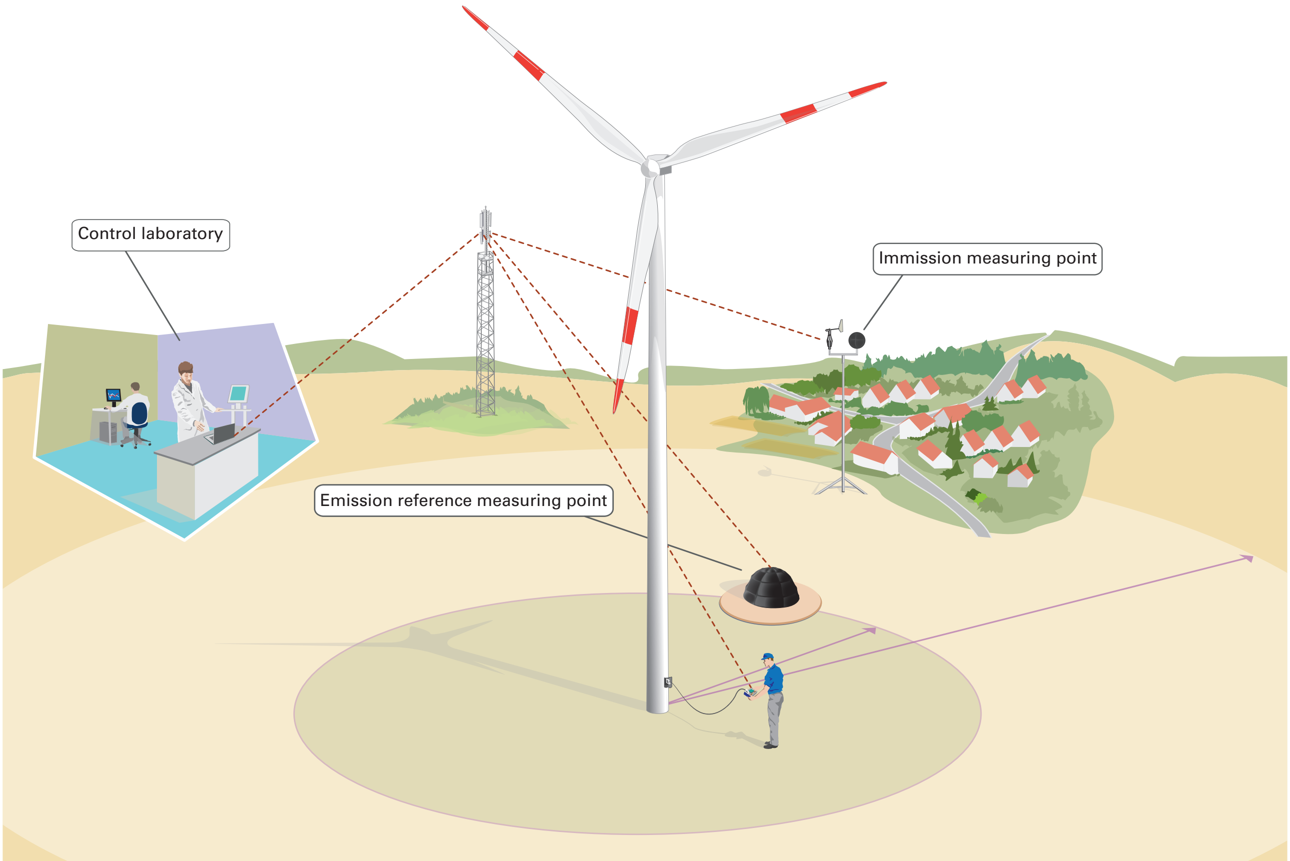

***Figure 9.2-1**: Basic design of a possible long-term monitoring station*

power plant via transducers or existing interfaces, and be registered by the appropriate data loggers. With this type of gathering of data, the data recording (sampling sequence, data formats, etc.) can be devised according to its own standard. Thus, optimal data integration into the overall system would be guaranteed. However, this would certainly require the support by trained personnel during the setup and connection of the measuring system to the turbine control.

WEATHER DATA

In addition to the noise measurement data, the meteorological variables – mean wind speed, mean wind direction (each in 10 s intervals) – as well as precipitation, air temperature and air pressure have to be determined. Commercially available weather stations (sensors and data loggers) equipped with sufficient data storage could be used for this purpose. The collected meteorological parameters are then linked with the other metrics in the data centre. If technically possible, the recording of meteorological data could already be carried out on location together with the noise measurement data in the sound level analyser. The wind data should be collected at a height of up to 10 m above ground. The respective masts that can also be used on rough terrain are provided by a number of manufacturers.

ACOUSTIC DATA

In order to measure the acoustic data, a combination of devices consisting of a standard sound level analyser and changeable microphone unit can be used. As far as necessary or appropriate, further functional units such as controller, monitoring system or meteorology recording can be included or attached. The noise measuring system is fundamentally suitable for determining emissions (DIN EN 61400-11 [6]), noise immissions (TA Lärm [10]) and low-frequency noise (DIN 45680 [4]). The following specifications must be met by the sound level analyser:

- Calibratable sound level meter according to DIN EN 61672-1:2003 [22] Class 1, with standard microphone and third octave filters according to DIN EN 61260:2003 [23] Class 1

- Usable range of levels: 18 dB(A) to 110 dB(A), usable frequency range: 1 Hz to 20 kHz
- Ongoing collection of different sound levels (L_{Aeq}, L_{AFmax}, L_{Ceq}, L_{CFmax}, $L_{TerzAeq}$, $L_{TerzAFmax}$) in periodic times of 0.1 s to 10 s
- Continuous recording of the audio signal and hourly storage as a WAV file. The data storage capacity must be sufficient for records of at least two weeks, or in the case of a restricted frequency range of the audio recording for recordings of at least four weeks
- Extensive trigger management (timed triggering and external trigger option)
- Alternatively usable infrasound microphone (lower limiting frequency ≤ 1 Hz, uncertainty at 1 Hz ≤ ± 3 dB)
- Additional weatherproof microphone plate with primary and secondary wind screens according to DIN EN 61400-11 [6]
- Additional primary and secondary wind screens for mounting on tripod or measuring mast for immission measurements according to TA Lärm [10]

DEVICE MONITORING

Ideally, the possibility should be given to monitor and control all measuring systems wirelessly via an Ethernet or GSM connection from the data centre. If permitted by the data connection, a transfer of the stored data to the data centre should also be possible.

In order to increase the transparency of the respective measuring project, a real-time display of measurement results on a publicly accessible website could also be enabled.

GENERAL REQUIREMENTS

In general, it must be possible to operate all devices of the long-term measuring station with 12 V direct voltage independently from the public power supply network. The measuring station should be equipped with the respective power supply units. A maintenance-free continuous operation of four weeks ought to be ensured. The long-term measuring station should generally be designed in a weatherproof manner. As far as necessary, all parts should be sufficiently protected from the weather (precipitation, sun, wind). Operation in an air temperature range of -5 °C to +30 °C must be made possible. The long-term measuring station must be fitted with safety features against damage by animals, against vandalism and against theft.

9.4 Central data evaluation

The evaluation of the data gathered on location and its compilation to measurement reports is generally carried out in the data centre after the end of the measurements. The nature and scope of the evaluation depends on the predefined task. The actual data evaluation can largely be carried out automatically. Analysis programmes for this purpose are commercially available. The following points should be considered for the evaluation:

- Data preparation: Individual data that is required but cannot be determined on location can be derived from the measured data or the audio recordings. (e.g. G-weighted noise levels, narrowband frequency analyses, tonalities, impulsiveness).
- Data synchronization: The individual values of the turbine data, the meteorological measurements and the acoustic measurements are to be consolidated for the same period lengths (e.g. 10 s) and to be synchronised to the same absolute points in time.
- Rectifying faults: If there is extraneous noise at the measurement point as well as noise from the wind power plant, this could lead to misinterpretations of the noise situation. The levels of the noise influenced by extraneous sources therefore must be excluded when determining the turbine noise levels. This requires a comprehensive plausibility check of all measured data for every individual case. Impulsive background noise can often be well recognized from the level curve, ongoing external noise interference can often be seen only on the basis of the level curves of individual frequency bands. When in doubt, the audio recordings will have to be referred to.

9.5 Applicability and benefits

The affected population is often rather sceptical when it comes to projected noise levels or measurements of wind turbines that are taken within a matter of hours. It is thus that the people affected often assume that the applied procedures do not take into account all facets of possible disturbances. Also, it is believed that the worst operating mode of the wind turbine is often not the basis for the noise measurements. In such cases, the use of a long-term measuring station is a good idea. In order to increase its acceptance, the general population could also be involved in the evaluation proceedings.

FIELDS OF APPLICATION

- Determination of the noise emissions and immissions caused by wind power plants subject to wind and plant operating conditions. Generation of different statistics on noise occurrence, plant parameters or wind conditions.
- Comparison of the results with the reference values and indicators in the TA Lärm and DIN 45680 [4, 5], as well as the level values used or specified in the approval procedure.
- Determination of the infrasound influencing a measurement point, possibly depending on the wind and plant operating conditions.
- Determination of noise exposure at a location before and after commissioning of wind turbines.
- Identification of specific or not regularly occurring noise or sound effects, for example implemented by complainants.
- Ultimately, the operation of such a long-term measuring station could be seen as a contribution towards the protection of the population against the harmful effects of noise, and in particular as a contribution to the pacification of the conflict situation on location.
- The use of a long-term measuring station is not suited as a means of carrying out acceptance tests. Such measurements require direct support through expert staff.

Appendix A1 – General information

The following sections provide information on infrasound and low-frequency noise in generally understandable form. This concerns the development, occurrence, spreading as well as the evaluation and perception of infrasound and low-frequency sound [15] [19] [24] [25] [26] [27] [28].

A1.1 LOW-FREQUENCY NOISE AND INFRASOUND

Put simply, sound consists of compressional waves. When such pressure fluctuations spread in the air, one refers to them as airborne noise. A human's sense of hearing is able to capture sound, the frequency (see Appendix A3) of which lies between approximately 20 Hz and 16,000 Hz (for children this value is about 20,000 Hz). Low frequencies correspond to low notes while high frequencies correspond to high notes. Sound below the audible range, i.e. with frequencies below 20 Hz, is called infrasound. Noise above the audible range, i.e. with frequencies above 20,000 Hz, is known as ultrasound. Low-frequency noise is defined as sound which is primarily within the frequency range below 100 Hz. Infrasound is thus a part of low-frequency sound.

Periodic air pressure fluctuations spread with a velocity of approximately 340 meters per second. Low-frequency vibrations have large wave lengths while high-frequency vibrations have small wave lengths. For example, the wavelength of a 20 Hz tone in air is about 17 m, while a frequency of 20,000 Hz has a wavelength of 1.7 cm (see ***Table A1-1***).

A1.2 SOUND PROPAGATION

The propagation of infrasound and low-frequency sound follows according to the same physical laws as all kinds of air-borne noise. A single sound source, such as a wind turbine generator, emits waves that spread in all directions in a spherical manner (***Figure A1-1***). As the sound energy is distributed across an ever growing area, the noise intensity decreases per square meter in an inverse proportion: With increasing distance it quickly becomes quieter (roughly 6 dB per doubling of distance). In addition, there is also the effect of absorption of sound through the air. A small part of the sound energy is converted into heat during the spread of the waves, resulting in additional absorption. This air absorption depends on the frequency: Low-frequency sound is only slightly absorbed while high-frequency is absorbed more. In comparison, the decrease of the sound level over distance significantly outweighs the decrease through air absorption. When spreading across flat surfaces, interference can occur, leading to highly fluctuating sound levels. A pressure build-up may occur in front of large obstacles leading to an increase in the sound pressure level. Standing waves may occur outdoors between the facades of buildings. Furthermore, a special feature of low-frequency sound waves is their low absorption through walls or windows, meaning that effects can also occur inside of buildings. Here too, the formation of standing waves may be the case. However, in the infrasound range these can arise only in large halls or churches; in common residential buildings the fundamental oscillations are at higher frequencies.

Table A1-1: *Relationship between frequency and wavelength for sound waves in the air*

Frequency	1 Hz	10 Hz	20 Hz	50 Hz	100 Hz	2,000 Hz
Wavelength	340 m	34 m	17 m	6.8 m	3.4 m	17 cm

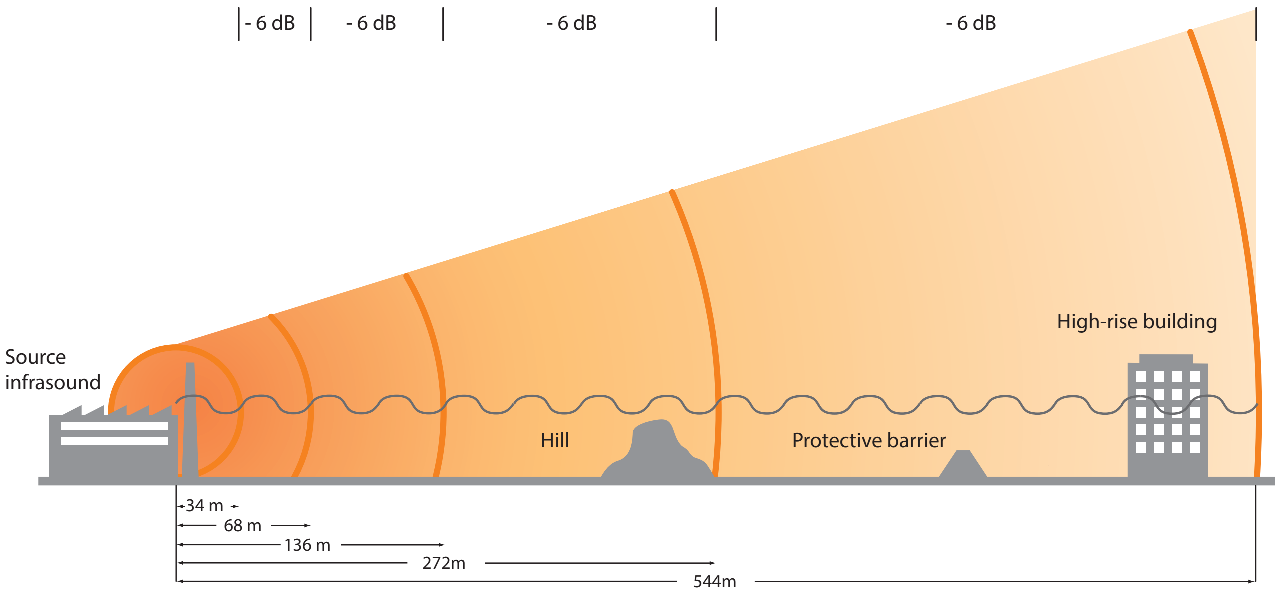

***Figure A1-1**: Exemplary presentation of spread of infrasound with a frequency of 10 Hz. The associated wavelength of 34 m is larger than the height of houses, trees and protective barriers. Therefore these hardly absorb the sound. However, the sound pressure level nevertheless decreases according to the same law as for audible sound: Each doubling of distance from the source results in a decrease in sound level of 6 dB. Image source: Bayerisches Landesamt für Umwelt [15]*

A1.3 INCIDENCE AND OCCURRENCE

Infrasound and low-frequency noise are everyday components of our environment. They are produced by a large number of different sources. These include natural sources, such as wind, waterfalls or sea surf, just as much as technical sources, such as heating and air conditioning systems, road and rail traffic, airplanes or speaker systems in nightclubs, etc.

A1.4 EVALUATION

The measurement and assessment of low-frequency noise are regulated in the technical instructions for the protection against noise (TA Lärm [10], please refer to Chapter 7.3 and Appendix A1. 5) as well as the standard DIN 45680 [4]. The impact of noise can be safely determined on the basis of these regulations. In this case the frequency range from 8 Hz to 100 Hz is considered. The crucial aspect when it comes to possible noise pollution is the human hearing threshold or perception threshold, which is outlined in the standard. See also the next section.

An own frequency weighting, the so-called G-weighting, exists for the area of infrasound. The relevantly weighted levels are specified as dB(G) – "decibel G". The A-weighting of noise dB(A) – "decibel A" – is more common, which is derived from human hearing. The G-weighting is focused at 20 Hz. Levels are amplified between 10 Hz and 25 Hz. Above and below that, the valuation curve quickly falls. The purpose of G-weighting is to characterise a situation regarding low frequencies or infrasound with only a single number. A disadvantage is that frequencies below 8 Hz and above 40 Hz hardly contribute at all. For more information please refer to "Frequency Evaluation" in Appendix A3, where you will also find an evaluation curve (***Figure A3-1***).

A1.5 PERCEPTION

In the area of low-frequency noise below 100 Hz there is a smooth transition from hearing, i.e. the sensations of volume and pitch, to feeling. Here the quality and nature of the perception changes. The pitch sensation decreases and does not apply at all for infrasound In general, the following applies: The lower the frequency, the higher the

***Table A1-2**: Hearing and perception threshold (in decibels) in the range of infrasound. The lower the frequency, the louder the noise or sound intensity has to be in order for a person to perceive something. At 8 Hz the sound pressure level has to be at 100 decibels. Humans can hear best in the area of 2,000 to 5,000 Hz. That is where the average hearing threshold is at 0 decibels and even below it (up to minus 5 decibels).*

Frequency (as a third octave centre frequency)	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz
Hearing threshold according to DIN 45680 (1997) [4]	103 dB	95 dB	87 dB	79 dB	71 dB
Perception threshold according to draft DIN 45680 (2013) [5]	100 dB	92 dB	84 dB	76 dB	69 dB

sound intensity has to be so that the noise is heard at all (see ***Table A1-2***). Low-frequency impact with high intensity is often perceived as ear pressure and vibrations. Permanent exposure to such high noise levels can lead to buzzing, vibrating sensations or a feeling of pressure in the head. In addition to the sense of hearing, other sensory organs can also register low-frequency sound. For example, the sensory cells of the skin convey pressure and vibration stimuli. Infrasound can also affect cavities in the body, such as lungs, sinuses and middle ear. Infrasound of very high intensity has a masking effect for the middle and lower acoustic range. That means: In the case of very strong infrasound, your hearing is unable to perceive quiet tones in frequencies above it.

But where are the limits between hearing, feeling and "no longer perceiving"? ***Table A1-2*** shows some levels of the hearing and perception thresholds for different frequencies. The hearing threshold of DIN 45680 (1997) [4] is defined in such a way that 50 % of the population will no longer perceive the respective frequency below the specified level. The perception threshold of DIN 45680 (2013) [5] is defined so that 90 % of people will no longer perceive the sound below this level. The limit from which low-frequency sound can be heard, varies from person to person. This is nothing unusual, as it is similar to what we are accustomed to regarding audible sound in everyday life. For almost 70 % of people, the hearing threshold lies in a range of ± 6 dB around the values shown in ***Table A1-2***. For particularly sensitive individuals, who make up around two to three percent of the total population, the hearing threshold is at least 12 dB lower. ***Figure A1-2*** provides a graphic depiction of the relationship of the two thresholds. The differences are relatively small.

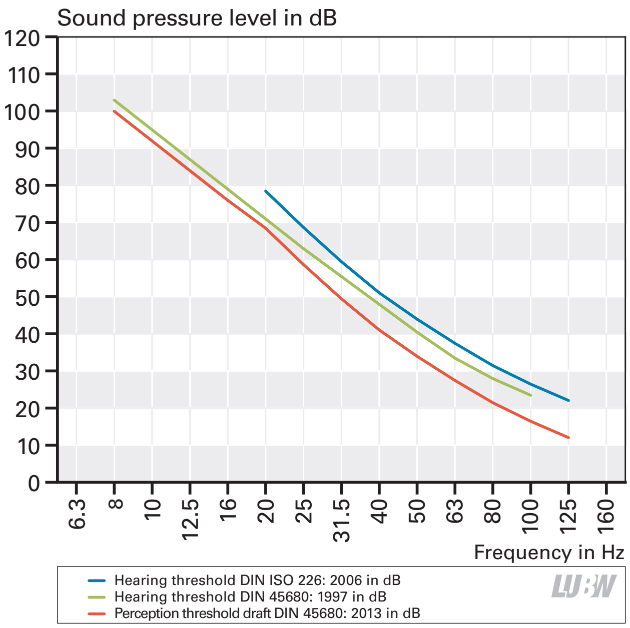

***Figure A1-2**: Representation of hearing and perception threshold according to ISO 226 [29], DIN 45680 (1997) [4] and draft DIN 45680 (2013) [5]. The perception threshold according to the draft of DIN 45680 is roughly 10 dB lower than the values of ISO 226.*

Laboratory tests on the impact of infrasound have shown that high intensities above the perception threshold are tiring and have an adverse effect on concentration, and can influence performance. The best proven reaction by the body is increasing fatigue after several hours of exposure. The balance system can also be affected. Some test persons had feelings of insecurity and anxiety, while others displayed a reduced respiratory rate. Furthermore, as is the case with audible sound, very high sound intensities can lead to a temporary hearing impediment – an effect often known by people who go to nightclubs. Long-term exposure to strong infrasound can also lead to permanent hearing loss. However, the infrasound levels that occur in the vicinity of wind power plants will hardly be able to cause any such effects, as they fall far short of the hearing or perception threshold. In scientific literature, any health effects could so far be shown only at sound levels above the hearing threshold. Below the hearing threshold, no effects on humans caused by infrasound could so far be proven [25].

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Appendix A2 – Sources and literature

[1] Windenergieerlass Baden-Württemberg – common administrative regulation of the Ministry of Environment, Climate and Energy (and other ministries) from 09.05.2012, joint official journal of the federal state of Baden-Württemberg from 30.05.2012, 2012 Edition, No. 7, pg. 413-441, Internet: um.baden-wuerttemberg.de, enter "Windenergieerlass" in the search field

[2] Law for the protection against harmful environmental impacts caused by air pollutants, noises, vibrations, and similar occurences (Bundes-Immissionsschutzgesetz – BImSchG) as amended by the notice from 17 May 2013 (BGBl. I pg. 1274) that was altered by article 1 of the law from 2 July 2013 (BGBl. I S. 1943).
Internet: http://www.gesetze-im-internet.de/bimschg

[3] Fourth Ordinance for the Implementation of the Federal Immission Protection Law (Ordinance on Installations Requiring a Permit – 4th BImSchV) from 2 may 2013 (BGBl. I pg. 973, 3756). Internet: http://www.gesetze-im-internet.de/bimschv_4_2013/BJNR097310013.html

[4] DIN 45680: Messung und Bewertung tieffrequenter Geräuschimmissionen in der Nachbarschaft (mit Beiblatt), date of issue 1997-03

[5] DIN 45680: Draft: Messung und Bewertung tieffrequenter Geräuschimmissionen (September 2013), date of issue 2013-09, with respect to perception threshold identical with draft 2011-08

[6] IEC 61400-11: Acoustic noise measurement techniques, Edition 2.1, date of issue 2006-11 – German version: DIN EN 61400-11: Windenergieanlagen – Teil 11: Schallmessverfahren, date of issue 2013-09

[7] Technische Richtlinie für Windenergieanlagen, Teil 1: Bestimmung der Schallemissionswerte, revision 18, as of 01.02.2008, editor: FGW Fördergesellschaft Windenergie und andere Erneuerbare Energien e. V.

[8] DIN 45645: Ermittlung von Beurteilungspegeln aus Messungen, Teil 1: Geräuschimmissionen in der Nachbarschaft, date of issue 1996-07

[9] ISO 7196: Acoustics – Frequency-weighting characteristic for infrasound measurements, date of issue 1995-03

[10] Technische Anleitung zum Schutz gegen Lärm – Sechste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz from 26 August 1998 (TA Lärm), GMBL 1998 Nr. 26, pg. 503-516, Internet: http://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_26081998_IG19980826.htm

[11] Møller H. & Pedersen C. S. (2004): Hearing at low and infrasonic frequencies, Noise & Health, Vol. 6, Issue 23, S. 37-57

[12] DIN 45669: Messung von Schwingungsimmissionen Teil 1: Schwingungsmesser – Anforderungen und Prüfungen, date of issue 2010-09; part 2: Messverfahren, date of issue 2005-06

[13] DIN 4150: Erschütterungen im Bauwesen, Teil 1: Einwirkungen auf Menschen in Gebäuden, date of issue 2001-06; Teil 2: Einwirkungen auf Menschen in Gebäuden, date of issue 1999-06; Teil 3: Einwirkungen auf bauliche Anlagen, date of issue 1999-02

[14] Henkemeier F. & Bunk O. (2010): Schalltechnischer Bericht Nr. 27257-1.006 über die Ermittlung und Beurteilung der anlagenbezogenen Geräuschimmissionen der Windenergieanlagen im Windpark Hohen Pritz, Mai 2010, Messungen der Fa. Kötter, im Auftrag des Landes Mecklenburg-Vorpommern, Landesamt für Umweltschutz, Naturschutz und Geologie (LUNG), Rheine, Internet: http://www.lung.mv-regierung.de/dateien/infraschall.pdf

[15] Bayerisches Landesamt für Umwelt & Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit (2014): Windkraftanlagen – beeinträchtigt Infraschall die Gesundheit?, Augsburg/Erlangen, Internet: http://www.lfu.bayern.de/umweltwissen/ doc/uw_117_windkraftanlagen_infraschall_gesundheit.pdf

[16] Bayerisches Landesamt für Umweltschutz (2000): Langzeit-Geräuschimmissionsmessung an der 1 MW-Windenergieanlage Nordex N54 in Wiggenbach bei Kempten (Bayern),

003892

Augsburg, Internet: http://www.lfu.bayern.de/laerm/messwerte/doc/windenergieanlage.pdf

[17] Møller H. & Pedersen C. S. (2010): Low-frequency noise from large wind turbines, Journal of the Acoustical Society of America, Vol. 129, No. 6, June 2011, S. 3727-3744

[18] EPA – Environment Protection Authority South Australia & Resonate Acoustics (2013): Infrasound levels near windfarms and in other environments, Adelaide, Internet: www.epa.sa.gov.au/files/477912_infrasound.pdf

[19] Borgmann R. (2005): Leitfaden Nichtionisierende Strahlung – Infraschall, Fachverband für Strahlenschutz, Garching, Internet: www.fs-ev.org

[20] Betke K. & Remmers H. (1998): Messung und Bewertung von tieffrequentem Schall, in: Deutsche Gesellschaft für Akustik (DEGA) (ed., 1998): Fortschritte der Akustik, Tagungsband der Deutschen Akustiktagung 1998, Oldenburg, Internet: http://www.itap.de/wp-content/uploads/2015/11/tieffrequent.pdf

[21] Turnbull C., Turner J. & Walsh D. (2012): Measurement and Level of Infrasound from Windfarms and other sources, Acoustics Australia, Vol. 40, No. 1, April 2012, pg. 45-50

[22] DIN EN 61672-1: Elektroakustik – Schallpegelmesser, Teil 1: Anforderungen (IEC 61672-1:2013); German version EN 61672-1:2013, date of issue 2014-07

[23] DIN EN 61260: Elektroakustik – Bandfilter für Oktaven und Bruchteile von Oktaven (IEC 61260:1995 + A1:2001); German version EN 61260:1995 + A1: 2001, date of issue 2003-03

[24] LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (2015): Windenergie und Infraschall – Tieffrequente Geräusche durch Windenergieanlagen, 6th edition October 2015, Karlsruhe, Internet: www.lubw.de/servlet/is/223628

[25] Twardella D. (2013): Importance of the expansion of wind energy for human health, in: UMID Umwelt und Mensch – Informationsdienst, pg. 14-18, Internet: www.umweltbundesamt.de/sites/default/files/medien/360/publikationen/umid_03_2013_internet_neu.pdf

[26] LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (2015): Fragen und Antworten zu Windenergie und Schall – Behauptungen und Fakten, Karlsruhe, Internet: www.lubw.de/servlet/is/255800

[27] Robert Koch-Institut (2007): Infraschall und tieffrequenter Schall – ein Thema für den umweltbezogenen Gesundheitsschutz in Deutschland?, Bundesgesundheitsblatt – Gesundheitsforschung – Gesundheitsschutz, Nr. 50, pg. 1582-1589, Internet: http://www.rki.de/DE/Content/Kommissionen/UmweltKommission/Archiv/Schall.pdf

[28] HA Hessen Agentur GmbH im Auftrag des Hessischen Ministeriums für Wirtschaft, Energie, Verkehr und Landesentwicklung (2015): Faktenpapier Windenergie und Infraschall, Internet: www.energieland.hessen.de/faktenpapier_infraschall

[29] DIN ISO 226: Akustik – Normalkurven gleicher Lautstärkepegel, date of issue 2006-04

[30] ISO 7196: Akustik – Frequenzbewertungs-Charakteristik für Infraschallmessungen, date of issue 1995-03

[31] DIN 45641: Mittelung von Schallpegeln, date of issue 1990-06

[32] Hau E. (2014): Windkraftanlagen: Grundlagen, Technik, Einsatz, Wirtschaftlichkeit, 5th edition, Berlin/Heidelberg

[33] Weinheimer J. (2014): Höhere Schallleistungspegel von Windenergieanlagen bei höherer Turbulenz?, in: Kötter Consulting Engineers (ed., 2014): Good Vibrations, Windenergie – Bauphysik – Immissionsschutz, September 2014, pg. 2/3, Internet: http://www.koetter-consulting.com/coRED/_data/149-14_gv_71_versand.pdf

[34] Watanabe T. & Møller H. (1990): Low frequency hearing thresholds in pressure field and in free field, Journal of Low Frequency Noise and Vibration, Vol. 9, No. 3 , pg. 106-115

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Appendix A3 – Explanation of terms and parameters

A-weighting

Frequency-dependent alteration of a noise or sound signal by means of A filter according to DIN EN 61672-1:2003 [22]. See also frequency weighting and dB(A).

Averaging level

See sound pressure level

Background noise

Noise with the wind power plant switched off. It consists particularly of the sound caused by wind in the vicinity and of noise coming from other sources of noise in the vicinity. The background noise may also include sound induced by the wind at the microphone. Also referred to in the report as the operating condition "turbine off".

C-weighting

Frequency-dependent alteration of a noise or sound signal by means of C filter according to DIN EN 61672-1:2003 [22]. See also frequency weighting and dB(C).

dB

Decibel, unit of measurement for the identification of levels, in this case sound pressure level (quod vide).

dB(A)

Decibel A, unit of sound pressure level in A-weighting. See also sound pressure level and A-weighting.

dB(C)

Decibel C, unit of sound pressure level in C-weighting. See also sound pressure level and C-weighting.

dB(G)

Decibel G, unit of sound pressure level in G-weighting. Is used particular with low-frequency noise incl. infrasound. See also sound pressure level and G-weighting.

dB(Z)

Decibel Z, unit of sound pressure level in Z-weighting that corresponds to the linear sound pressure level unweighted in terms of frequency. Formerly also referred to as dB(lin).

Emission

See sound emission

Extraneous noise

Noise that is not caused by the turbine being measured and can temporarily lead to an increase of background noise. Disturbing extraneous noise is excluded from the evaluation by placing markers, and is therefore included neither in the represented total noise nor in the background noise.

Frequency

Number of oscillations per second; the unit is hertz (Hz). The total audible frequency range is divided into:

- Infrasound: Sound with frequencies below 20 Hz
- Audible sound: Sound in the range of 20 Hz to about 16,000 Hz (limit is age-dependent)
- Ultrasound: Sound above roughly 16,000 Hz
- Low-frequency sound: Sound at frequencies below 100 Hz, including infrasound

Frequency weighting (noise)

The frequency content of noise is weighted differently according to the specific objective. In addition to the generally usual A-weighted and C-weighted noise levels, G-weighted and Z-weighted noise levels are also determined and represented in this study.

By default, the frequency weighting A is used for the valuation of sound signals in the normal audible sound range. It approximately constitutes the hearing sensitivity of the human ear in the low and medium sound intensity level. The description and assessment of noise emission and immissions generally follows by means of A-weighted levels. The evaluation of low-frequency noise including infrasound requires separate restrictions of the frequency ranges; A-weighted sound levels that are determined across the entire frequency band are unsuitable for this.

The frequency weighting C approximately corresponds to the auditory sensation of the ear at high volumes. It is applied in particular when assessing noise level peaks in the scope of occupational safety and health. In addition, the

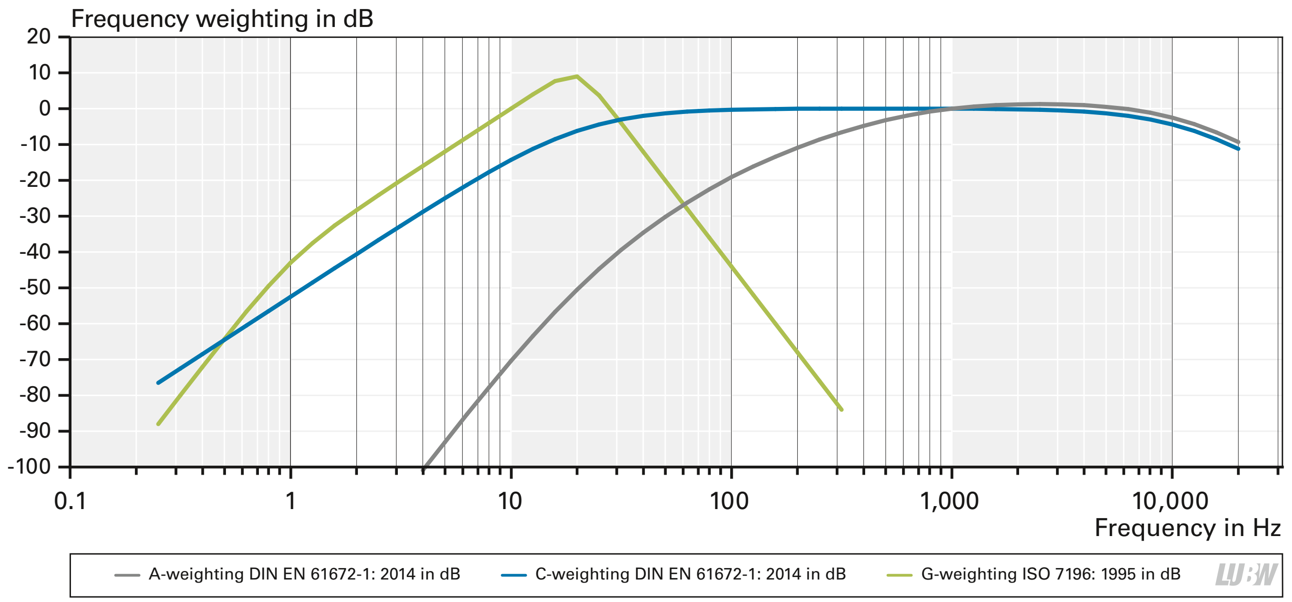

***Figure A3-1**: Course of the frequency weighting curves A, C and G in the range below 500 Hz according to ISO 7196 and DIN EN 61672-1 (2013) [22]*

level difference of measured C-weighted and A-weighted levels is seen as an indicator for possible low-frequency noise contamination in the area of immission control.

The frequency weighting G is a filter that was defined for the effect adaptation of infrasound. Its focus lies at 20 Hz (see Figure A3-1). However, no relevant reference or comparative values are known for the quantitative classification of any infrasound effects or determined G-weighted levels.

The frequency weighting Z (zero) describes a linear band pass filter without any effect on the frequency.

Frequency spectrum

See spectral analysis

G-weighting

Frequency-dependent change of noise or sound signal using G filter according to ISO 7196:1995 [30]. See frequency weighting and dB(G).

Hearing threshold

See Appendix A1.5

Immission

See sound immission

Infrasound

See Appendix A1.1

Level

Logarithm of the relationship of two identical sizes. For the sound pressure level, the ratio of sound pressure, which is caused by noise, to a fixed reference size (hearing threshold) is formed. See also sound pressure level.

L_{eq}

Energy equivalent average of the (time-varying) sound pressure level course within a reference period. See also sound pressure level.

L_{max}

Maximum sound pressure level in a measurement interval. See also sound pressure level.

Low-frequency sound

See Appendix A1.1

Narrowband spectrum

See spectral analysis

Noise

Noise can be considered unwanted, disturbing or harassing sound. While sound can be well-measured and characterized as a physical phenomenon, human feelings also play a part when it comes to noise.

Operating noise

Noise with wind turbine switched on, including background noise. Is referred to as total noise throughout the report.

Perception threshold

The perception threshold used in this report is composed of the perception threshold according to Table 2 in DIN 45680 (2013 draft) [5] and values from literature.

The values of the draft standard are based on DIN ISO 226 [29]; they are 10 dB below the hearing threshold specified therein. For frequencies of 8 Hz to 20 Hz they are supplemented by the values determined by WATANABE & MØLLER [34]. The course corresponds to the 90 % percentile of audible threshold distribution.

Since no standardized threshold levels exist in the frequency range below 8 Hz, the values of the hearing threshold proposed by MØLLER & PEDERSEN [11, Figure 10] were taken for the representations in this measurement report in the range of 1.6 Hz to 8 Hz (***Table A3-1***).

Sound

Put simply, sound consists of compressional waves. Airborne sound is the propagation of pressure fluctuations in the air as a wave motion. If this happens in solid materials, e.g. the floor or walls, it is called structure-borne sound. In order to characterize sound, variables such as sound level (characterizes the strength of the sound) or frequency (denotes the pitch) are used.

Sound emission

The noise coming from a turbine in accordance with § 3 para. 3 BImSchG [2]

Sound immission

The noise effecting humans, animals, etc. in accordance with § 3 para. 2 BImSchG [2]

Sound pressure level L

Often simply referred to as sound level. 20-fold decimal logarithm of the ratio of a given effective value of sound pressure to a reference sound pressure (e.g. hearing threshold), where the effective value of the sound pressure is determined with a standard frequency and time weighting (L in dB). Sound pressure levels of the normal range of hearing are determined primarily by the frequency weighting A and the time rating F according to DIN EN 61672-1 [22] (see also frequency weighting). The types of frequency and time weightings are usually indicated as indices of the formula sign, e.g. L_{AF} in dB(A). The definition of the sound pressure level L for a sound pressure p is:

$$L = 10 \cdot lg \frac{p^2}{p_0^2} \,(dB) = 20 \cdot lg \frac{p}{p_0} \,(dB)$$

Here p_0 is a reference sound pressure in the region of the hearing threshold, defined as $2 \cdot 10^{-5}$ Pa. Sound level differences of 1 dB are only just recognisable, differences of 3 dB can be heard clearly. Sound level differences of 10 dB correspond to roughly double or half the impression of loudness respectively.

- The addition of two identical sound levels (doubling of the sound power) leads to an increase of the sum level by 3 dB.
- The reduction of a road's traffic volume by half results in a 3 dB lower level.
- In the case of a single point source, a doubling of distance leads to a reduction of the sound level by 6 dB.

The instantaneous sound pressure level is the current level value of a time-varying noise, for example specified as $L_{AF}(t)$ in dB(A).

The maximum sound pressure level or maximum level is the maximum value of the fluctuating sound pressure level curve within a reference period, referred to as L_{max} in dB. For the frequency weighting A and the time rating F, the level is referred to as L_{AFmax} and specified in dB(A).

The average sound level or equivalent continuous sound level L_{eq} is the energy equivalent mean value of the temporally variable sound pressure level curve L(t) within a reference period, expressed in dB. It is formed according to DIN 45641 [31] or directly with a measuring instrument according to DIN EN 61672-1 [22]. For the frequency weighting A and time weighting F, the time-average sound pressure level is referred to as L_{AFeq} and expressed in dB(A).

Spectral analysis

Spectral analysis is an important tool for the analysis of acoustic signals. The signal is fragmented into defined frequency bands and a sound level is determined for each individual band. A distinction is made between frequency bands of absolute and relative bandwidth.

In the case of narrowband spectra, the frequency range that is to be analysed is divided up into bands of the same absolute width. Here in this report, a bandwidth of 0.1 Hz was consistently used. That enabled a high resolution depiction of the frequency spectra of the sound signal.

Octave and third octave spectra (1/3-octave spectra) are composed of frequency bands of relative bandwidth. The centre frequency of an octave band has a ratio of 1:2 to the centre frequency of the adjacent bands; third octave bands have a ratio of 1:1.26. The starting value for the determination of the centre frequencies is the frequency of 1,000 Hz. The frequency bandwidths within octave or third octave spectra thus differ. The third octave centre frequencies from 1 Hz are: 1 Hz, 1.25 Hz, 1.6 Hz, 2 Hz, 2.5 Hz, 3.15 Hz, 4 Hz, 5 Hz, 6.3 Hz, 8 Hz, 10 Hz, 12.5 Hz, 16 Hz, 20 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, 80 Hz, 100 Hz, 125 Hz etc. – see also [23].

Third octave representation

Representation of a sound signal in a frequency spectrum. See also spectral analysis and third octave spectrum.

Third octave level

Sound pressure level within a third octave frequency band. See also spectral analysis.

Third octave spectrum

Frequency spectrum in which the frequency range and the corresponding level proportions are divided into thirds. See also spectral analysis.

Total noise

Noise with wind turbine switched on, including background noise. Also referred to in the report as the operating condition "turbine on".

Turbulence intensity

The turbulence intensity (also known as degree of turbulence) was here formed from the average of the quotients of standard deviation and arithmetic mean of the wind speed. It is a measure of the variation of the wind speed (gusts). The turbulence intensity is given in percent and is subject to many influences, e.g. ground roughness, medium wind speed, atmospheric situation or buildings. Its lowest values (5 % or less) are reached over the sea, the highest (20 % or more) are reached over built-up areas and forest [32]. While the turbulence intensity has no significant effect on measurements in the A level range (audible sound) [33], this is not documented for low frequencies. Here an influence can by all means be expected. Some manufacturers of wind turbines link the warranty condition for their guaranteed values of acoustic power to maximum turbulence intensities during measurement, e.g. 16 %. The turbulence intensity is determined in accordance with DIN EN 61400-11 [6].

Vibrations

Vibrations are oscillations of solid bodies.

Vibrational immissions

Vibrational immissions are the oscillations that occur at the measurement point.

Vibration velocity

The vibration velocity (speed) is the velocity of an oscillating mass at the measurement point in the predetermined measurement direction, stated in millimetres per second (mm/s). This variable is based on the assessment of vibration impacts on buildings and on people in buildings. The vibration is defined initially through the ground motion, i.e. the vibration displacement (amplitude), characterized as a function of time. The vibration velocity can then be derived by differentiating with respect to time.

Table A3-1: The hearing threshold levels used to represent the perception threshold in the report according to [5] and [11]

Source	Third octave centre frequency in Hz	Perception threshold level W_{Terz} in dB
Threshold level - taken from [11]	1.60	124.0
	2.00	122.0
	2.50	120.0
	3.15	117.0
	4.00	113.0
	5.00	108.5
	6.30	105.0
Threshold level - taken from [5]	8.0	100.0
	10.0	92.0
	12.5	84.0
	16.0	76.0
	20.0	68.5
	25.0	58.7
	31.5	49.5
	40.0	41.1
	50.0	34.0
	63.0	27.5
	80.0	21.5
	100.0	16.5
	125.0	12.1

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Vibration severity

In the vibration frequency range of 1 Hz to 80 Hz that is relevant for the perception of vibration, the perceptibility is proportional to the vibration velocity. Below approximately 10 Hz, the perception at lower frequencies is significantly lower. This is taken into account for the evaluation of measurement data through the use of special filtering, the so-called KB-evaluation according to DIN 4150 Part 2. Inputs above 80 Hz are cut off by a blocking filter (band limitation) as they do not contribute to perception. The band-limited, frequency and time-weighted signal is designated as weighted vibration severity $KB_F(t)$. The highest value achieved during the assessment time, the maximum weighted vibration strength KB_{Fmax}, is an important evaluation parameter for the tactility of vibration effects.

Wavelength

For a wave (here acoustic wave), the distance from a "wave crest" to the next "wave crest" or "trough" to "trough" is referred to as wavelength (general distance from one point to the next point of the same phase). The wavelength is related to the frequency as follows: The wavelength is the propagation speed divided by the frequency of the wave. Sound waves in air can generally be registered by the human ear in the approximate wavelength range of 2 cm to about 20 m.

Z-weighting

Unweighted or linear noise or sound signal according to DIN EN 61672-1:2003 [22]. See frequency weighting and dB(Z).

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Appendix A4 – Measuring systems used

Below is a description of the used measurement systems and equipment. The sound level measuring instruments used meet the specifications for Class 1 for sound level meters according to IEC 61672. The dynamic range of the microphone capsule type 40AZ is 14 dB(A) to 148 dB according to the manufacturer, the usable frequency range is 0.5 Hz to 20 kHz. For the remaining microphone capsules used, the usable frequency range is 3.15 Hz to 20 kHz.

Measurements at wind turbines (Section 4)

- 4 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverbrant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity and temperature sensor type DTF 485, manufacturer: Reinhardt System- und Messelectronic GmbH, D-86911 Diessen-Obermühlhausen
  - Wind sensor type WMT 701, manufacturer: Vaisala GmbH, D-22607 Hamburg

- 1 acoustic emission measurement system type RoBin, manufacturer: Wölfel Meßsysteme, D-97204 Höchberg

- 4 vibration meters type SM 6 (triaxial) according to DIN 45669, consisting of:
  - Sensor Nederland / Wölfel Meßsysteme
  - Supply and AD conversion: System Red Sens with radio modules
  - Coupling of the measuring sensors according to DIN 45669-2. The measuring chain was checked before and after the measurement.

- 1 data acquisition system, consisting of:
  - Notebook Dell Latitude with Elovis radio antenna for Red Sens
  - Measurement and evaluation software MEDA
  - Sampling: upper limit frequency, 400 Hz corresponds to sampling rate of 976.6 μs, manufacturer: Wölfel Meßsysteme, D-97204 Höchberg

Road traffic measurements (Section 5.1)

- 1 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" Type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

LUBW Long-term measuring stations (Section 5.2)

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40CD, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 2 meteorology sensors, consisting of:
  - Precipitation monitor model 5.4103.10.00, manufacturer: Adolf Thies GmbH & Co. KG, D-37083 Göttingen
  - Temperature and humidity sensor type HMP 155, manufacturer: Vaisala GmbH, D-22607 Hamburg

- Ultrasonic aemometer type 85004, manufacturer: R. M. Young Company, USA-2801 Aero Park Drive

Measurements at motorway (Section 5.3)

- 3 sound level meters combinations type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Interior noise measurements car, minibus (Section 5.4)

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Urban background measurements (Section 6)

- 2 sound level meter combinations type DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB-Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combination DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB-Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

Measurements in a residential building (Section 7)

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 40AZ, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combination type NOR 140, consisting of:
  - Sound level analyser type Nor 140, manufacturer: Norsonic AS, N-3421 Lierskogen
  - Free-field microphone 1/2" type 1225, manufacturer: Norsonic AS, N-3421 Lierskogen

Measurements in rural area (Section 8.1)

- 2 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" Type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 sound level meter combinations DUO Smart Noise Monitor, consisting of:
  - Sound level analyser type DUO, manufacturer: 01dB Metravib SAS, F-69760 Limonest
  - Free-field microphone 1/2" type 40AZ on reverberant plate with primary and secondary wind screen in accordance with IEC 61400-11, manufacturer: G.R.A.S. Sound & Vibration A/S, DK-2840 Holte

- 1 meteorology sensor, consisting of:
  - Air pressure, humidity, temperature and wind sensor type WXT 520, manufacturer: Vaisala GmbH, D-22607 Hamburg

Note on the inherent noise of the measuring chain

In order to determine the minimum noise limit of the deployed acoustic measuring chain, sound level measurements were carried out inside buildings at two different locations during the night. The locations were chosen so that the least possible background noise was at hand. The measured values in the range of 1 Hz to 1 kHz are at least 20 dB below the sound levels to be determined here. The influence of the inherent noise of the measuring chain on the measurement results is therefore negligible.

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The Pattern of Complaints about Australian Wind Farms Does Not Match the Establishment and Distribution of Turbines: Support for the Psychogenic, 'Communicated Disease' Hypothesis

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Abstract

Background and Objectives: With often florid allegations about health problems arising from wind turbine exposure now widespread, nocebo effects potentially confound any future investigation of turbine health impact. Historical audits of health complaints are therefore important. We test 4 hypotheses relevant to psychogenic explanations of the variable timing and distribution of health and noise complaints about wind farms in Australia.

Setting: All Australian wind farms (51 with 1634 turbines) operating 1993–2012.

Methods: Records of complaints about noise or health from residents living near 51 Australian wind farms were obtained from all wind farm companies, and corroborated with complaints in submissions to 3 government public enquiries and news media records and court affidavits. These are expressed as proportions of estimated populations residing within 5 km of wind farms.

Results: There are large historical and geographical variations in wind farm complaints. 33/51 (64.7%) of Australian wind farms including 18/34 (52.9%) with turbine size >1 MW have never been subject to noise or health complaints. These 33 farms have an estimated 21,633 residents within 5 km and have operated complaint-free for a cumulative 267 years. Western Australia and Tasmania have seen no complaints. 129 individuals across Australia (1 in 254 residents) appear to have ever complained, with 94 (73%) being residents near 6 wind farms targeted by anti wind farm groups. The large majority 116/129(90%) of complainants made their first complaint after 2009 when anti wind farm groups began to add health concerns to their wider opposition. In the preceding years, health or noise complaints were rare despite large and small-turbine wind farms having operated for many years.

Conclusions: The reported historical and geographical variations in complaints are consistent with psychogenic hypotheses that expressed health problems are "communicated diseases" with nocebo effects likely to play an important role in the aetiology of complaints.

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Introduction

The attribution of symptoms and disease to wind turbine exposure is a contentious "modern health worry" [1] which has seen increasing attention from governments, their regulatory agencies and courts after organised opposition to wind farms, predominantly in Anglophone nations. Two broad hypotheses have been advanced about those reporting symptoms they attribute to exposure to wind turbines.

1. both audible noise and sub-audible infrasound generated by wind turbines can be directly harmful to the health of those exposed.
2. psychogenic factors – including nocebo responses to the circulation of negative information about their putative harms – are likely to be relevant to understanding why of those exposed, only small proportions claim to be adversely affected.

The evidence for a physical basis for these symptoms remains largely anecdotal. There has been a profusion of claims mostly by wind farm opponents about harms to exposed humans and animals (currently numbering 223 different diseases and symptoms) [2]. Despite this, 18 reviews of the research literature on wind turbines and health published since 2003 [3–20] have all reached the broad conclusion that the evidence for wind turbines being directly harmful to health is very poor. These suggest that only small minorities of exposed people claim to be annoyed by

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wind turbines – typically less than 10% [14]. They conclude that the relationship between wind turbines and human responses is "influenced by numerous variables, the majority of which are non-physical" [14].

Variables associated with wind turbine annoyance include pre-existing negative attitudes to wind farms [14], including their impact on landscape aesthetics [21], having a "negative personality" [22], subjective sensitivity to noise [14], and being able to see wind turbines [5,23]. Similarly, deriving income from turbines [24] or enjoying reduced power bills can have an apparent "protective effect" against annoyance and health symptoms [18]. Such factors, which are similar to characteristics of other psychogenic illnesses ("New Environmental Illnesses" [25] and "Modern Health Worries" [26]) were found to be more predictive of symptoms than objective measures of actual exposure to sound or infrasound [14].

A large literature on nocebo effects exists about reported pain [27], but these effects have also been documented for other imperceptible agents such as electro-magnetic and radio frequency radiation [28–30]. Perceived proximity to mobile telephone base stations and powerlines, lower perceived control and increased avoidance (coping) behaviour were associated with non-specific physical symptoms in a study which found no association between reported symptoms and distance to these sources of electromagnetic radiation [31].

The psychogenic theory about wind turbine "illness" is supported by a recent New Zealand study [32], in which healthy volunteers exposed to both sham and true recorded infrasound who had been previously given information about possible adverse physiological effects of infrasound exposure reported symptoms aligned with that information. The adverse effects information provided to subjects was sourced from anti wind farm internet sites which the authors concluded indicated "the potential for symptom expectations to be created outside of the laboratory, in real world settings."

A psychogenic contagion model may be applicable to this phenomenon. Mass Psychogenic Illness (MPI) is described [33–35] as a constellation of somatic symptoms, suggestive of an environmental cause or trigger (but with symptoms without typical features of the contaminant, varying between individuals, and not related to proximity or strength of exposure) which occurs between two or more people who share beliefs related to those symptoms and experience epidemic spread of symptoms between socially connected individuals. The rapid development of fear and anxiety is key to the transmission of disease by disruption of behaviour and activities of those involved. Transmission or contagion is increased by the general excitement related to the phenomenon, including media reports, researcher interest, and labeling with a specific clinical diagnostic term.

Boss' review of factors promoting mass hysteria noted that "media reports are used as cues by potential cases for appropriate illness behavior responses and can initially alarm those at risk …Too often, it is the media-created event to which people respond rather than the objective situation itself … Development of new approaches in mass communication, most recently the Internet, increase the ability to enhance outbreaks through communication." [33].

While modern wind farms have operated since the early 1980s [36], the earliest claims alleging that wind turbines might cause health problems in those exposed appear to date from 2003 (see below); this increased rapidly after 2008, following publicity given to a self-published book, "Wind Turbine Syndrome" [37], by US physician Nina Pierpont, whose partner edits a virulent anti wind farm website [38]. Google Trends data of web-based searches for "Wind turbine noise", "Wind Turbine Syndrome" and "wind turbine health" show that "noise" began to appear from 2007 and that "syndrome" and "health" began to track together from 2008, suggesting the book generated this sudden interest in the phenomenon, rather than riding a wave of interest. Furthermore, a 2007–11 Ontario study of newspaper coverage of wind farms showed that 94% of articles featured "dread" themes [39].

"Labeling" of an illness is one of the key features associated with spread of mass psychogenic illness, along with community and media interest [33]. There have been three attempts to popularise portentous quasi-scientific names for health problems said to be caused by wind turbines: Wind Turbine Syndrome, Vibro Acoustic Disease [40] and Visceral Vibratory Vestibular Disturbance [41], although none of these have gained scientific acceptance as diagnostic terms. As described earlier, many features of MPI apply to Wind Turbine Syndrome. Furthermore, the most reported symptoms in over one third of all MPIs of nausea/vomiting, headache, and dizziness [33], are also frequently featured as common symptom complaints arising with wind turbines, suggesting these symptoms may be plausibly explained as psychogenic.

Wind farm opponent groups have been very active in the last five years in three Australian states (Victoria, NSW and South Australia) publicising the alleged health impacts of turbines. This has created insurmountable problems for researching the psychogenic and nocebo hypotheses using either cross-sectional or prospective research designs because it is unlikely that any communities near wind farms now exist which have not been exposed to extensive negative information. For this reason, audits of the history of complaints are essential because they allow consideration of whether health and noise complaints arose during years prior to the "contagion" of communities with fearful messages about turbines.

To date, there has been no study of the history and distribution of noise and health complaints about wind turbines in Australia. The two theories (the "direct effects" and the "psychogenic"), would predict differing patterns of spatial and temporal spread of disease. We sought to test 4 hypotheses relevant to the psychogenic argument.

1. Many wind farms of comparable power would have no history of health or noise complaints from nearby residents (suggesting that exogenous factors to the turbines may explain the presence or absence of complaints).
2. Wind farms which have been subject to complaints would have only a small number of such complaining residents among those living near the farms (suggesting that individual or social factors may be required to explain different "susceptibility").
3. Few wind farms would have any history of complaints consistent with claims that turbines cause acute health problems (suggesting that explanations beyond turbines themselves are needed to explain why acute problems are reported).
4. Most health and noise complaints would date from after the advent of anti wind farm groups beginning to foment concerns about health (from around 2009) and that wind farms subject to organised opposition would be more likely to have histories of complaint than those not exposed to such opposition (suggesting that health concerns may reflect "communicated" anxieties).

Table 1 sets out both the predictions of the "direct effects" model of causation, and the observed findings of our historical

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Table 1. Prediction of "direct effects" model versus observations explained by psychogenic model.

Key hypotheses re distribution of complainants	Characteristic	Predictions of Direct Effects Model	Observations with Psychogenic Model
Spatial (geographic)	Distribution of wind farms with complainants	All wind farms (especially those with >1 MB turbines) should have complainants	Inconsistent distribution associated with presence or absence of anti wind farm activity
	Proportion of complainants residing around wind farms	Only in those "susceptible" but should be similar across all wind farms	Generally very low, but higher at wind farms targeted by anti wind farm groups
Temporal	Timing and latency of first complaints	Turbine exposure followed by both acute (immediate) and chronic health effects	Absence of or long delays in reporting acute effects common

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review of the distribution and timing of complaints, which are more consistent with a psychogenic model.

Methods

Information on the commencement of turbine operation, the number of turbines operating, average turbine size and the megawatt (MW) capacity of each wind farm was located from public sources such as wind farm websites.

Wind farm operators have clear risk management interest in any reactions of nearby residents to the farms they operate. In the planning, construction and power generation phases of wind farm operation they monitor local community support and complaints submitted to them, in news media and via any complaint notifications from local government. In Victoria, companies are required by law to register all complaints with the state government. In September 2012 all wind farm owners in Australia were asked to provide information on:

- the actual or estimated number of residents within a 5 km radius of each wind farm they operated. Google Maps and census data were also used to obtain this data (see below).
- whether the company had received or was aware of any health and/or noise complaints, including sleeping problems, that were being attributed to the operation of their wind farms.
- the number of individuals ("complainants") who had made such complaints (direct complaints to the companies, those voiced in local media, to local government or state or national enquiries).
- the date at which the first complaint occurred.
- whether there had been any anti wind farm activity in the local area such as public meetings addressed by opponents, demonstrations or advertising in local media.

Any documentation of complaints such as internet links or news clips about public was requested. Companies were explicitly asked to de-identify any private complaints which could identify those complaining, unless these complaints had been made public by the complainants.

It is possible that wind companies may nonetheless be unaware of some health and noise complaints about their operations or that they might downplay the extent of complaints and provide underestimates of such complaints. To corroborate the information on the number of complainants provided by the companies, we therefore reviewed all 1,594 submissions made to three government enquiries on wind farms: the 2011–2012 Senate enquiry into the Social and Economic Impact of Rural Wind Farms (1,818 submissions) [42]; the 2012 NSW Government's Draft NSW Planning Guidelines for Wind Farms (359 submissions) [43]; and the Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012 (217 submissions) [44]. We searched all submissions for any mentions by residents living in the vicinity of operating wind farms (as opposed to those being planned) of their health or sleep being adversely affected or that they were annoyed by the sound of the turbines.

We also searched daily media monitoring records supplied to the Clean Energy Council by a commercial monitoring company from August 2011 (when the monitoring contract began) until January 2013. This monitoring covered print news items, commentary and letters published in Australian national, state and regional newspapers mentioning any wind farm, as well as television and radio summaries about all mentions of wind farms. It was important to use this source of monitoring rather than use on-line databases like Factiva, as the latter do not cover all small rural news media which is where much coverage of debate about rural wind farms was likely to be found.

Finally, a pre-print of this paper was published on the University of Sydney's e-scholarship repository on March 15 2013. In the next six months the paper was opened over 10,800 times, making it the most opened document among 7761 in that repository across these 4 months. This generated considerable correspondence, and in one case (Hallett 2), information was provided about extra complainants who had complained via a legal case. These were then included.

In reviewing the submissions and media monitoring, only complaints from those claiming to be personally affected by the operation of an existing wind farm in Australia were noted. Expressed concerns about possible future adverse effects or that wind turbines *could* be harmful were not classified as evidence of personal experience of harm or annoyance. There were many of these. Third party statements, such as comments about unnamed neighbours with problems, were not accepted as evidence of harm.

Where the numbers of complainants determined from this corroborative public source searching exceeded the numbers provided to us by the wind companies, we chose the larger number. Where the numbers determined from public sources were less, we used the larger number provided by the companies. Our estimate of the number of complainants thus errs on the least conservative side. Nearly all those who publicly complained did not seek anonymity, being named in media reports or not electing to have their parliamentary submissions de-identified. However, we have chosen not to list their names in this report.

The companies provided estimates of the number of residents currently living within 5 km of each wind farm. Some companies

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Table 2. Complainant numbers at 51 Australian wind farms, 1993–2013.

Wind farm name (state) *owner*	**Installed Capacity (MW)+(number of turbines)+average turbine size MW**	**Date commenced operation & total years (to Dec 2012)**	**Approx. population within 5 km**	**Health or noise complainants (Y/N) & number (persons unless specified)**	**Date of first complaint (months since opened)**	**Local or visiting opposition group activity?**
A: Farms with total >10 MW capacity						
Albany/Grasmere (WA) *Verve*	35.4 (18) 1.96	Oct 2001 (11y 2m)	200	N	–	N
Bungendore/Capital/ Woodlawn (NSW) *Infigen*	189 (90) 2.1	Nov 2009 (3y 1m)	76 houses 198	Y:10	Dec 2009 (1 m)	Y
Canunda (SA) *International Power*	46 (23) 2.0	Mar 2005 (7y 10m)	20 houses 52	N	–	N
Cape Bridgewater (Vic) *Pacific Hydro*	58 (29) 2.0	Nov 2008 (4y 1m)	68 houses 177	Y:6	2 Feb 20110 (16m)	Y
Cape Nelson South (Vic) *Pacific Hydro*	44 (22) 2.0	Jun 2009 (3y 6m)	170 houses 425	Y:2	10 Feb 2010 (8m)	Y
Cathedral Rocks (SA) *TRUenergy, Acciona & EHN*	66 (33) 2.0	Sep 2005 (7 y 3 m)	0	N	–	N
Challicum Hills (Vic) *Pacific Hydro*	52.5 (35) 1.5	Aug 2003 (9 y 4 m)	55 houses 143	N	–	N
Clements Gap (SA) *Pacific Hydro*	56.7 (27) 2.1	Feb 2010 (2 y 10 m)	41	Y:3	On-going from earlier	Y
Codrington (Vic) *Pacific Hydro*	18.2 (14) 1.3	Jun 2001 (11 y 6 m)	50	N		N
Collgar/Merriden (WA) *Collgar*	206 (111) 1.85	May 2011 (1 y 7 m)	15	N	–	N
Cullerin Range (NSW) *Origin*	30 (15) 2.0	Jul 2009 (3 y 5 m)	50	N	–	N
Emu Downs (WA) *APA*	80 (48) 1.66	Oct 2006 (6 y 2 m)	50	N	–	N
Gunning/Walwa (NSW) *Acciona*	46.5 (31) 1.5	May 2011 (1 yr 7 m)	25 houses 65	Y:1	Jan 2012 (8 m)	N
Hallett 1/Brown Hill (SA) *AGL*	95 (45) 2.11	Sep 2008 (4 y 3 m)	120	N		Y
Hallett 2/Hallett Hill (SA) *AGL*	71.4 (34) 2.1	Mar 2010 (2 y 9 m)	120	Y:13*	On-going from earlier	Y
Hallett 4/North Brown Hill (SA) *AGL*	132 (63) 2.1	May 2011 (1 y 7 m)	200	Y:1	On-going from earlier	Y
Hallett 5/Bluff Range (SA) *AGL*	53 (25) 2.1	Mar 2012 (9 m)	140	Y:1	Apr 2012 (1 m)	Y
Lake Bonney (SA) *Infigen*	278.5 (112) 2.8	Mar 2005 (7 y 9 m)	255	Y:2	June 2012 (7 y 3 m)	N
MacArthur (Vic) *AGL/ Meridian*	420 (140) 3.0	Sep 2012 (3 m)	15	Y:8 houses = 21	2 days after 2/140 turbines commenced operation	Y
Mortons Lane (Vic) *CGN Wind Energy Ltd*	19.5 (13) 1.5	Dec 2012	14 houses 36	N	–	N
Mt Millar (SA) *Meridian*	70 (35) 2.0	Feb 2006 (6 y 10 m)	10 houses 26	N	–	N
Oaklands Hill (Vic) *AGL*	67.2 (32) 2.1	Feb 2012 (10 m)	250	Y:6	On-going from earlier	Y
Snowtown (SA) *Trust Power*	100.8 (47) 2.14	Nov 2008 (4 y 1 m)	4 houses 10	N	–	N
Starfish Hill (SA) *Ratch*	34.5 (23) 1.5	Sep 2003 (9 y 3 m)	200	N	–	N
Toora (Vic) *Ratch*	21 (12) 1.75	Jul 2002 (10 y 5 m)	674	Y:2	Early (precise date not known)	Y
Walkaway (Alinta) (WA) *Infigen*	89.1 (54) 1.65	Apr 2006 (6 y 8 m)	3 houses 8	N	–	N

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Table 2. Cont.

Wind farm name (state) ***owner***	**Installed Capacity (MW)+(number of turbines)+average turbine size MW**	**Date commenced operation & total years (to Dec 2012)**	**Approx. population within 5 km**	**Health or noise complainants (Y/N) & number (persons unless specified)**	**Date of first complaint (months since opened)**	**Local or visiting opposition group activity?**
Waterloo (SA) *TRUenergy*	111 (37) 3.0	Dec 201 (2 y)	75 houses 195	Y:11	Feb 2011 (2 m)	Y
Wattle Point (SA) *AGL Hydro*	91 (55) 1.65	Nov 2005 (7 y 1 m)	560	N	–	N
aubra (Vic) *Acciona*	192 (128) 1.5	Mar 2009 (3 y 10 m)	283 houses 736	Y:29	13 Mar 2009 (immediate)	Y
Windy Hill (Qld) *Ratch*	12 (20) 0.6	Feb 2000 (12 y 10 m)	200	Y:1	Early (precise date not known)	N
Wonthaggi (Vic) *Transfield*	12 (6) 2.0	Dec 2005 (7 y)	6900	Y:∼10	Feb 2006 (2 m)	Y
Woolnorth:Bluff Point (Tas) *Roaring 40 s & Hydro Tas.*	65 (37) 1.76	Aug 2002 (10 y 4 m)	NI	N	–	N
Woolnorth:Studland Bay (Tas) *Roaring 40 s & Hydro Tas.*	75 (25) 3.0	May 2007 (5 yr 7 m)	NI	N	–	N
34.Yambuk (Vic) *Pacific Hydro*	192 (128) 1.5	Jan 2007 (5 y 11 m)	88	N	–	N
Sub-total: 34 farms	3130.3 MW (1567 turbines)		12334	16 farms with 119 complainants		14
B: Farms with <10 MW capacity						
Blayney (NSW) *Eraring Energy*	9.9 (15) 0.66	Oct 2000 (12 y 2 m)	37	N	–	N
Bremer Bay (WA) *Verve*	0.6 (1) 0.6	Jun 2005 (7 y 6 m)	250	N	–	N
Coober Pedy (SA) *Energy Generation*	0.15 (1) 0.15	1999 (13 y)	3500	N	–	N
Coral Bay (WA) *Verve*	0.825 (3) 0.275	Oct 2006 (6 y 2 m)	200	N	–	N
Crookwell (NSW) *Union Fenosa/Eraring*	4.8 (8) 0.6	Jul 1998 (14 y 5 m)	200	Y:4	Jan 2012 (13 y 6 m)	Y
Denham (WA) *Verve*	1.6 (4) 0.4	Jun 1998 (14 y 6 m)	600	N	–	N
Esperance, 9 Mile Beach (WA) *Verve*	3.6 (6) 0.6	2003 (8 y)	50	N	–	N
Esperance, 10 Mile Lagoon (WA) *Verve*	2.025 (9) 0.225	1993 (19 y)	50	N	–	N
Hampton Park (NSW) *Wind Corp*	1.32 (2) 0.66	Sep 2001 (11 y 3 m)	150	N	–	N
Huxley Hill, King Island (Tas) *Hydro Tas*	2.458 (5) 0.49	Feb 1998 (14 y 1 m)	10 houses (26)	N	–	N
Hopetoun (WA) *Verve*	1.2 (2) 0.6	Mar 2004 (8 y 9 m)	600	N	–	N
Kalbarri (WA) *Verve*	1.6 (2) 0.8	Jul 2008 (4 y 5 m)	10	N	–	N
Kooragang, Newcastle (NSW) Energy Australia	0.6 (1) 0.6	1997 (15 y)	3–4 km from Mayfield 9000	N	–	N
Leonards Hill (Vic) *Community owned*	4.1 (2) 2.05	Jun 2011 (1 y 6 m)	232	Y:6	On-going from earlier	Y
Mt Barker (WA) *Mt Barker Power*	2.4 (3) 0.8	Mar 2011 (1 y 9 m)	2000	N	–	N
Rottnest Island (WA) *Rottnest Island*	0.6 (1) 0.6	Sep 2006 (6 y 3 m)	150	N	–	N
Thursday Island (Qld) *Egon Energy*	0.225 (2) 0.113	Aug 1997 (15 y 5 m)	2500	N	–	N

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Table 2. Cont.

Wind farm name (state) *owner*	Installed Capacity (MW)+(number of turbines)+average turbine size MW	Date commenced operation & total years (to Dec 2012)	Approx. population within 5 km	Health or noise complainants (Y/N) & number (persons unless specified)	Date of first complaint (months since opened)	Local or visiting opposition group activity?
Sub-total:17 farms	38 MW 67 turbines		20405	2 farms with 10 complainants		2
Total:51 farms	3168.3 MW 1634 turbines		32739	18 farms with 129 complainants		16

NI = no information.
*13 residents submitted affidavits in a court case but only 2 complained to the company (*AGL*), and none to the local Council or Environmental Protection Agency.
Average residents per house in 2011:2.6 http://www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/0.
doi:10.1371/journal.pone.0076584.t002

provided estimates of the number of individuals, while others provided data on the number of houses. In Table 2, we have multiplied cells showing the number of *houses* by 2.6, this being the average number of residents per household in Australia today, to give a total estimate of surrounding residents.

Results

Table 2 shows the history and distribution of complaints from all 51 Australian wind farms. Complaints came either from individuals or from households with several occupants each or collectively complaining. Some wind companies initially reported the number of complainants as *households*, while others reported individual complainant numbers. In these cases we sought clarification from companies about whether complaints came from single individuals, couples or more than two members of a family so as to report total the estimated total number of individual complainants.

Hypothesis 1: Many Wind Farms would have no History of Complaints

Of all 51 wind farms, 33 (64.7%) had never been subject to health or noise complaints, with 18 (35.3%) receiving at least one complaint since operations commenced. The 33 farms with no histories of complaints, and which today have an estimated 21,633 residents living within 5 km of their turbines, have operated for a cumulative total of 267 years.

Of the 18 wind farms which had received complaints, 16 were larger wind farms ($\geq$10 MW capacity). In summary, 18/34 (52.9%) of larger wind farms, and 15/17 (88.2%) of small farms have never experienced complaints. Wind farm opponents sometimes argue that it is mainly very large, "industrial" wind turbines which generate sufficient audible noise and infrasound to cause annoyance and health problems. If 1 MW is taken to define a "large" turbine, 18/34 (52.9%) of farms using large turbines had never attracted complaints while 15/17 (88%) of farms using smaller turbines had no histories of complaints. Both the total energy generating capacity of farms and whether the turbines used were over 1 MW were thus significant predictors of residents having ever complained, with small total capacity farms being far less likely to have complainants (88% vs 53%; $\chi^2 = 6.18$, 1 df, $p = 0.013$).

The distribution of farms which have ever received complaints is highly variable across Australia. Figure 1 shows no consistency between the percentages of farms receiving complaints in different states, whether they have many or few wind farms. Western Australia has 13 wind farms (3 with large turbines), including some of the longest running in Australia (Esperance 10 Mile Lagoon 1993, Denham 1998). No complaints have been received at any of these wind farms. Verve, which operates 8 farms in the state replied "we have never received any form of notification of health complaints in the vicinity of our wind farms." The three farms in Tasmania have also never received complaints.

Our hypothesis about many wind farms – including those with large turbines – having no history of complaints, with strong spatial (geographical) factors being associated with farms receiving complaints was thus strongly confirmed.

Hypothesis 2: There would be a Small Proportion of Complaining Residents

Nationally, a total of 129 individuals in Australia appear to have ever formally or publicly complained about wind farm noise or health problems affecting them. Of these, well over half (94 or 73%) came from residents living near just six wind farms (Waubra = 29, McArthur = 21, Hallett 2 = 13, Waterloo = 11, Capital = 10 and Wonthaggi ~10). Of the remaining farms which have experienced complaints, 9 had between 2 and 6 complainants, and 4 had only single complainants. Of 18 wind farms which had attracted complaints, 11 (72%) have had 6 or less complainants.

There are an estimated 32,789 people living within 5 km of the 50 wind farms for which we obtained residential estimates. Most (20,455 or 62%) live near the 17 smaller wind farms, while 12,334 live within 5 km of the 32 larger farms. In summary, nationally, an estimated 129 individuals have complained out of an estimated 32,789 nearby residents: a rate of about 0.4% or 1 in 254. Of the 34 wind farms with larger (>1 MW) turbines, their 124 complainants represented some 1 in 100 of the surrounding 12,366 residents. Large wind farms with relatively large surrounding rural populations and no histories of complaint include Wattle Point (560), Albany, Starfish Hill (each 200) and Challicum Hills (143).

Again, our hypothesis that the number of complainants living near those wind farms with any history of complaints would be a small proportion of the exposed population, was strongly confirmed.

Hypothesis 3: Few Wind Farms would have any History of Complaints Consistent with Claims that Turbines cause Acute Effects

Wind farm complainants describe both acute and chronic adverse effects. Acute effects are of particular interest to the psychogenic hypothesis because it is often claimed that even brief exposure to wind turbines can cause almost immediate onset of

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symptoms. For example, a recent report describes a visit to turbine-exposed houses where people become immediately affected: "The onset of adverse health effects was swift, within twenty minutes, and persisted for some time after leaving the study area" [45]. Symptoms are said to disappear when those affected move away temporarily, only to return as soon as they come back. A highly publicised Lake Bonney complainant who had hosted turbines on his previous property without complaint for six years today claims he and his wife are affected at their new address, further away, but that symptoms disappear as soon as they leave their new home for one or two days [46].

If wind turbine exposure can cause such "instant" problems, any history of delayed or non-reporting of such complaints and the absence of any reports about such complaints in the news media, months or sometimes years after various wind farms began operating creates serious coherency problems for such claims. Such delays would be incompatible with there being widespread or important "acute" effects from exposure.

Table 2 shows that first complaint timing ranged from immediately after turbines commenced operation (sometimes at only a fraction of full capacity) to many months and even many years later (eg: Crookwell, 13.5 years, Lake Bonney, over 7 years later. In five cases (Clements Gap, Hallet 2 & 4, Leonards Hill, Waubra), wind companies advised that complaints anticipating health problems were received before the farms commenced operation. Of the 51 wind farms, 33 (64.7%) have seen no complaints; 6 (11.8%) saw complaints commence at times ranging from 2 months to 13.5 years after turbine operation; and 12 (23.5%) saw either on-going complaints continue from before the wind farms commenced operation or within the first month.

Early complaints from some wind farms could be consistent with acute effects caused directly by turbine exposure but also with nocebo effects caused by anticipation of adverse effects [32]. However, gaps of months or sometimes years between the commencement of turbine operation and complaints are inconsistent with turbines causing acute effects. Moreover, if such effects were serious or common, clinical case reports would have almost certainly appeared in peer reviewed journals, given the many years that wind farms have operated in Australia. No such reports have been published.

Hypothesis 4: Most Complaints would Date from 2009 or Later, when Anti Wind Farm Groups began to Publicise Alleged Health Effects

The nocebo hypothesis would predict that the spread of negative, often emotive information would be followed by increases in complaints and that without such suggestions being spread, complaints would be less. Australia's first still operational wind farm commenced operation in 1993 at 10 Mile Lagoon near Esperance, Western Australia. However, objections to wind farms in Australia appear to date from the early years of the 2000 s when press reports mentioned negative reactions of some in rural communities to their intrusiveness in bucolic country landscapes ("behemoths" [47]), bird and bat strikes, the divisiveness engendered in communities by the perceived unfairness of some landowners being paid hosting fees of up to $15,000 per year per turbine while neighbours received none, and debates about the economics of green energy. Unguarded, frank NIMBYism "I'm quite happy to admit that this is a not-in-my-backyard thing, because my backyard is very special" was also evident in 2002 [47].

Groups explicitly opposing wind farms ostensibly because of agendas about preserving pristine bush and rural environments were active from these early years and included many branches of the Australian Landscape Guardians (for example Prom Coast (2002), Spa Country [48], Grampians-GlenThompson [49], Western Plains, Daylesford and District). Key figures in the Landscape Guardians have links with mining and fossil fuel industries [50]. Interests with overt climate change denial agendas also actively opposed wind farm developments, particularly in Victoria. Chief among these were the Australian Environment Foundation, registered in February 2005.

However, health concerns were marginal in these early oppositional years, with one early press report from September 2004 [48] noting "some objectors have done themselves few favours by playing up dubious claims about reflecting sunlight, mental health effects and stress to cattle".

An unpublished British report said to refer to data gathered in 2003 on symptoms in 36 residents near unnamed English wind farms is frequently noted by global wind turbine opponents as the first known report of health effects from wind turbines, although curiously, it does not appear to have been produced until 2007 [51]. The Daylesford and Districts Landscape Guardians referred to Harry's work in a 2007 submission opposing a wind farm at Leonards Hill [52].

In Australia, a rural doctor from Toora, Victoria, David Iser, produced another unpublished report [53] in April 2004 following his distribution of 25 questionnaires to households within 2 km of the local 12 turbine, 21 MW wind farm, which had commenced operation in October 2002. Twenty questionnaires were returned, with 12 reporting no health problems. Three reported what Iser classified as "major health problems, including sleep disturbances, stress and dizziness". Like that of Harry, Iser's report provides no details of sample selection; whether written or verbal information accompanying the delivery of the questionnaire may have primed respondents to make a connection between the wind turbines and health issues; whether those reporting effects had previous histories of the reported problems; nor whether the self-reported prevalence of these common problems were different to those which would be found in any age-matched population.

In the 10 years between the commencement of operation of the first Esperance wind farm and the end of 2003 when the Harry and Iser health impact reports [51,53] began being highlighted by turbine opposition groups, 12 more wind farms commenced operation in Australia. In that decade, besides two complainants from Toora, we aware of only one other person living near the north Queensland Windy Hill wind farm who complained of noise and later health soon after operation commenced in 2000. Importantly in that decade, five large turbined wind farms at Albany, Challicum Hills, Codrington, Starfish Hill and Woollnorth Bluff Point commenced operation but never received complaints.

With the exception of those just mentioned and Wonthaggi (~10 complainants in 2006, but none today) all other health and noise complainants (n = 116) first complained after March 2009–six years after Iser's Toora small, unpublished survey of health complaints [53] - and particularly from the most recent years when anti wind farm publicity from opposition groups focused on health has grown. Again, the nocebo and the 'communicated disease' hypotheses would predict this changed pattern and contagion of complaints, driven by increasing community concern. Sixty nine percent of wind farms began operating prior to 2009 while the majority of complaints (90%) were recorded after this date.

Responding to the nocebo hypothesis and the view that opposition groups were fomenting a 'communicated disease', the Waubra Foundation's Sarah Laurie stated: "There is also plenty of evidence that the reporting of symptoms for many residents at

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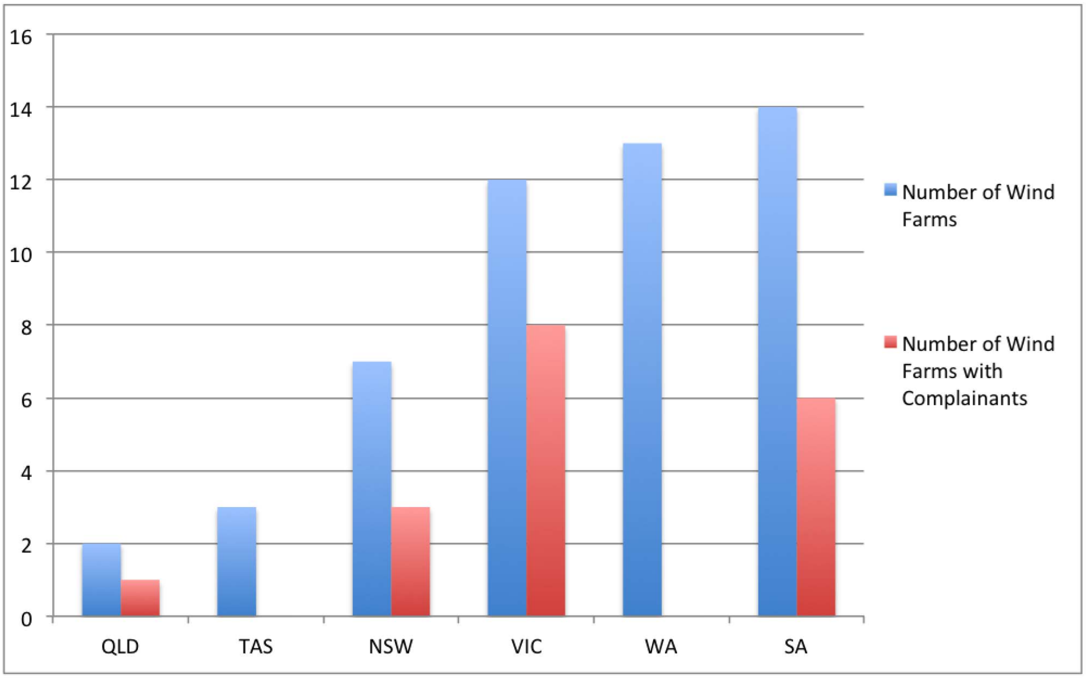

Figure 1. Farms with wind turbine complainants by state, Australia 1993–2012.
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wind developments in Victoria such as Toora, Waubra and Cape Bridgewater *preceded the establishment of the Waubra Foundation* (emphasis in original). In the case of Dr David Iser's patients at Toora the time elapsed is some 6 years." [54].

This statement neglects to note that the Waubra Foundation's registration in July 2010 was preceded by several years of virulent wind turbine opposition – which included health claims – by the Landscape Guardians and the Australian Environment Foundation. For example, in November 2009, 8 months before the formation of the Waubra Foundation the Western Plains Landscape Guardians published a full-page advertisement in the local Pyrenees Advocate newspaper headed "Coming to a house, farm or school near you? Wind Turbine Syndrome also known as Waubra Disease". It listed 12 common symptoms (e.g. sleeping problems, headaches, dizziness, concentration problems). Peter Mitchell is the founding chairman of the Waubra Foundation and in 2009 and at least until February 2011, was also actively advocating for the Landscape Guardians [55].

Table 2 shows that of the 18 wind farms which have seen complainants, 15 (83%) have experienced local opposition from anti wind farm groups. No wind farm with any history of wind turbine opposition avoided at least one health or noise complaint. We conclude that health and noise complaints were rare prior to the decision of anti wind farm groups to focus on these issues and that anti wind farm activists are likely to have played an important role in spreading concern and anxiety in all wind farms areas in which they have been active.

Discussion

This study shows there are large historical and geographical differences in the distribution of complainants to wind farms in Australia. There are many wind farms, large and small, with no histories of complaints and a small number where the large bulk of complaints have occurred. Just over half of wind farms with larger turbines have seen complaints, but nearly just as many have not. These differences invite explanations that lie beyond the turbines themselves.

Our historical audit of complaints complements recent experimental evidence [32], that is strongly consistent with the view that "wind turbine syndrome" and the seemingly boundless and sometimes bizarre range of symptoms associated with it has important psychogenic nocebo dimensions [2]. While wind turbines have operated in Australia since 1993, including farms with >1 MW turbines from 2001 (Albany and Codrington), health and noise complaints were very rare until after 2009, with the exception of Wonthaggi which saw about 10 complainants in 2006.

Several wind farm operators reported that many former complainants had now desisted. For example, Waubra management advised that not all complainants identified by our public searches had complained to them, and that more than half of the 17 complainant households who had complained to them, had had their complaints resolved. Similarly, Wonthaggi management said that none of some 10 complainants from 2006/2007 were still complaining today. Some of these former complainants from different farms had had their houses noise tested with the results showing they conformed to the relevant noise standard, some received noise mitigation (e.g. double glazing), while others simply stopped complaining.

Opponents sometimes claim that only "susceptible" individuals are adversely affected by wind turbines, using the analogy of motion sickness. Our data produce problems for that explanation: it is implausible that no susceptible people would live around any wind farm in Western Australia or Tasmania, around almost all older farms, nor around nearly half of the more recent farms. No credible hypotheses other than those implicating psycho-social factors have been advanced to explain this variability.

As anti wind farm interest groups began to stress health problems in their advocacy, and to target new wind farm developments, complaints grew. Significantly though, no older

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farms with non-complaining residents appear to have been targeted by opponents. The dominant opposition model appears to be to foment health anxiety among residents in the planning and construction phases. Health complaints can then appear soon after power generation commences. Residents are encouraged to interpret common health problems like high blood pressure and sleeping difficulties as being caused by turbines.

For example, sleeping problems are very common, with recent Australian and New Zealand estimates ranging from 34% [56], to moderately poor (26.4%) and very poor sleep quality (8.5%) [57]. A German study undertaken to obtain benchmark reference data on common symptoms and illnesses experienced in the past 7 days in the general population for comparison with those experienced by clinical trial enrollees presents data on several problems most often attributed to wind turbines. These include headache (45.3%), insomnia (25.6%), fatigue and loss of energy (19.1%), agitation (18.4%), dizziness (17%) and palpitations (8.6%) [58].

A case brought before The Ontario Environmental Review Tribunal by residents claiming to be affected by a wind farm, collapsed when the Tribunal requested that complaints supply their medical records to determine whether their complaints pre-dated the operation of the wind farm [59].

Wind farm opponents frequently argue complainants are legally "gagged" from speaking publicly about health problems, thus underestimating the true prevalence of those affected. This is said to apply to turbine hosts who are contractually gagged or to non-hosts who have reached compensation settlements with wind companies after claiming harm. The first claim is difficult to reconcile with the example provided by a high profile Lake Bonney wind farm host who continues to complain publicly without attracting any legal consequences [27]. Confidentiality clauses are routinely invoked in any legal settlement to protect parties' future negotiating positions with future complainants. They usually refer to the settlement figure rather than to the reasons for it.

We purposefully took a liberal view of what a "complainant" was, by including those who had voiced their displeasure about noise, sleep or health in news media or submissions even if they had never lodged a formal complaint with the relevant wind farm company. Despite this, the numbers complaining in Australia were very low and largely concentrated in a small number of "hotbeds" of anti wind farm activism.

A 2012 CSIRO report on nine wind farm developments in three Australian states found widespread acceptance among local residents of both operating and planned farms, and noted that: "The vocal minority are more often prominent in the media … These groups often contact local residents early in the project and share concerns about wind farms." And that "The reasons for opposition by some participants suggest that wind farms proposals are triggering a range of underlying cultural or ideological concerns which are unlikely to be addressed or resolved for a specific wind farm development. These underlying issues include pre-existing concerns that rural communities are politically neglected by urban centres, commitment to an anti-development stance, and opposition to a 'green' or 'climate action' political agenda." [60].

Limitations

The data we obtained on the number of individuals or occupied houses near the farms were current estimates. These numbers may have varied in different directions for different farms over the 20 year period that wind farms have operated in Australia. But no data are available on that variation. Our estimates of the ratios of complaints to population are therefore unavoidably fixed around the most current population estimates. They would include children who do not lodge complaints, but who are often mentioned by wind farm opponents as subject to health effects [2].

It is possible that there were other complainants who complained earlier than in the periods covered by our corroborative checks. However, this seems highly unlikely: Australian anti wind farm groups would have strong interests in widely publicising such complainants, had they existed. The Waubra Foundation for example, repeatedly refers to the 2004 Iser report [53], in its efforts to emphasise that health concerns had been raised before the Waubra Foundation became established [54] As wind farm opponents have not highlighted more complainants than we have identified, this strongly suggests there were no earlier health or noise complainants.

It is also possible that some of the health complainants are disingenuous, thereby inflating the true number of people actually claiming to experience turbine-related health problems when their objections may be only aesthetic. Controversy arose when an anti wind farm activist who lives 17 km from the Waterloo wind farm was recently accused of "coaching" residents who disliked the local wind farm to explicitly mention health issues [61].

We selected the 5 km distance from turbines as a compromise between the 2 km minimum setback distance designated by the Victorian government for future wind farm approvals, and the 10 km often named by the Waubra Foundation as the advisable minimum distance. We also note here, that one prominent critic of wind farms claims to to be able to personally sense low frequency noise up to 100 km away from wind turbines under certain conditions [62]. Had we chosen the 10 km distance counseled by the Waubra Foundation, this would have significantly increased the numbers of people exposed but not complaining.

The estimates provided by the wind companies of the number of residents within 5 km of wind farms need to be seen as approximations. Census data is available by local government areas and by the Australian Bureau of Statistics statistical regions. However, these do not correspond with the 5 km zone of residence of interest here. The wind companies which provided this data obtained it from their own knowledge of the number of residences near their wind farms and we checked local township sizes from Australian census data. This information is typically obtained during the planning stages of wind farm development when development applications often require such estimations to be provided. At least one company used Google Earth photography to calculate their estimate of the number if dwellings. However, such estimates will always be imprecise and approximations only. They nonetheless provide "ballpark" denominators against which the known number of complainants can be compared.

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Author Contributions

Analyzed the data: SC AStG KW VC. Wrote the paper: SC AStG KW VC. Conceived of study: SC. Collected data: SC AStG KW VC. Contributed to writing: SC AStG KW VC.

References

1. Petrie KJ, Sivertsen B, Hysing M, Broadbent E, Moss-Morris R, et al. (2001) Thoroughly modern worries: the relationship of worries about modernity to reported symptoms, health and medical care utilization. J Psychosom Res 51: 395–401.
2. Chapman S (2013) Symptoms, diseases and aberrant behaviours attributed to wind turbine exposure. Available: http://tobacco.health.usyd.edu.au/assets/pdfs/publications/WindfarmDiseases.pdf. Accessed 2013 Jun 19.
3. Pedersen E, Halmstad HI (2003) Noise annoyance from wind turbines - a review. Swedish Environmental Protection Agency. Report 5308. Available: http://www.naturvardsverket.se/Documents/publikationer/620-5308-6.pdf. Accessed 2012 Jul 20.
4. Leventhall G (2004) Low frequency noise and annoyance. Noise & Health 6: 59–72.
5. Chatham-Kent Public Health Unit, Ontario (2008) The health impact of wind turbines: a review of the current white, grey and published literature. Available: http://www.wind-works.org/cms/fileadmin/user_upload/Files/Health_and_Wind_by_C-K_Health_Unit.pdf. Accessed 2013 Mar 19.
6. Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, et al. (2009) Wind turbine sound and health effects. An expert panel review. Prepared for: American Wind Energy Association and Canadian Wind Energy Association Available: http://www.tuulivoimayhdistys.fi/sites/www.tuulivoimayhdistys.fi/files/wind_turbine_sound_and_health_effects.pdf. Accessed 2012 May 2.
7. Minnesota Department of Health, Environmental Division (2009) Public Health Impacts of Wind Turbines. Available: www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf. Accessed 2012 Jul 20.
8. Chief Medical Officer of Health (CMOH) Report Ontario (2010) The potential health impact of wind turbines. Available: http://www.health.gov.on.ca/en/common/ministry/publications/reports/wind_turbine/wind_turbine.pdf. Accessed 2012 May 2.
9. Hanson M.A. Advisory Group on Non-inoising Radiation (2010) Health effects of exposure to ultrasound and infrasound. Report of the independent advisory group on non-ionising radiation. Available: www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1265028759369. Accessed 2012 Apr 15.
10. Health Protection Agency. A report by the Ad Hoc Expert Group on Noise and Health (2010) Environmental Noise and Health in the United Kingdom. Available: http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1279888026747. Accessed 2012 Aug 20.
11. National Health and Medical Research Council (2010) Wind turbines and health. A rapid review of the evidence. Available: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/new0048_evidence_review_wind_turbines_and_health.pdf. Accessed 2012 Jun 14.
12. Bolin K, Bluhm G, Eriksson G, Nilsson ME (2011) Infrasound and low frequency noise from wind turbines: exposure and health effects. Environmental Research Letters Vol 6. Available http://iopscience.iop.org/1748-9326/6/3/035103/.
13. Fiumicelli D (2011) Windfarm noise dose-response: a literature review. Acoustics Bulletin: 26–34.
14. Knopper LD, Ollson CA (2011) Health effects and wind turbines: A review of the literature. Environmental Health Vol 10.Available http://www.ehjournal.net/content/10/1/78.
15. Ellenbogen JM, Grace S, Heiger-Bernays WJ, Manwell JF, Mills DA, et al. (2012) Wind Turbine Health Impact Study. Report of Independent Expert Panel. Prepared for: Massachusetts Department of Environmental Protection. Massachusetts Department of Health. Available: http://www.mass.gov/dep/energy/wind/turbine_impact_study.pdf. Accessed 2012 May 2.
16. Jakobsen J (2005) Infrasound emission from wind turbines. J Low Freq Noise Vibration Active Control 24: 145–155.
17. National Research Council (USA) (2007) Impact of wind energy development on humans (Chapter 4: pp97–120) of: Environmental Impacts of Wind-Energy Projects. Available: http://www.vawind.org/assets/nrc/nrc_wind_report_050307.pdf Accessed 2012 Jul 20.
18. Massachusetts Department of Environmental Protection (2012) Wind Turbine Health Impact Study: Report of Independent Expert Panel. Available: http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf. Accessed 2013 Mar 8.
19. Health Impact Assessment Program, Research and Education Services, Office of Environmental Public Health, Public Health Division, Oregon Health Authority (2012) Strategic health impact assessment on wind energy development in Oregon. Available: http://public.health.oregon.gov/HealthyEnvironments/TrackingAssessment/HealthImpactAssessment/Documents/Wnd%20Energy%20HIA/Wind%20HIA_Final.pdf. Accessed 2013 Mar 8.
20. Department of Health, Government of Victoria (2013) Wind farms, sound and health. Technical information. Available: http://docs.health.vic.gov.au/docs/doc/5593AE74A5B486F2CA257B5E0014E33C/$FILE/Wind%20farms,%20sound%20and%20%20health%20-%20Technical%20information%20WEB.pdf. Accessed 2013 May 2.
21. Johansson M, Laike T (2007) Intention to respond to local wind turbines: the role of attitudes and visual perception. Wind Energy 10: 435–451.
22. Taylor J, Eastwick C, Wilson R, C L (2013) The influence of negative oriented personality traits on the effrect of wind turbine noise. Pers Indiv Differ 54: 338–343.
23. Pedersen E, Waye K (2007) Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med 64: 480–486.
24. Pedersen E, van den Berg F, Bakker R, Bouma J (2009) Response to noise from modern wind farms in The Netherlands. J Acoust Soc Am 126: 634–643.
25. Henningsen P, Priebe S (2003) New environmental illnesses: what are their characteristics? Psychother Psychosom 72: 231–234.
26. Petrie KJ, Wessely S (2002) Modern worries, new technology, and medicine. BMJ, 324: 690–691.
27. Tracey I (2010) Getting the pain you expect: mechanisms of placebo, nocebo and reappraisal effects in humans. Nat Med 16: 1277–1283.
28. Stovner LJ, Oftedal G, Straume A, Johnsson A (2008) Nocebo as headache trigger: evidence from a sham-controlled provocation study with RF fields. Acta Neurol Scand Suppl 188: 67–71.
29. Danker-Hopfe H, Dorn H, Bornkessel C, C. S (2010) Do mobile phone base stations affect sleep of residents? Results from an experimental double-blind sham-controlled field study. Am J Hum Biol 22: 613–618.
30. Witthoft M, Rubin GJ (2013) Are media warnings about the adverse health effects of modern life self-fulfilling? An experimental study on idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF). J Psychosom Res 74: 206–212.
31. Baliatsas C, van Kamp I, Kelfkens G, Schipper M, Bolte J, et al. (2011) Non-specific physical symptoms in relation to actual and perceived proximity to mobile phone base stations and powerlines. BMC Pub Health 11: 421.
32. Crichton F, Dodd G, Schmid G, Gamble G, Petrie K (2013) Expectations and wind turbine symptoms. Health Psychol doi: 10.1037/a0031760.
33. Boss LP (1997) Epidemic hysteria: a review of the published literature. Epidemiol Rev 19: 233–243.
34. Page LA, Keshishian C, Leonardi G, Murray V, Rubin GJ, et al. (2010) Frequency and predictors of mass psychogenic illness. Epidemiol 21: 744–747.
35. Balaratnasingam S, Janca A (2006) Mass hysteria revisited. Current Opinion in Psychiatry 19: 171–174.
36. Wikipedia History of wind power. Available: http://en.wikipedia.org/wiki/History_of_wind_power. Accessed 2013 Mar 4.
37. Pierpont N (2009) Wind Turbine Syndrome. A report on a natural experiment. Available: http://www.windturbinesyndrome.com/. Accessed 2012 Jun 14.
38. Pierpont N What is wind turbine syndrome? Available: http://www.windturbinesyndrome.com/wind-turbine-syndrome/what-is-wind-turbine-syndrome/]. Accessed 2013 Mar 4.
39. Deignan B, Harvey E, Hoffman-Goetz L (2013) Fright factors about wind turbines and health in Ontario newspapers before and after the Green Energy Act. Health, Risk & Society. DOI:10.1080/13698575.2013.776015.
40. Chapman S, St George A (2013) How the factoid of wind turbines causing "vibroacoustic disease" came to be "irrefutably demonstrated". ANZJPH 33: 244–249.
41. Pagano M. Are wind farms health risks? US scientist identifies "wind turbine syndrome". The Independent. 2009 Aug 2 http://www.independent.co.uk/environment/green-living/are-wind-farms-a-health-risk-us-scientist-identifies-wind-turbine-syndrome-1766254.html. Accessed.
42. Parliament of Australia, Senate Standing Committees on Community Affairs (2012) The Social and Economic Impact of Rural Wind Farms. Available: http://www.aph.gov.au/Parliamentary_Business/Committees/Senate_Committees?url = clac_ctte/completed_inquiries/2010-13/impact_rural_wind_farms/submissions.htm. Accessed 2013 Mar 13.
43. NSW Government Planning and Infrastructure (2012; March 14) Draft NSW Planning Guidelines: Wind Farms. Submissions. Available: http://www.planning.nsw.gov.au/Development/Onexhibition/tabid/205/ctl/View/mid/1081/ID/66/language/en-US/Default.aspx. Accessed 2013 Feb 21.
44. Parliament of Australia Senate (2012) Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012. Available: http://www.aph.gov.au/Parliamentary_Business/Committees/Senate_Committees?url = ec_ctte/completed_inquiries/2010-13/renewable_energy_2012/submissions.htm. Accessed 2013 Mar 13.
45. Ambrose S, Rand R. The Bruce McPherson Infrasound and Low Frequency Noise Study. Available: http://docs.wind-watch.org/BruceMcPhersonInfrasoundandLowFrequencyNoiseStudy.pdf. Accessed 2011 Dec 14.
46. Anon (2013) Health issues raised in windfarm debate. Available: http://www.borderwatch.com.au/story/262103/health-issues-raised-in-windfarm-debate/. Accessed 2013 Mar 11.
47. Fyfe M (2002) Turbines spark coastal controversy (The Age). Available: http://www.dioxides.com.au/dioxides-articles/2002/7/8/turbines-spark-coastal-controversy/. Accessed 2012 May 14.
48. van Tiggelen J. An ill wind blowing. Sydney Morning Herald - Good Weekend. 2004 Sept 4 http://web.archive.org/web/20130429182528/http://spacountryguardians.org.au/display.php?newpageid = 78. Accessed 2012.
49. Parliament of Victoria (2009) Environment and Natural Resources Committee. Inquiry into the appeals process for renewabale energy projects. Available: http://www.parliament.vic.gov.au/images/stories/committees/enrc/renewable_energy/transcripts_of_evidence/Grampians-Glenthompson_Landscape_Guardians_Inc.pdf. Accessed 2013 Mar 5.

50. Keane S (2011) The ugly landscape of the Guardians. Available: http://www.independentaustralia.net/2011/environment/the-ugly-landscape-of-the-guardians/. Accessed 2012 Jun 14.
51. Harry A (2007) Wind turbines, noise and health. Available: http://www.wind-watch.org/documents/wind-turbines-noise-and-health Accessed 2012 Apr 15.
52. Wild C (2007) Leonards Hill residents and objectors in opposition to planning permits. Submission to VCAT Application 2006/231.
53. Iser D (2004) Report to Council. Available: http://docs.wind-watch.org/Dr.-Iser-Submission-to-NHMRC.pdf. Accessed 2012 May 2.
54. Laurie S (2013) Statement of Dr Sarah Elisabeth Laurie, CEO Waubra Foundation. Planning and Environment List No 2910 of 2012 between Cherry Tree Wind Farm Pty Ltd (Applicant) and Mitchell Shire Council (First Respondent) and Trawool Valley Whiteheads Creek Landscape Guardians Inc (Second Respondent) and Ors. Available: http://docs.wind-watch.org/Cherry-Tree-VCAT-Sarah-Laurie.pdf. Accessed 2013 Mar 8.
55. Mitchell P (2011) Will somebody listen please? Submission to the Senate Community Affairs Committee Inquiry.The Social and Economic Impact of Rural Wind Farms. Available: https://senate.aph.gov.au/submissions/comittees/viewdocument.aspx?id = 8bc7dfd2-a9f3-4572-a078-a705bcbd8fc5. Accessed 2013 Mar 8.
56. Wilsmore BR, Grunstein RR, Fransen M, Woodward M, Norton R, et al. (2012) Sleep, blood pressure and obesity in 22,389 New Zealanders. Intern Med J 42: 634–641.
57. Soltani M, Haytabakhsh MR, Najman JM, Williams GM, O'Callaghan MJ, et al. (2012) Sleepless nights: the effect of socioeconomic status, physical activity, and lifestyle factors on sleep quality in a large cohort of Australian women. Arch Womens Ment Health 15: 237–247.
58. Rief W, Barsky AJ, Glombiewski JA, Nestoriuc Y, Glaesmer H, et al. (2011) Assessing general side effects in clinical trials: reference data from the general population. Pharmacoepidemiol Drug Saf 20: 405–415.
59. Ontario Environmental Review Tribunal (2012) Middlesex-Lambton Wind Action Group Inc v Director, Ministry of the Environment. Available: http://www.ert.gov.on.ca/files/201202/00000300-BKF5BC0DDLO026-CBT55E313IO026.pdf. Accessed 2013 Mar 26.
60. CSIRO (2012) Exploring community acceptance of rural wind farms in Australia: a snapshot. Available: http://www.csiro.au/en/Organisation-Structure/Flagships/Energy-Flagship/Exploring-community-acceptance-of-rural-wind-farms-in-Australia.aspx. Accessed 2013 Mar 27.
61. Swallow J. Green groups cry foul over email to generate "fake" complaints against Waterloo wind farm in South Australia. Adelaide Now. 2012 Jun 12 http://www.adelaidenow.com.au/business/sa-business-journal/green-groups-cry-foul-over-email-to-generate-fake-complaints-against-waterloo-wind-farm-in-south-australia/story-e6fredel-1226489395372. Accessed 2013 May 13.
62. Papadopoulos G (2012) Wind turbines and low frequency noise: implications for human health Available: https://www.wind-watch.org/documents/wind-turbines-and-low-frequency-noise-implications-for-human-health/.Accessed 2013 Mar 14.

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION BY CROWNED RIDGE WIND, LLC FOR A PERMIT OF A WIND ENERGY FACILITY IN GRANT AND CODINGTON COUNTIES	)))))	EL19-003 **CERTIFICATE OF SERVICE**

I hereby certify that true and correct copies of Chris Ollson's Rebuttal testimony and attachments in this matter were served electronically to the parties listed below on the 24th day of May, 2019, addressed to:

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