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Abstract

Some individuals have reported various symptoms that they have intuitively associated with infrasound from wind turbines. Scientific evidence on the potential association or studies focusing directly on the health effects of wind turbine infrasound are lacking. This research project aimed at assessing whether wind turbine infrasound has harmful effects on human health. A questionnaire study, sound measurements, and provocation experiments were conducted. In the questionnaire study, symptoms intuitively associated with wind turbine infrasound were relatively common within 2.5 km from the closest wind turbine and symptom spectrum was broad. Many of the symptomatic respondents associated their symptoms also with vibration or electromagnetic field from wind turbines. In measurements, infrasound levels were similar to the levels occurring typically in urban environments. The captured sound samples with the highest infrasound levels and amplitude modulation values were used in the double blinded provocation experiments. The participants who had previously reported wind turbine infrasound related symptoms were not able to perceive infrasound in the noise samples and did not find samples with infrasound more annoying than those without previous wind turbine infrasound related symptoms. Further, wind turbine infrasound exposure did not cause physiological responses in either participant group.

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Tiivistelmä

Jotkut henkilöt ovat raportoineet monenlaisia oireita, jotka he ovat itse yhdistäneet tuulivoimaloiden infraääneen. Mahdollisesta yhteydestä ei ole tieteellistä näyttöä eikä aiemmissa tutkimuksissa ole selvitetty nimenomaan tuulivoimaloiden infraäänen terveysvaikutuksia. Tämän tutkimusprojektin tavoitteena oli arvioida, onko tuulivoimaloiden infraäänellä haitallisia vaikutuksia ihmisten terveyteen. Projektissa tehtiin kyselytutkimus, äänimittauksia ja altistuskokeita. Kyselytutkimuksessa tuulivoimaloiden infraääneen yhdistetyt oireet olivat melko yleisiä 2,5 kilometrin säteellä lähimmästä tuuliturbiinista ja oireiden kirjo oli hyvin laaja. Moni oireilevista liitti oireitaan myös tuulivoimaloiden aiheuttamaan tärinään ja sähkömagneettiseen kenttään. Melumittauksissa infraäänitasot olivat samaa suuruusluokkaa kuin tyypillisesti kaupunkiympäristöissä. Mittauksissa nauhoitettuja eniten infraääntä ja amplitudimodulaatiota sisältäviä ääninäytteitä käytettiin kaksoissokkoutetuissa altistuskokeissa. Henkilöt, jotka olivat ilmoittaneet saavansa oireita tuulivoimaloiden infraäänestä, eivät havainneet infraääntä ääninäytteissä eivätkä kokeneet infraääntä sisältäviä näytteitä häiritsevämpinä kuin henkilöt, jotka eivät olleet saaneet aiemmin oireita tuulivoimaloiden infraäänestä. Infraäänialtistus ei aiheuttanut fysiologisia vasteita kummassakaan ryhmässä.

Tämä julkaisu on toteutettu osana valtioneuvoston selvitys- ja tutkimussuunnitelman toimeenpanoa (tietokayttoon.fi). Julkaisun sisällöstä vastaavat tiedon tuottajat, eikä tekstisisältö välttämättä edusta valtioneuvoston näkemystä.

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Referat

Vissa individer har rapporterat olika symptom som de intuitivt har förknippat med infraljud från vindturbiner. Att infraljud eventuellt skulle vara förenat med symptom saknas det vetenskapliga bevis på eller studier som fokuserar direkt på hälsoeffekterna av infraljud från vindturbiner. Detta forskningsprojekt syftade till att bedöma om infraljud från vindturbiner har skadliga effekter på människors hälsa. En enkätundersökning, ljudmätningar och provokationstest genomfördes. I enkätundersökningen var symtom intuitivt associerade med infraljud från vindturbiner relativt vanliga inom 2,5 km från närmaste vindturbin och symptomspektrumet var brett. Många av de symtomatiska respondenterna associerade sina symptom också med vibrationer eller elektromagnetiskt fält från vindturbiner. Vid mätningar liknade infraljudnivåer de nivåer som vanligtvis förekom i stadsmiljöer. De lagrade ljudsampler med de högsta infraljudnivåerna och amplitudmoduleringsvärdena användes i dubbelblindade provokationsexperiment. Personer som tidigare hade rapporterat att de hade fått infraljudsrelaterad symptom från vindturbiner, kunde inte uppfatta infraljud i bullerproverna och fann inte prover med infraljud mer irriterande än personer som inte tidigare hade rapporterat infraljudsrelaterad symptom från vindturbiner. Vidare orsakade infraljudsexponering av vindturbin inte fysiologiska svar i någon av deltagargrupperna

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Contents

Preface

This report describes the implementation and results of the research project Wind Turbine Sound, Its Physiological Effects, Annoyance, and Association with Diseases based on the government report on the National Energy and Climate Strategy for 2030 and commissioned by the Government's analysis, assessment and research activities, VN TEAS. The aim of the research project was to find out whether wind turbine infrasound has harmful effects on human health.

The project was conducted as multidisciplinary research by VTT Technical Research Centre of Finland Ltd. (VTT, coordinator), Finnish Institute for Occupational Health (FIOH), University of Helsinki (UH), and Finnish Institute for Health and Welfare (THL) from August 2018 to May 2020. THL conducted a questionnaire study in the vicinity of wind power areas, VTT and THL performed a noise measurement campaign, and VTT, FIOH, and UH designed and carried out the experiments exploring perception, annoyance and psychophysiological effects in relation to wind turbine infrasound.

Above all, the authors want to thank the participants of the questionnaire study, the telephone interview and the laboratory experiments as well as the study nurses Nina Lapveteläinen and Riitta Velin for their invaluable help. Wind power operators EPV Tuulivoima Oy, Puhuri and Ilmatar are thanked for providing operational data for the noise measurements, and Finnish municipalities and municipal federations, Suomen Tuulivoimayhdistys ry and Tuulivoima-kansanlaisyhdistys ry for providing help in the selection of wind power areas for the questionnaire study. Finally, the authors want to thank Marko Antila, Jari Kataja, Tomi Passi, Sanna Mylläri, Kati Pettersson, Lauri Ahonen, Arja Uusitalo, Tuula Riihimäki, assisting personnel from FIOH, and the steering group members Vesa Pekkola (chair), Saara Leppinen (secretary), Susanna Ahlström, Antti Hautaniemi, Sanna Jylhä, Anja Liukko, and Ari Saarinen for their collaboration.

Helsinki, Kuopio, and Kangasala, June 2020

Authors

1 Introduction

Wind energy is one of the fastest growing forms of renewable energy worldwide. Finland has a short history in industrial scale wind power production and thus, approximately 80% of installed turbines have large nominal capacity (3–4 MW) and the hub height is typically more than 100 m. Wind turbines are known to produce broadband aerodynamic sound containing also low frequencies and infrasound. In general, audible wind turbine sound (WTS) is considered more annoying than many other environmental noise sources[1].

Annoyance and sleep disturbance are the most common and studied effects of any audible broadband noise in living environments. Regarding wind turbine sound, the World Health Organization (WHO) has concluded that the evidence for the association between audible wind turbine sound and annoyance is moderate but the dose-response function is yet to be established, and the evidence for sleep disturbance is limited. Apart from annoyance and sleep disturbance, there is no evidence for other health effects.[2] After the WHO report, the health effects of broadband wind turbine sound have been studied in two large research projects in Canada[3–5] and Denmark[6–9]. In these studies, the proximity of wind turbines or modeled wind turbine sound pressure level were not associated with symptoms or diseases. Instead, annoyance due to wind turbine audible sound, lights, and shadow flicker where associated with negative health effects[10]. It is also generally accepted that many non-acoustic personal and contextual factors such as attitudes, risk perceptions, visual aspects, economic interests, and trust on authorities are associated with wind turbine noise annoyance[11].

Instead of audible sound, public discussion has recently focused on exposure to infrasound from wind turbines. In many countries, some individuals living in the vicinity of wind power plants have reported various non-specific symptoms such as headache and other aches, dizziness, nausea, fatigue, ear pressure sensations, tinnitus, and cardiovascular symptoms (e.g., high blood pressure, arrhythmia), and have intuitively linked their symptoms with wind turbines, especially wind turbine infrasound.

In Finland, the government report on the National Energy and Climate Strategy for 2030 stated in 2017 that the Finnish Ministry of Economic Affairs and Employment will commission an independent and comprehensive report on the negative health and environmental impacts of wind power before the act on the operating aid scheme is drafted. As the first phase of the research project an extensive review on scientific literature[12] was conducted. The main conclusion was that there is currently no scientific evidence that infrasound from wind turbines could cause the reported symptoms but due to a small amount of studies, the possibility of negative health effects cannot be ruled out and additional studies are justified. This second phase of the project was conducted as multidisciplinary research by VTT Technical Research Centre of Finland Ltd., Finnish Institute for Occupational Health, University of Helsinki, and Finnish Institute for Health and Welfare.

1.1 Review of the Literature

1.1.1 Characteristics of WTS

Wind turbine sound has several special characteristics. Firstly, it can propagate freely since it is generated at higher altitudes than surrounding obstacles. Wind turbine sound includes low frequency (20–200 Hz) and infrasound (below 20 Hz) waves which have practically zero attenuation due to atmospheric absorption and the natural or built structures have much lower effect on their path when compared to waves at higher frequencies. In practice, only the attenuation mechanism concerning the lowest frequencies of infrasound is the geometrical spreading of sound energy. Secondly, it is not abated at night similarly than traffic noise. Thirdly, the noise emission from a wind turbine mainly depends on wind conditions if the effect of ice accumulation is ignored. Under similar weather conditions, the emission remains the same regardless of the time of year. The farther away from the wind turbine the noise levels are examined, the more impact environmental conditions and other sounds will have and the variation is greater[13]. In addition, the sound is regularly variating/intermittent originating from blade rotation and typically described as distinctive swishing or thumping sound.

1.1.2 Perception of Wind Turbine Infrasound in Experimental Studies

The present understanding is that infrasound could have health effects only if the sound pressure level is high, i.e., above hearing threshold. The sensitivity of the human ear is very poor in the infrasound range, but still it is possible to measure detection thresholds for frequencies below 20 Hz[14,15]. Among individuals with normal hearing organ, the standard deviation of the hearing threshold is around 5 dB[16].

Some experimental data exist for infrasound hearing thresholds.[17] The numerical values shown in Table 1.1 were obtained for a small number of otologically normal, young people down to 4 Hz.[18] No experimental data exist for frequencies below that, but if estimated based on the Watanabe and Møller data, at 1 Hz, which is the dominant infrasound frequency from wind turbines, shape-preserving piecewise cubic extrapolation gives 114 dB and piecewise cubic spline extrapolation gives 125 dB (see Fig. 1.1). However, it can not be excluded that some people could perceive wind turbine infrasound even at lower sound pressure levels than this estimate.

Table 1.1: Hearing threshold levels for the low frequency and infrasonic range[18]

Frequency, Hz	4	8	10	12.5	16	20	25	31.5	40	50	63	80	100
Level, dB	107	100	97	92	88	79	69	60	51	44	38	32	27

The authors are aware of only two studies which have measured perception of wind turbine infrasound. These studies used actual recordings from wind turbines, low-pass filtering the audible parts of the spectrum. Firstly, Yokoyama et al.[20] found that detection thresholds were very similar to previously measured thresholds for single infrasound frequencies. Thus, very high intensity levels were required before the infrasound components could be detected. In addition, they found that infrasound had almost no effect to loudness perception.

Nguyen et al.[21] measured the audibility of infrasound in wind turbine sound using signal detection theory measures (d'). They used 10-second samples at a G frequency weighted sound pressure level L_G = 48 dB, which is below the normal hearing threshold, with and without amplitude modulation (AM) components. Detectability was above chance only in participants scoring higher

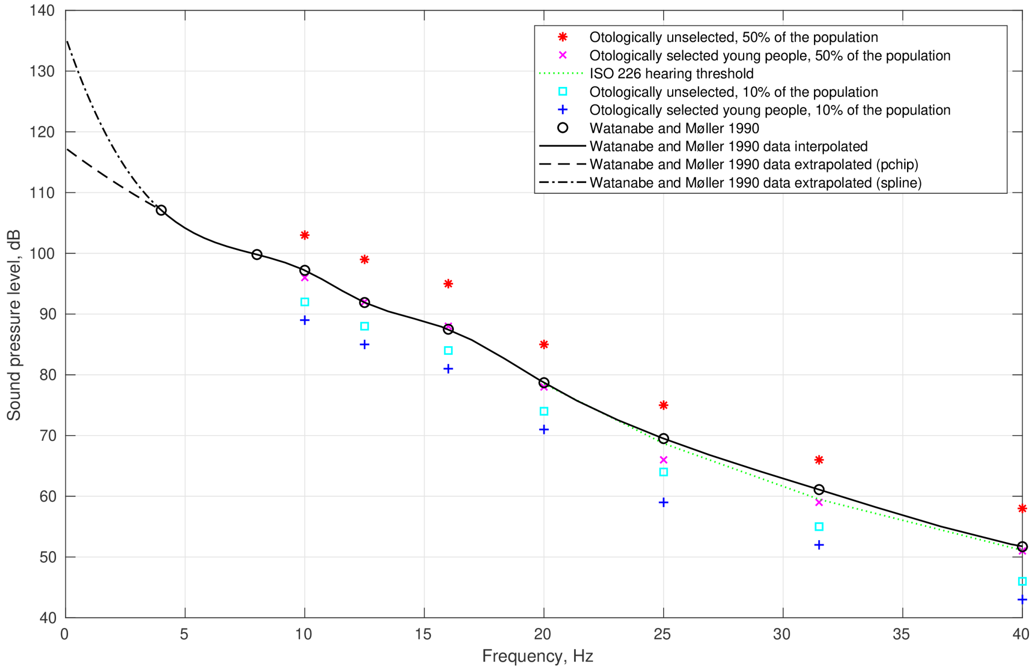


Figure 1.1: Hearing thresholds at very low frequencies adapted from several sources[17–19].

on the Weinstein Noise Sensitivity Scale[22]. In addition, participants scoring lower on this scale were biased to respond that infrasound was not present. Unfortunately, only very few participants were studied (7 per group), and therefore the results can be treated as just preliminary.

1.1.3 Annoyance Due to Wind Turbine Sound in Experimental Studies

Experimental studies on the effect of wind turbine sound, in general, on annoyance and stress are scarce, and studies exploring influence of wind turbine infrasound on annoyance are lacking. A couple of experimental studies propose that particularly the element of amplitude modulation (AM) (i.e., periodic temporal level variations often observed for wind turbine noise) in audible wind turbine sound is the main reason why wind turbine sound is easily detectable and annoying. For instance, Yoon et al.[23] showed that subjective loudness of wind turbine noise can be increased when the turbine sound includes AM in comparison to sound samples that do not include AM. Lee et al.[24] in turn presented wind turbine noise recorded by five free-field microphones. The stimuli of the study consisted of 50 stimuli with varying degree of AM that were presented for 30 seconds. It was found that the noise annoyance recorded on an 11-point numerical scale increased with the AM. Similarly, Schäffer et al.[25] investigated which acoustic characteristics of wind turbines are associated with annoyance by comparing annoyance responses to wind turbine noise and road traffic noise in controlled laboratory listening tests. It was found that wind turbine noise was associated with higher annoyance reactions than road traffic noise in particular when AM was present.

1.1.4 Other Relevant Studies

One isolated study using functional magnetic resonance imaging (fMRI) has found that exposure to infrasound levels near but below the hearing threshold may induce activity across several brain regions that are involved in emotional and autonomic control. This was not seen with higher infrasound levels. Weichenberger et al.[26] used a 12 Hz pure tone stimulus 2 dB below individual hearing thresholds of the subjects, ranging 79–96 dB. The extrapolation of this finding to much lower levels generated by wind turbines is not straightforward, because the maximum infrasound levels at 12 Hz from near the source vary between 40–60 dB.[12,27,28] and mere brain activation is an indication far from developing other responses or further, adverse health effects.

Some experimental studies have shown that negative expectations towards wind turbine sound can induce symptoms. In the study of Crichton et al.[29] 54 participants were exposed to 10 minutes of infrasound and 10 minutes of sham infrasound. Half of the participants were presented audiovisual information from the Internet, designed to invoke negative expectations, i.e. exposure to infrasound causes specified symptoms. Half of the participants were presented information showing infrasound associated with wind turbines in a positive light. It was found that negative expectancy participants reported significant increases in the intensity and number of symptoms during exposure to both infrasound and sham infrasound. Similar effect was later observed by Tonin et al.[30]. These findings support the view that negative expectations related to wind turbine noise could be one explanation the link between wind turbine exposure and health complaints.

1.2 Research Questions and Objectives

Some individuals living in the vicinity of wind power plants have symptoms that they have intuitively associated with wind turbine infrasound but the reason for these symptoms is currently not known. Other gaps in knowledge are the prevalence and severity of these symptoms as well as the level of exposure to wind turbine infrasound inside homes close to wind power plants.

The main objective of this research project was to find out whether wind turbine infrasound has harmful effects on human health. The specific objectives were:

- To characterize wind turbine noise as an exposure
  - What are the full spectrum sound levels, down to 0.1 Hz, inside houses near the wind power plants?
  - What are the characteristics of the sound, both audible and inaudible infrasound?
- To describe symptoms that are intuitively associated with infrasound from wind turbines, i.e., wind turbine infrasound related symptoms.
  - What is the prevalence of wind turbine infrasound related symptoms in the vicinity of wind power plants?
  - What factors are associated with wind turbine infrasound related symptoms?
- To study how infrasound produced by wind turbines affects humans, in particular, perception, annoyance, and physiological responses
  - Can low-frequency and infrasound wind turbine noise be perceived at typical and at extreme noise levels?
  - What is the dependence between the depth of amplitude modulation and annoyance at low frequencies?
  - Does infrasound increase reported annoyance and psychophysiological responses?
  - What is the reactivity of the autonomic nervous system (ANS) to audible wind turbine sounds and its infrasound?

– Are individuals who attribute their symptoms to wind turbines more sensitive to infrasound? Are they more able to detect infrasound and do they experience more annoyance compared to controls?

The abbreviation Wind Turbine Related Symptoms (WTRS) is used for self-reported symptoms of participants in the experimental study. Two journal article manuscripts[31,32] based on this technical report, have been submitted for review.

To assist in the reading, a list of the abbreviations is provided, starting on page 151. A short index can be found on page 154.

The most of the measurement statistics were placed in Appendix A and some more descriptive WTS data in Appendix B. The result tables of the questionnaire study can be found from Appendix C and the questionnaire form in Appendix D.

2 Sound Measurements

Almost 12 terabytes of full spectrum wind turbine sound existed from our earlier projects, but that data didn't meet the requirements of this project: either it was lacking the lowest frequencies or the choice of measurement location was wrong. The most of the previous measurements were made using measurement microphone models with frequency response starting from 3–4 Hz (-3 dB), but now there was a need to capture several octaves lower frequencies. Also, the previous measurements didn't contain long-term measurement data from inside the houses, which was on the focus of the research plan. The most common reason for the low number of long-term indoor measurements is that the residents have to move out during the measurements.

The main objective was to capture the sound samples to the provocation experiment, but also to characterize wind turbine noise as an indoors exposure. This goal was achieved by measuring the full spectrum sound using microphones, which were traceable calibrated between 0.050 Hz and 20 000 Hz, inside houses near the wind power plants.

2.1 Description of the Locations

Several houses where WTS was identified as a problem were suggested to us. The primary measurement targets were defined to be the wind power plants with the most powerful turbines ($\geq$ 3 MW), complaints about infrasound, and a house near the plant, but without inhabitants. Other selection criteria were wind direction and electricity supply. Two house owners agreed that the houses were not occupied during a several months measurement period. The operators of two nearby wind power plants agreed to cooperate and promised operational data transfer. These two houses were located in Southern (Kurikka) and Northern Ostrobothnia (Raahe), where the most of the wind power capacity is located in Finland.

2.1.1 Santavuori Wind Power Plant

Santavuori wind power plant (WPP) is located in the municipality of Ilmajoki, Finland. During the measurement campaign, there were 17 Vestas V126 3.3 MW turbines, producing total 56.1 MW and over 150 GWh per year. The turbines were equipped with 126-meter-diameter rotors at a hub height of 137 m. The operation of the WPP started in summer 2016.

An old log house from the beginning of the last century from the nearest city, Kurikka, was selected as the first measurement target, see Fig. 2.1. The house owner told that the house has been her home, but during the last years, it has been used only during summer time and there was no heating during the measurement campaign. During the measurements, all the doors (also inside the house) were kept closed. The nearest turbine from the house was located 1585 m to the East. The most obvious other noise sources were the highway 3 (E12, 7157 vehicles/day[33]) passing about 700 m from the house and the sounds of agricultural machinery in nearby fields.

Figure 2.1: The old log house located in Kurikka was almost 1.6 km from the nearest wind turbine.

2.1.2 Kopsa Wind Power Plant

The second measurement target, a house abandoned by residents because of WTS, was located about 1.5 km from the nearest turbine of Kopsa wind power plant (WPP) in the municipality of Raahe, Finland. The house was brick-faced (see Fig. 2.2) and it was currently used for incidental accommodation of the maintenance staff, but the operator agreed to keep the house empty during the measurement campaign. During the measurements there were 17 wind turbines in the Kopsa WPP (total 54 MW). Seven of the turbines were commissioned in August 2013 and were Siemens models SWT-3.0-DD (each 3.0 MW) with 113 m rotors at a hub height of 143 m. The other ten turbines started their operation in December 2014 and were similar to Santavuori WPP: Vestas V126 (3.3 MW, diameter 126 m, hub height 137 m).

The nearest turbines, about 1500 meters from the house, were the older and louder Siemens models. There was a main road 88 about 160 m with little traffic (1735 vehicles/day[33]) to the North from the house, behind a dense spruce forest. The most obvious other noises were the sounds of agricultural machinery in nearby fields. All the doors (also inside the house) were kept closed during the measurements and air conditioning was shutdown. The house was electrically heated, but other electrical equipment were shutdown, e.g. cooler, freezer, wall clocks etc.

2.2 Measurement Procedure

2.2.1 Preparations

Property owners were asked for permission to make noise and vibration measurements in their houses. A study bulletin was prepared which included information e.g. about the background, purpose and the target group of the study, research description, benefits and potential disadvantages of research, how personal data will be processed, volunteering, rights of the research participant, and some other information.

Figure 2.2: A view from the front yard of the house in Raahe. The outdoors infrasound microphone with a ground plate and a secondary hemispherical windshield of about one meter in diameter.

In addition, a Privacy Statement was prepared. The privacy statement was based on the EU Data Protection Regulation (2016/679, the "Data Protection Regulation") and applicable national law.

A total of 308 days of new indoors and outdoors WTS data was captured, both full spectrum sound, and vibration to all 3 degrees of freedom, combined with local meteorological data, all the operational data of all the wind turbines in the wind power plants, and WTS data near the closest wind turbine. For details, see Table 2.1. The sound and vibration data was captured also from the wind power plant (WPP) area (Fig. 2.6). The vibration data was taken for certainty, if some unexpected phenomenon in sound analysis would need explanatory support from the vibration data. However, vibration data was not utilized in this project.

Table 2.1: Data table for the immission measurements

Location	Kurikka (Santavuori WPP)	Raahe (Kopsa WPP)
House distance	1.59 km	1.50 km
Immission, indoors	Sound & 3D vibration	Sound & 3D vibration
Immission, outdoors	Sound	Sound
Emission, outdoors	Sound & 3D vibration	NA
Local weather data	At house and in WPP	At house only
Operator data	Angle, power, rotor speed weather parameters, SODAR	Angle, power, rotor speed weather parameters
Started	2018.11.25	2019.06.28
Ended	2019.05.27	2019.10.29
Duration	184 days	124 days

2.2.2 Equipment

The equipment consisted of weather, sound and vibration measurement devices. In addition to having access to the operational weather data of all the wind turbines, meteorological data was captured at heights of 2 and 10 m in all the locations using Davis Vantage Pro 2 Plus weather stations and wireless Davis Envoy 8x data loggers (Davis Instruments Corporation, Hayward, California, USA. Fig. 2.3). G.R.A.S. 47AC infrasound microphones (G.R.A.S. Sound & Vibration A/S, Holte, Denmark) were used to capture the full spectrum sound. The frequency response of the microphones covered the frequency range 0.05–20 000 Hz and their sensitivity in the lowest third octave bands (between 0.05–250 Hz) was frequently monitored during the campaign with a low frequency calibrator (G.R.A.S. 42AE) and conventional sound calibrators. Vibration was captured using Brüel&Kjær Type 4504 A (Brüel&Kjær, Denmark), triaxial DeltaTron accelerometers, both in the wind power plant area, and indoors, for later use.

All the equipment were carefully prepared for the campaign. In all outdoor measurements, GFM 920.1 (Microtech Gefell GmbH, Gefell, Germany) ground plates with secondary windscreens were utilized. Due to snow and freezing conditions in Finland (Fig. 2.6), also the secondary windscreens were equipped with electric heating. Additionally a palm-sized plastic film was attached on the underside surface of the outer windscreen to prevent direct rainwater from hitting the microphone in the center of the plate. The acoustic effect of the plastic film and heating cables is included in the insertion losses of the secondary windscreens, which were measured according to standard IEC 61400-11:2012 Annex E[34]. In the Figure 2.4, the measurement setup and a close view of the sound source (loudspeaker) on a mast at a height of 4 m in the right pane. The measured horizontal distances from the mast were 4.8, 6.0, and 7.2 metres. An example of the results is shown in the Figure 2.5. The effect of windscreens approaches zero at frequencies below 100 Hz and is virtually zero for infrasound.

Figure 2.3: The weather mast in the courtyard of the house in Kurikka.

With the exception of microphones, all the other equipment in outdoors measurements (and in the house of Kurikka, which was not heated during wintertime) were housed in weatherproof and heated enclosures, see Fig. 2.7.

The whole measurement chain was optimized for infrasound and then carefully validated in all third octave bands from 0.05 Hz to 250 Hz using the 42AE low frequency calibrator as a reference sound source for the 47AC microphones. Sensitivity curves for the microphones were already captured utilizing a combination of a Brüel&Kjær Type UA0035 adapter and G.R.A.S GR0752 spacers and then further used for creating atmospheric pressure and temperature fixed sensitivity curves for all the used measurement amplifiers and AD converters. In Fig. 2.8, an example of the measured sensitivity for one microphone and measurement channel. ICP power supplies (PCB Model 482A22, USA) and a measurement amplifier (Acoutronic SensoBox Model AC CCE-G2211121, Sweden) were used to power up the microphones and

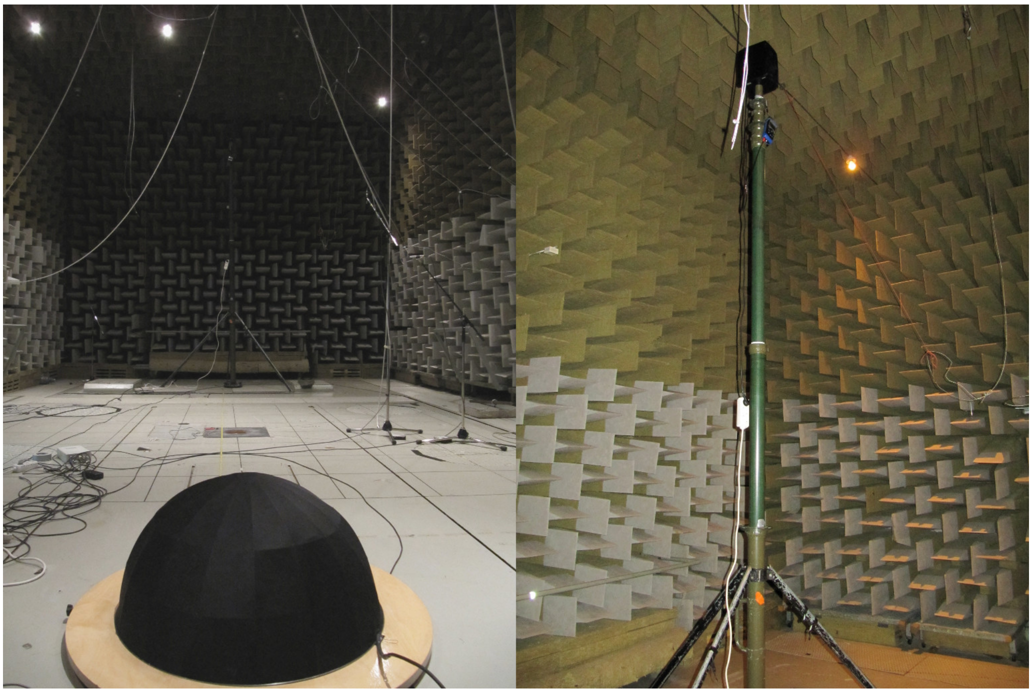


Figure 2.4: Insertion loss measurement of the windscreens in a semianechoic chamber.

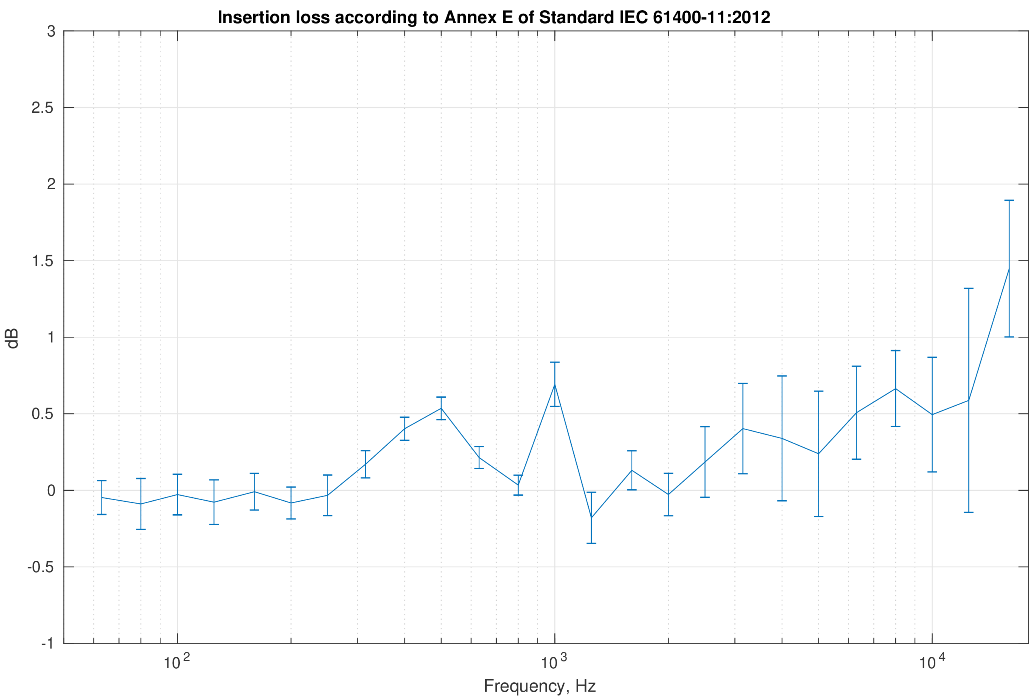


Figure 2.5: Insertion loss of a Microtech Gefell GFM 920.1 secondary windscreen.

Figure 2.6: A microphone (middle) and the equipment box (pictured right) in Santavuori area.

commercial AD converters (Echo Audiofire12, preamplifiers modified for very low frequency usage) were validated for sound measurements (see Fig. 2.10). A direct-coupled (DC) LMS Scadas Type SC310-UTP unit (Siemens, Germany) was utilized as a main validation front end and a HP 33120A as a signal generator (see Fig. 2.9). All the measured acoustic and vibration data was captured at a sampling frequency of 48 kHz and a resolution of 24 bits, continuously around the clock.

2.2.3 Sensor Locations

The indoors microphones were placed in the room of the house which was the closest to the wind power plant (WPP): in Kurikka to a kitchen and in Raahe a bedroom (Fig. 2.11). The outdoor microphones were placed on open areas in the courtyard of houses (Fig. 2.2), and the microphones in the wind power plant area, about 200 m from the nearest wind turbine to the house (Fig. 2.6). The accelerometers were glued to the foundation of the houses and to a large underground stone (possibly bedrock) in the WPP.

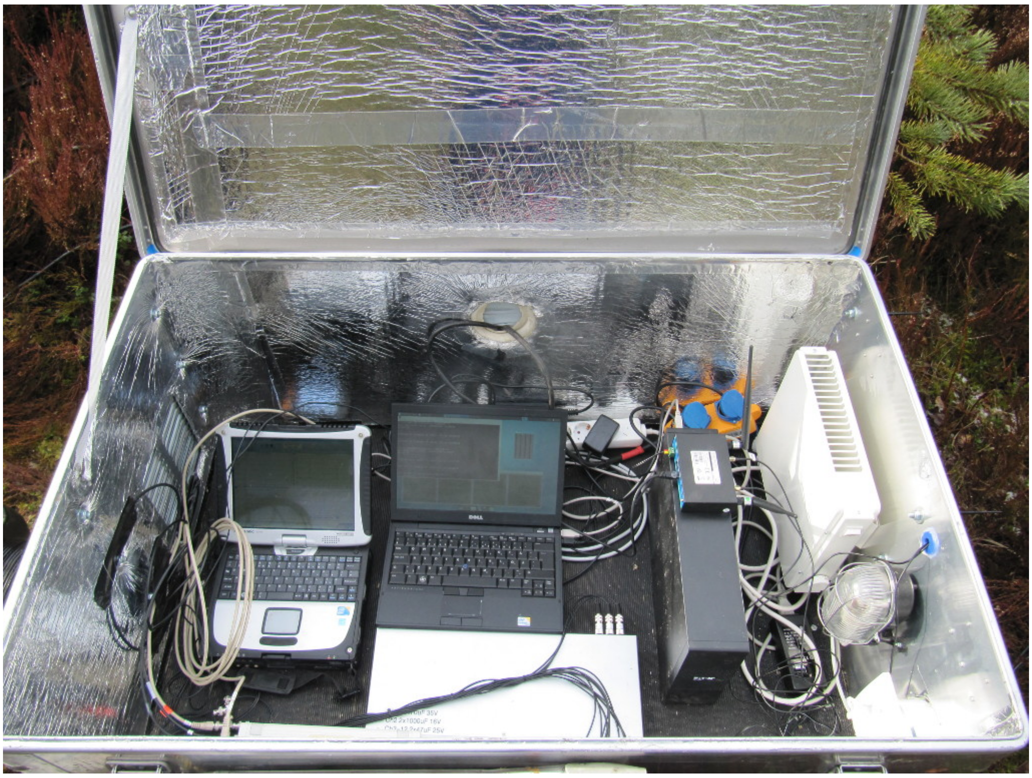


Figure 2.7: Outdoors measurement devices in a heated equipment box.

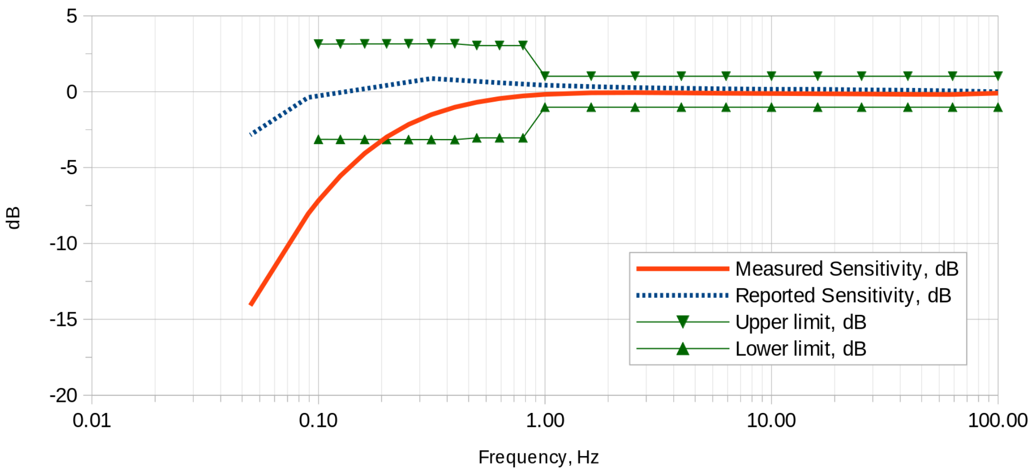


Figure 2.8: An example of the measured low frequency response of the full infrasound measurement chain (red curve), including the effects of the ICP power supply, and AD converter. The other curves are the blue dotted sensitivity curve of the microphone, reported by the manufacturer, and manufacturer's tolerance limits in green.

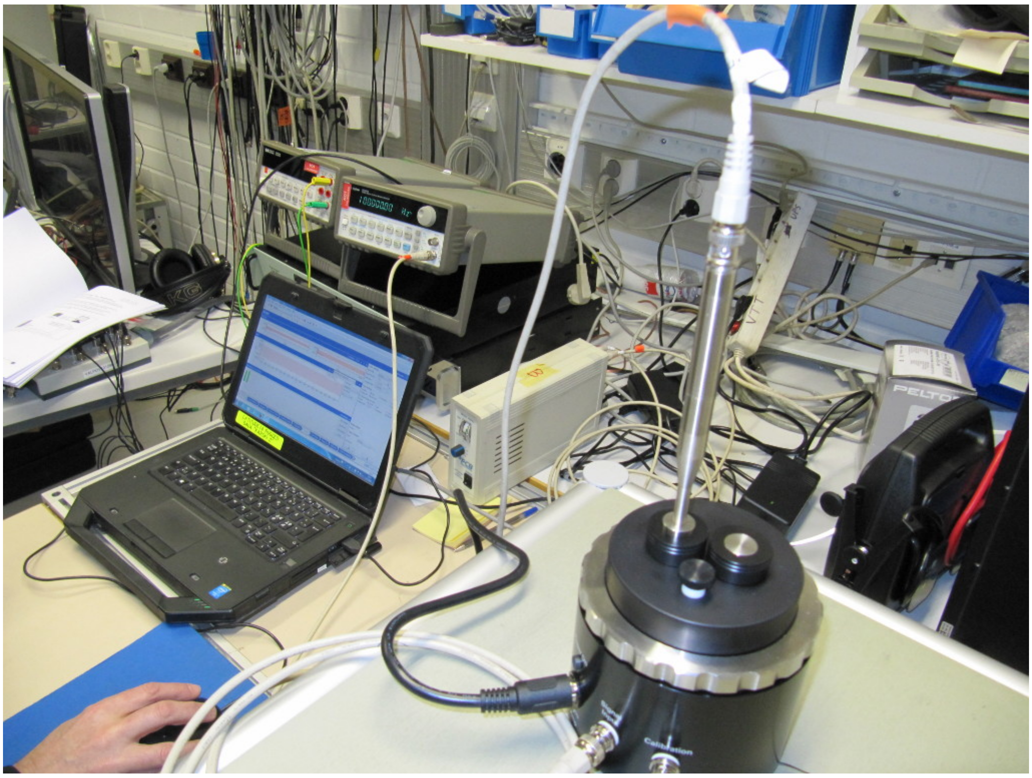


Figure 2.9: Infrasound microphone calibration using the G.R.A.S 42AE low frequency calibrator.

2.3 Analysis

The signal analysis and statistical data processing was performed primarily via MATLAB® [35] and R [36]. The characteristics of wind turbine sound was analyzed as equivalent continuous sound pressure level values in third octave bands between 0.1 and 10 000 Hz, the overall levels with frequency weightings A, G, and Z. In addition to the microphone specific calibration coefficient, the third octave band values between 0.05 and 16 Hz were compensated with the measured microphone and channel-specific (ICP power supply and AD converter) attenuation factors (see Fig. 2.8 as an example).

The analysis was also performed in 10-minute chunks, as the sliding analysis would have taken significantly longer. The selection of this 10-minute calculation window is discussed in Sec. 5.2. The average signal energy was calculated by integrating the squared sound pressure levels over time over the entire measurement period. All constant band spectra presented in this report have

Figure 2.10: A five channel measurement setup streaming data from two microphones and a triaxial accelerometer to a cloud-based computational resource.

been calculated with an FFT filter for every third octave band in the frequency range 0.1–10 000 Hz, and the average sound levels have been calculated only for the bands shown in the figures with their weights. Ten minutes equivalent continuous sound pressure levels were calculated for all the data, but also one minute data for the Raahe indoors data, to spot interesting samples more accurately. The frequency bands below 1 Hz were included only in $L_{Z,600\ s}$ estimates. Also, some time domain characteristics was calculated, e.g. the depth of amplitude modulation. All this data was used in statistical analysis for selecting samples of the provocation experiment sub-study.

2.3.1 Data Evaluation

Due to a quantity of measurements data, listening through all the samples would have been an almost impossible task. An automatic data evaluation, based on experience from similar long-term measurements, was performed.

Figure 2.11: Indoors microphone positioned over a bed, a half metre above the head position.

First, all the clipping samples (with absolute values exceeding 99.9% of the maximum possible amplitude) were removed. There were a few clipping samples in Kopsa measurements, where the the maximum level of the measurement chain was adjusted to be lower than in Santavuori and Kurikka. Next, the samples were checked for known artificial tones, like calibration signals at 250 or 1000 Hz and these were removed from further analysis. In addition to doing the calibration of the measurement chain before and after the campaign, calibrations were performed several times during the measurements ”on the fly”, i.e. applying the calibrator (Brüel & Kjær Type 4220 pistophone or Type 4231 sound calibrator) on the microphone without interrupting the continuous recording procedure. For example, the mode value of interfering frequencies in the removed samples in Kurikka indoors measurement is 1000 Hz (Table 2.2): which is just about eliminating samples that contain a 1000 Hz calibration signal. Also, it is notable that for Raahe indoors both the mean and maximum frequencies for the removed indoors samples were much lower than for other locations: first, sound insulation of the house is better (however, not good) and natural background noise sources (birds, etc.) are missing, and second, no calibration was performed during the measurements, just like in Kurikka. Finally, anomalies in the frequency bands between 20 and 10 000 Hz were separated based on comparing the level of single bands to the linear equivalent level of the audible frequency range and samples exceeding 20 dB were automatically removed from further analysis. For the total number and statistics of the interfering frequencies in the removed samples see Table 2.2. In the Table, also the total number of acquired measurements is shown, and for the Raahe indoors data the statistics contain values for both the $L_{Z,600\ s}$ and $L_{Z,60\ s}$ evaluations. The outdoors data for both Raahe and Kurikka showed extraordinary high levels in upper frequency bands in data evaluation. Despite the measurement accuracy in calibration level checks, the results must be treated with caution. This infrasound microphone model is not weatherproof and these abnormal results may tell about some electrical problems due to high moisture conditions.

Table 2.2: Statistics of the removed samples

Location	Raahe, in (10 min)	Raahe, in (1 min)	Raahe, out	Kurikka, in	Kurikka, out	Santavuori
Measurements	15192	155982	8370	24830	24830	13259
Removed	109	1031	329	376	415	124
Mean, Hz	80.7	69.3	562	897	834	845
Mode, Hz	125	125	80	1000	250	400
Min, Hz	20	20	20	25	20	200
Max, Hz	125	200	2500	3150	6300	6300

2.4 Results

The objective of this sub-study was to provide worst-case samples in terms of infrasound levels and amplitude modulation to the provocation experiments. This was achieved by statistical analysis of the data from the four different measurement locations (Table 2.2). The selection of the samples and their properties will be covered later in this report, in Chapter 4. In addition to explaining in Section 2.3.1, the problematics of data acquisition, evaluation, and validation is discussed more in Sections 5.1–5.3. This section only shows some common descriptive statistics for the two indoors locations.

The overall equivalent sound pressure levels (A, G, and Z frequency weighted), in the third octave band figures below, were calculated over the whole validated (Sec. 2.3.1) measurement period, which is marked on the top of each figure. In addition to the overall level bars of the third octave bands between 0.1–10000 Hz, the minimum and maximum 10 minutes L_{eq} curves are plotted. These were selected by finding the minimum and maximum total energy in the infrasound 1/3 octave bands (0.1–20 Hz).

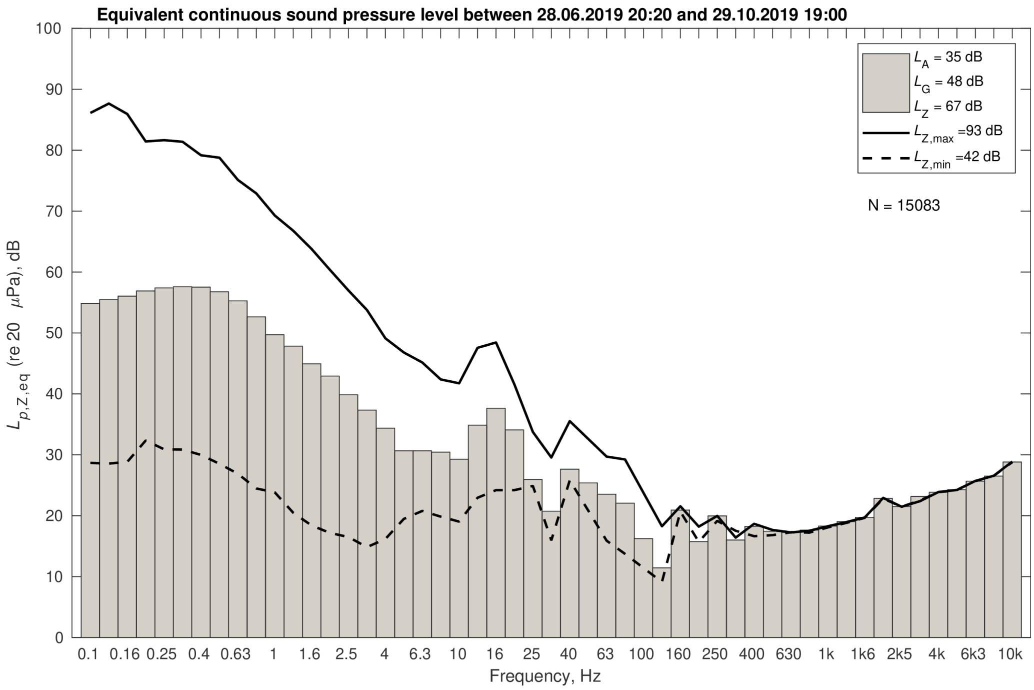


Figure 2.12: Raahe, indoors, third octave bands for all the validated data based on 600 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

The plotted measurement period varies for some locations because not all the data was included to the calculation of the estimates due to some invalid data found by the automatic data validation algorithms. For example, some outdoors measurement probably suffered from problems caused by moisture on the microphones and some unexplained interference was found in some analysis. The interference signal extends to such high frequencies (8 kHz) that it cannot originate from a wind turbine because such high frequency contents of sound is absorbed over a very short distance. Because of this, the number of validated measurements, *N*, in the outdoor measurements is lower than *N* for indoor measurements on the same location. It is worth noting that a validated measurement is not necessarily a valid measurement, see Section 5.3.

There is a notable difference in infrasound frequencies between the Figures 2.12 (Raahe) and 2.13 (Kurikka). The Kurikka house is located near a busy road, in the middle of active farming and despite of the automatic validation,

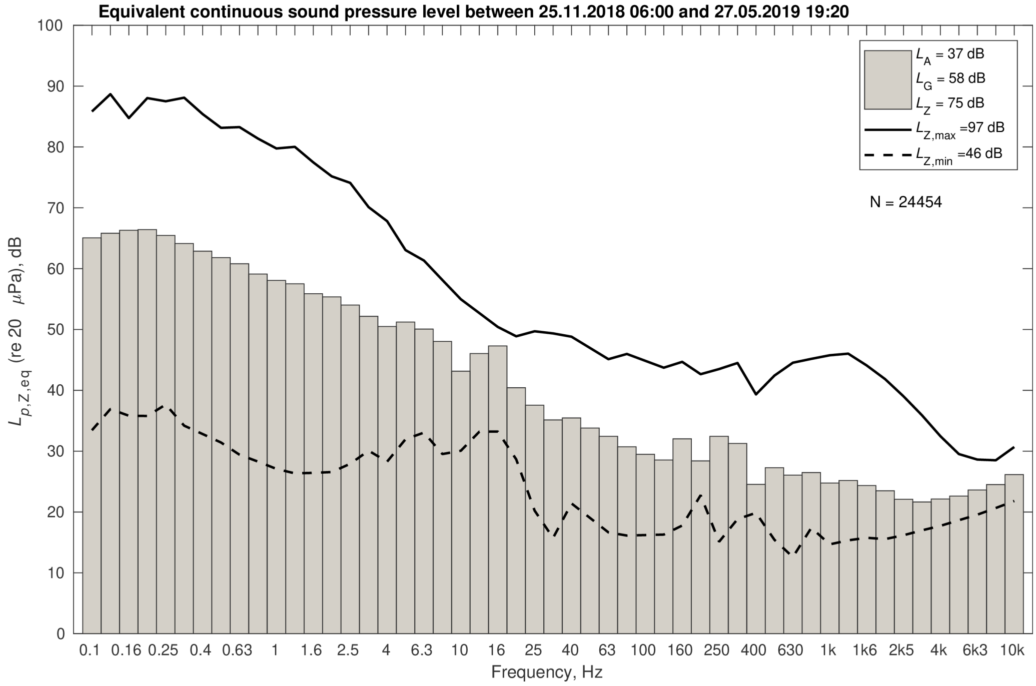
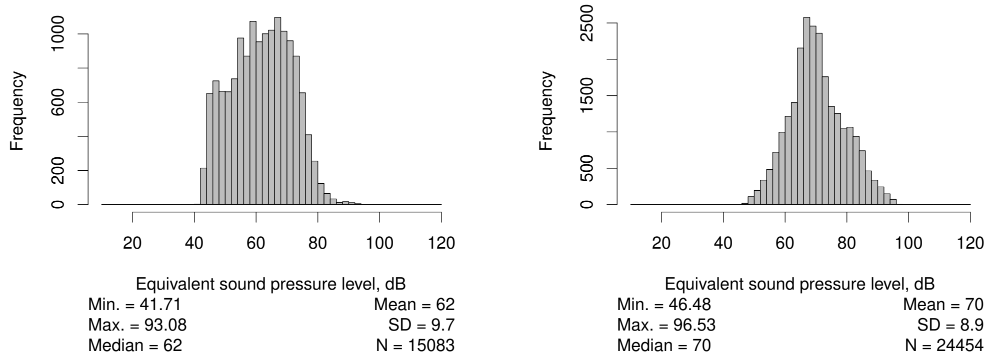


Figure 2.13: Kurikka, indoors, equivalent sound pressure level.

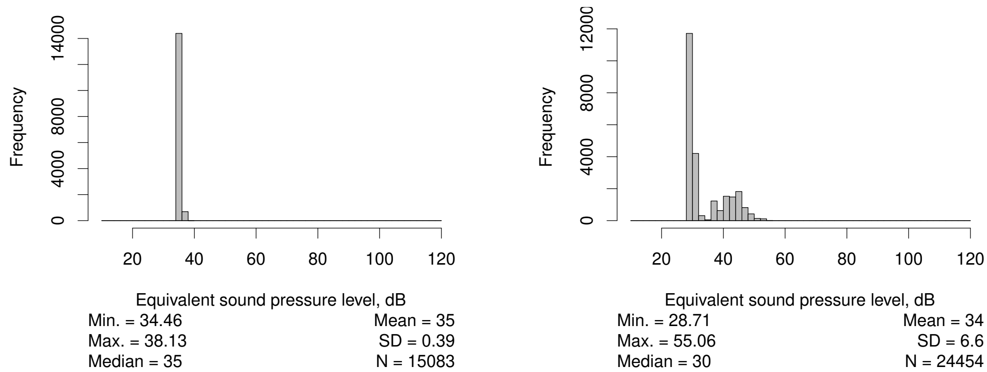
these low frequency bands may have traces of non-wind turbine infrasound. Also the distribution of the equivalent sound pressure levels differs a lot between these two locations. In the Kurikka house, the unweighted $L_{p,Z,600\ s}$ is quite normally distributed, with a center near 70 dB, but in the Raahe house, the levels between 44 and 74 dB occur almost equally often (Fig. 2.14).



a) $L_{p,Z,600\ s}$ b) $L_{p,Z,600\ s}$

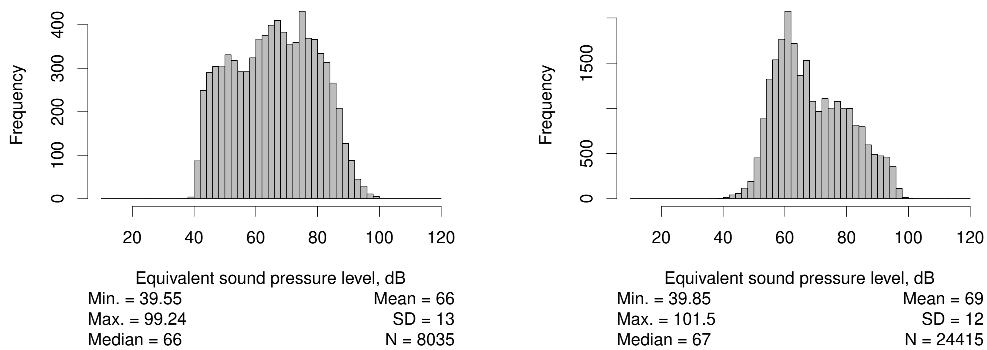
Figure 2.14: Histograms for Raahe (a) and Kurikka (b) indoors equivalent sound pressure levels.

The unweighted equivalent continuous sound pressure levels in houses near wind power plants were about 20 dB higher than in previous long-term measurements in natural areas[37]. According to the equivalent continuous sound pressure levels, the most important frequencies were less than 1 Hz and frequencies below 2 Hz, if the highest equivalent levels are considered, see Fig. 2.14 (Raahe $L_{Z,max}$ = 93 dB and Kurikka $L_{Z,max}$ = 97 dB). Both the unweighted and A-weighted levels measured from the dwellings were of the same order of magnitude as those found in urban dwellings. Indoors infrasound levels ranged from 42 to 97 dB and A-weighted levels from 29 to 55 dB (Fig. 2.15). The sound levels in the yards varied between 40 and 100 dB in both locations (Fig. 2.16). For a few moments the infrasound level for frequencies below 2 Hz exceeded 100 dB in Raahe, and the maximum level was 102 dB (Fig. 2.16 b). The equivalent continuous sound pressure level in the long-term emission measurement was of the same order of magnitude as in our previous shorter period emission measurement campaign[37], L_Z = 74 dB (L_A = 52 dB), as depicted in Figure B.1.



a) $L_{p,A,600\,s}$ b) $L_{p,A,600\,s}$

Figure 2.15: Histograms for Raahe (a) and Kurikka (b) indoors equivalent sound pressure levels.



a) 0.1–2 Hz, $L_{p,Z,600\,s}$ b) 0.1–2 Hz, $L_{p,Z,600\,s}$

Figure 2.16: Histograms for Raahe (a) and Kurikka (b) indoors equivalent sound pressure levels.

No ground reflection correction has been made in the measurement results. In the measurements using the ground plate, for the A-weighted sound levels, a correction would be justified, but in the interests of consistency, all the results shown in this report are without ground corrections. This is discussed more in Section 5.1.

More detailed statistics can be found from the Appendix A, for Santavuori (Figs. A.1–A.5), Kurikka indoors (Figs. A.11–A.15), Raahe outdoors (Figs. A.16–A.20), and Raahe indoors measurements (Figs. A.21–A.33). These Appendixes also introduce several new factors: histograms for day and night time SPL values, $L_{p,\mathrm{Z,eq,\ 7\text{-}22}}$ and $L_{p,\mathrm{Z,eq,\ 22\text{-}7}}$, and histograms for both some selected frequency bands and for some combined frequency bands: 0.1–2 Hz, 2–20 Hz, 20–100 Hz, 100–10000 Hz (the highest band of the interval is not included, except for the last range, 100–10000 Hz).

In addition, more descriptive statistics, including the variation of amplitude modulation values as a function of time, for these long-term wind turbine sound measurements can be found in Appendix B.

2.5 Measurement Uncertainty

All measurements involve measurement uncertainty. For electrical components, the largest source of measurement uncertainty is the microphone, for which the manufacturer declares a tolerance of $\pm$ 3 dB for frequencies below 1 Hz and $\pm$ 1 dB for the higher frequencies (1–10000 Hz, see Figure 2.8). The sensitivity of the signal chain from the microphone to the data acquisition system was always checked before and after moving the setup to a new location, and also several times during the measurements with the piston sound source Brüel & Kjær Type 4220, which had a measurement uncertainty of 0.08 dB according to the calibration certificate.

The main objective of these sound measurements was to capture and select the worst-case moments of wind turbine infrasound. The selection of the samples was based on statistics of a number of measurements. In that sense, it wasn't a priority to minimize the measurement uncertainty, but careful notes, completion of protocols, and calibrations made it possible to keep the uncertainty small.

3 Questionnaire Study

3.1 Materials and Methods

The questionnaire study received a supporting statement from ethical working group (TuET) of Finnish Institute for Health and Welfare (THL) in December 2018. Since all wind power plant areas in Finland could not have been included in the study due to limited resources, the idea was to identify those areas in Finland that appear to be the most problematic in terms of symptoms intuitively associated with wind turbine infrasound. In January-February 2019, a link to Webropol questionnaire was sent by email to health protection authorities in 40 municipalities and municipal federations with own wind power or having a neighboring municipality with wind power, an interest organization for wind power industry (Suomen Tuulivoimayhdistys ry) and two civic organizations representing individuals who report symptoms because of wind turbines (Tuulivoima-Kansalaisyhdistys ry and Suomen Ympäristöterveys ry). They were asked to report wind power plant areas where the residents have symptoms that they have intuitively associated with wind turbine infrasound. A reply was received from 16 municipalities, Suomen Tuulivoimayhdistys and Tuulivoima-Kansalaisyhdistys ry. Based on answers, the following four wind power plant areas were selected for the study:

- Siikajoki, Vartinoja I (9 x 2.7 MW turbines, TuuliSaimaa Oy)
- Ilmajoki (Kurikka), Santavuori (17 x 3.3 MW turbines, EPV Tuulivoima Oy)
- Siikainen (Merikarvia), Jäneskeidas (8 x 3.3 MW turbines, TuuliWatti Oy)
- Pori, Peittoonkorpi (12 x 4.5 MW turbines, TuuliWatti Oy) + 4 smaller areas (6 x 2–3.3 MW turbines, Suomen Hyötytuuli Oy, Pohjantuulen Voima Oy, TuuliWatti Oy)

Table 3.1: Sampling strategy

Wind power plant area	Distance between respondents' home and closest wind turbine ⩽ 2.5 km n	> 2.5–5 km n	> 5–10 km n	> 10–20 km n	**Total n**	Proportion of all dwellings %	Proportion of the sample %
Siikajoki	28	72	400	400	**900**	20	19
Ilmajoki	176	400	400	400	**1376**	10	28
Siikainen	26	145	400	400	**971**	43	20
Pori	400	400	400	400	**1600**	18	33
Total	**630**	**1017**	**1600**	**1600**	**4847**	16	
Proportion of all dwellings, %	79	33	15	10			

THL defined 20 km buffers around selected wind power plants and identified postal codes in these areas. Based on postal codes, Population Register Centre provided building codes, building coordinates and the number of dwelling units in each building. After that, THL calculated the distance to the closest wind turbine (in the selected study areas) for each building code and defined 16 sampling areas, i.e., four distance zones ($\leq$ 2.5 km, $>$ 2.5 – –5 km, $>$ 5 – –10 km, $>$ 10 – –20 km) in four wind power plant areas (Siikajoki, Ilmajoki, Siikainen, Pori). Some areas in Pori were excluded from the study since they consisted mainly of densely populated city center and thus, have other noise and infrasound sources in addition to wind turbines. Digital and Population Data Services Agency performed a random sampling within the 16 sampling areas in March 2019. The aim was to get 400 dwellings per distance zone from each of the wind power plant areas. However, in the two closest distance zones in Siikajoki and Siikainen and in the closest distance zone in Ilmajoki, the number of inhabited dwellings was lower than 400, and thus, all inhabited dwellings in those areas were included. One adult ($\geq$ 18 years of age) from each dwelling was randomly selected to the sample (Table 3.1).

A self-administered questionnaire was mailed in Finnish or Swedish to all persons in the sample (n=4 847) in April 2019 and a reminder to non-respondents (n=3 986) in June 2019. After the first mailing, the response rate was 18% and the final response rate was 28% (n=1 351) (Table 3.2). Attendance was encouraged by providing a link to an alternative electronic questionnaire and mentioning in the cover letter of both mailings that two tablet computers will be allotted to the respondents. In the second mailing, an additional appeal letter was sent. TKP-Print Oy performed the mailings and data entry. The questionnaire included a large array of questions regarding the presence, frequency and severity of wind turbine infrasound related symptoms, perceived exposure, annoyance and sleep disturbance caused by audible sound and infrasound from wind turbines and car traffic, quality of life, living

Table 3.2: Response rates

	Distance between respondents' home and closest wind turbine									
	$\leqslant$ 2.5 km		$>$ 2.5–5 km		$>$ 5–10 km		$>$ 10–20 km			**Total**
Wind power plant area	%	n	%	n	%	n	%	n	**%**	**n**
Siikajoki	61	17	46	33	30	119	23	92	**29**	**261**
Ilmajoki	45	80	29	117	29	117	21	83	**29**	**397**
Siikainen	35	9	41	60	26	102	25	98	**28**	**269**
Pori	33	132	28	111	23	92	22	89	**27**	**424**
Total	**38**	**238**	**33**	**321**	**27**	**430**	**23**	**362**	**28**	**1351**

environment, building characteristics, health status, life habits, noise sensitivity, sensitivity to other exposures in living environment, opinions and risk perceptions, and background information.

Due to relatively low response rate, a short telephone interview was conducted among non-respondents in order to assess whether they differ from respondents especially in terms of symptom prevalence. The aim was to get an interview response from 10% of non-respondents. Address information was updated by Population Register Centre in September-November 2019, and LeadCloud provided telephone numbers. After excluding those who have actively refused to answer (by calling or returning an empty questionnaire form), those over 85 years, and those who had moved away or died after the sampling, the total number of non-respondents was 3039. Of those, the telephone number was available for 1824 persons (60%). Tutkimustie Oy performed the interviews, and after 2 664 call attempts to 1688 persons in November–December 2019, a total of 318 persons had agreed to answer the short interview. This interview consisted of identical questions on the presence, frequency and severity of wind turbine infrasound related symptoms, as well as exposure, annoyance and sleep disturbance caused by audible sound and infrasound from wind turbines than the self-administered questionnaire.

3.1.1 Statistical Analyses

To describe the data, the prevalence of exposure, annoyance and sleep disturbance related to audible sound, infrasound and vibration from wind turbines and car traffic as well as risk perceptions regarding wind turbine infrasound were calculated. Descriptive data were presented separately for all distance zones ($\leq$ 2.5 km, $>$ 2.5–5 km, $>$ 5–10 km, $>$ 10–20 km) and separately for all respondents and those reporting wind turbine infrasound related symptoms. In addition, a cross-tabulation between annoyance indoors caused by audible sound from wind turbines and annoyance indoors caused by infrasound from wind turbines was done to see whether the same persons are annoyed by both audible sound and infrasound.

For multivariate modeling, the shapes of the studied associations were assessed by applying a generalized additive model with thin-plate regression spline using proc gampl in SAS Enterprise Guide. Due to non-linear associations, some continuous variables such as certain scores and the distance to the closest wind turbine were used as categorical in the models. Potential multicollinearity of the independent variables was checked with cgeneralized variance inflation factor in the car package using R Statistical Software 3.6.0. Except for collinearity diagnostics, all statistical analyses were performed with SAS Enterprise Guide 7.15 HF8.

In the first stage of multivariate modeling, the associations between each independent variable and the dependent variable (presence of wind turbine infrasound related symptoms) were tested in bivariate models. The variable was included in the multivariate models only if the p value for the bivariate association was smaller than 0.2. In the second stage, all independent variables with $p<0.2$ from the first stage where added to the model at the same time and after that, the variable with the biggest p value was eliminated one by one until the final model had only variables with $p<0.2$.

The strategy in multivariate modelling was to build three separate models to prevent potential override of different variable groups:

1. Building and individual characteristics
   - distance to the closest turbine (zones)
   - building type
   - main material for building structure
   - window structure of the building
   - age
   - sex
   - occupational status
   - life habits

- chronic diseases (score)
- impaired hearing
- noise sensitivity

2. Annoyance and opinions
   - annoyance caused by wind turbine lights during a dark hours
   - annoyance caused by shadow flicker
   - annoyance caused by audible sound from wind turbines indoors
   - opinion about the effect of the wind turbines on landscape
   - opinion about personal health risk caused by wind turbine infrasound
   - opinion about the effect of wind turbine infrasound on different diseases (score)
   - opinion about the health effects of wind power production (score)
   - opinion about wind power as a form of energy production (score)
   - opinion about decision making at home municipality (score)
   - opinion about receiving enough information about wind turbine projects at home municipality
   - trust in public sector in relation to the health effects of wind power production (score)
   - trust in wind power companies in relation to the health effects of wind power production
   - functional disorders (score)
   - sensitivity to environmental exposures other than noise (score)
3. Combined model: all variables in models 1 and 2.

3.2 Results

3.2.1 Prevalence and Severity of Wind Turbine Related Symptoms

A total of 5% of all respondents (70 individuals) reported symptoms that they have intuitively associated with wind turbine infrasound (referred later also as symptomatic respondents). In the closest distance zone, the prevalence was 15% (34 individuals). Further, 2% of all respondents (21 individuals) associated their symptoms with vibration and 2% (31 individuals) with electromagnetic field from wind turbines. The respective percentages in the closest distance zone ($\leq$ 2.5 km) were 5% (11 individuals) and 4% (8 individuals) (Table C.1). Of those associating their symptoms with wind turbine infrasound, 47% associated their symptoms also with vibration or electromagnetic field from wind turbines. One individual reported only vibration and electromagnetic field related symptoms, 12 individuals reported only vibration related symptoms and 5 individuals only electromagnetic field related symptoms. Of all respondents (n=1 296), 6 individuals in the closest distance zone and 5 individuals within $>$ 5–10 km from the closest wind turbine reported to feel wind turbine vibration inside their home every week or more often (data not shown here).

Regarding the respondents' families, 5% of the respondents (46 individuals) with spouses reported that their spouses have had symptoms intuitively associated with wind turbine infrasound whereas a total of 3% of respondents (17 individuals) having children reported that their children have had symptoms intuitively associated with wind turbine infrasound. The respective percentages in the closest distance zone were 14% (23 individuals) for the respondents with spouses and 8% (7 individuals) for the respondents having children (Table C.1).

One third of the symptomatic respondents (23 individuals) reported that they have visited a doctor because of the symptoms that they have suspected to result from wind turbine infrasound. Further, 17% (11 individuals) reported that they have been on a sick leave because of wind turbine infrasound related symptoms. These proportions were almost the same in the closest distance zone. Half of the symptomatic respondents (36 individuals) reported having symptoms at least several times per week. The symptom prevalence was a bit lower (41%) in the closest distance zone. Around 30% of the symptomatic respondents (19 individuals) rated their symptoms difficult or extremely difficult, and the prevalence in the closest distance zone was of same magnitude (11 individuals) (Table C.2). Five individuals had difficult or extremely difficult symptoms several times per week of more often (data not shown here). With regard to harmful effects of wind turbine infrasound on different aspects of life, 53% (35 individuals) of the symptomatic respondents reported quite or very harmful effect on mental well-being, 40% (27 individuals) on health, and 29% (19 individuals) on working capacity (Table C.2).

Of the symptomatic respondents, 49% (34 individuals) reported ear symptoms (for example pressure sensations in the ear or tinnitus), 45% (32 individuals) sleep disturbance, 26% (18 individuals) cardiac symptoms (for example arrhythmia), 24% (17 individuals) headache, 21% (15 individuals) dizziness, 13% (9 individuals) anxiety, 9% (6 individuals) fatigue, high blood pressure or joint and other aches, and 7% (5 individuals) nausea or difficulties in concentrating (data not shown here). Only a few individuals reported having eye problems, skin irritation, gastrointestinal problems, asthma, irritable bowel syndrome, low body temperature, stress, irritation, depression, stroke, fibromyalgia, cataract, numbness in limbs, brain fog, and pressure sensation in the brain because of wind turbine infrasound. With regard to vibration and electromagnetic field from wind turbines, sleep disturbance, headache, tinnitus, arrhythmia, gastrointestinal problems, joint and muscle aches, dizziness, nausea, asthma, nightmares, brain tumour, and Parkinson's disease as well as a trembling sensation of the bed/room/building and a thumping sound were reported.

3.2.2 Factors Associated with Wind Turbine Infrasound Related Symptoms

Among participants without missing variables in multivariate modeling, the age range was 18–96 years, the median age was 61 years (25^{th} percentile 47, 75^{th} percentile 70) for all respondents (n=1 137) and 56 years (25^{th} percentile 42, 75^{th} percentile 63) for respondents with wind turbine infrasound related symptoms (n=57). The proportion of women was 53% among all respondents and 57% among symptomatic respondents. The median distance between the respondent's home and the closest wind turbine was 6.6 km (25^{th} percentile 3.4, 75^{th} percentile 10) among all respondents and 3.3 km (25^{th} percentile 2.0, 75^{th} percentile 7.3) among symptomatic respondents (data not shown here). Descriptives for the variables in the final multivariate models are presented in Table C.3).

Based on bivariate models, life habits, building type, and window structure of the building were not associated with the probability of having wind turbine infrasound related symptoms.

The model for building and individual characteristics showed that living within 2.5 km from the closest wind turbine, having two or more chronic diseases, having impaired hearing and being sensitive to noise were statistically significantly associated with increased probability of having wind turbine infrasound related symptoms. On the other hand, being a pensioner was statistically significantly associated with decreased probability of having symptoms (Table C.4). Main material for building structure, age, sex, and life habits were not associated with the probability of being symptomatic.

In the model for annoyance and opinions, having at least one functional disorder, being highly or extremely annoyed indoors by audible noise from wind turbines, being at least slightly annoyed by wind turbine lights during dark hours, having negative opinion about the health effects of wind power production, considering personal health risk due to wind turbine infrasound as high or extreme, and considering the effect of wind turbine infrasound on different diseases major were statistically significantly associated with increased probability of having wind turbine infrasound related symptoms (Table C.4). The effect of wind turbines on landscape, annoyance caused by shadow flicker from wind turbines, opinion about wind power as an energy production form, opinion about decision making at home municipality, receiving enough information about wind power projects in home municipality, and trust in public sector and wind power companies in relation to the health effects of wind power production were not associated with the probability of being symptomatic.

The third model included both building and individual characteristics and annoyance and opinions. Living within 2.5 km from the closest wind turbine, having two or more chronic diseases, having one or more functional disorders, being at least occasionally annoyed by shadow flicker from wind turbines, not receiving enough information about wind power projects in home municipality, having negative opinion about the health effects of wind power production, considering personal health risk due to wind turbine infrasound as high or extreme, and considering the effect of wind turbine infrasound on different diseases major were statistically significantly associated with increased probability of having wind turbine infrasound related symptoms. On the other hand, being a pensioner was statistically significantly associated with decreased probability of having symptoms (Table C.4). Main material for building structure, age, sex, life habits, the effect of wind turbines on landscape, annoyance caused by wind turbine lights during dark hours, annoyance caused by audible sound from wind turbines, impaired hearing, noise sensitivity, sensitivity to other exposures in living environment, opinion about wind power as an energy production form, opinion about decision making at home municipality, trust in public sector and wind power companies in relation to the health effects of wind power production were not associated with the probability of being symptomatic.

3.2.3 Perceived Exposure, Annoyance and Sleep Disturbance

The prevalence of perceived exposure, annoyance and sleep disturbance caused by audible sound, infrasound and vibration from wind turbines are presented in Tables C.5, C.7, and C.9. Of all questionnaire respondents, 2% (30 individuals) reported to be highly or extremely annoyed indoors at home and 3% (33 individuals) reported that their sleep is highly or extremely disturbed because of audible wind turbine sound. Regarding wind turbine infrasound, the respective proportions were 4% (46 individuals) for annoyance indoors and 4% (47 individuals) for sleep disturbance. In the closest distance zone ($\leq$ 2.5 km) the prevalence of high or extreme annoyance indoors was 7% (17 individuals) and the prevalence of high or extreme sleep disturbance was 10% (22 individuals) caused by audible noise. Regarding infrasound, the respective percentages were 10% (23 individuals) and 11% (25 individuals). Only 1% of all respondents (17 individuals for annoyance, 19 individuals for sleep disturbance) reported vibration from wind turbines to annoy highly or extremely or to cause high or extreme sleep disturbance. In the closest distance zone, the respective percentages were 2% (5 individuals) and 4% (8 individuals).

For comparison, the prevalence of perceived exposure, annoyance and sleep disturbance caused by audible sound, infrasound and vibration from car traffic are presented in Tables C.6, C.8, and C.10. The prevalence of high or extreme annoyance indoors and sleep disturbance caused by audible sound and vibration from car traffic was the same than caused by wind turbines among all questionnaire respondents. Regarding infrasound, however, the prevalence of high or extreme annoyance indoors and sleep disturbance was four-fold for wind turbine infrasound when compared with car traffic infrasound.

The cross-tabulation showed that the majority of those annoyed indoors by audible sound from wind turbines were also equally annoyed indoors by wind turbine infrasound (Table C.11).

Of those having wind turbine infrasound related symptoms, 29% (20 individuals) reported to be highly or extremely annoyed indoors by audible wind turbine sound, and in the closest distance zone, the prevalence was 44% (14 individuals). The prevalence of high or extreme sleep disturbance was 34% among all symptomatic persons (23 individuals) and 56% (18 individuals) in the closest distance zone (Table C.12). Half of the symptomatic persons reported high or extreme annoyance indoors (34 individuals) or sleep disturbance (36 individuals) caused by wind turbine infrasound. The respective percentages in the closest distance zone were 59% (20 individuals) and 65% (22 individuals) (Table C.13). Vibration from wind turbines caused high or extreme annoyance indoors to 15% (10 individuals) and high or extreme sleep disturbance to 19% (13 individuals) of symptomatic respondents. The respective percentages were 16% (5 individuals) and 25% (8 individuals) in the closest distance zone (Table C.14).

The cross-tabulation showed that the majority of those symptomatic persons annoyed indoors by audible sound from wind turbines were also equally annoyed indoors by wind turbine infrasound (Table C.15).

3.2.4 Risk Perceptions

Of all questionnaire respondents, 10% considered wind turbine infrasound as a high or extreme risk to their personal health whereas 18% considered it as a high or extreme risk to health in general. Approximately one fifth of them thought that exposure to wind turbine infrasound has a major effect on mood, sleep quality and blood pressure. The prevalence was lower for diabetes (6%), heart disease (13%) and cancer (7%) (Table C.16). Of symptomatic respondents, 75% considered wind turbine infrasound as high or extreme risk to their personal health whereas 77% considered it as a high or extreme risk to health in general. Almost 70% of symptomatic respondents thought that exposure to wind turbine infrasound has a major effect on mood, blood pressure and heart diseases whereas approximately 20% thought the same for diabetes and cancer (Table C.17).

3.2.5 Telephone Interview

The reasoning behind the telephone interview among non-respondents was to see whether they differ from respondents in terms of symptom prevalence. From interview respondents, 5% (15 individuals) reported symptoms that they have intuitively associated with wind turbine infrasound. The symptom prevalence in closest distance zone was 13% (6 individuals). Regarding the interview respondents' families, 2% of respondents with spouses (7 individuals) reported that their spouses and 2% of respondents having children (6 individuals) reported that their children have had wind turbine related symptoms (Table C.18). Of the interview respondents, 2% (6 individuals) reported to be highly or extremely annoyed indoors and 3% (9 individuals) reported that their sleep is highly or extremely disturbed due to audible wind turbine sound (Table C.19). Regarding wind turbine infrasound, the respective percentages were 2% (5 individuals) and 2% (6 individuals) (Table C.20).

To further assess non-response, age and sex distribution was calculated among all questionnaire respondents, telephone interview respondents and non-respondents. Median ages were 62 years among the questionnaire respondents (n=1333), 61 years among the telephone interview respondents (n=321), and 55 years among non-respondents (n=3143). The proportion of women was 54% among the questionnaire respondents, 42% among the telephone interview respondents, and 49% among non-respondents (data not shown here).

4 Provocation Experiments

4.1 Infrasound Detection and Annoyance Experiments

Based on previous studies, wind turbine infrasound is perceived at high noise pressure levels, which are not likely to be present at the distance of dwellings of inhabitants. So far, there is not sufficient evidence if the presence of infrasound affects annoyance to wind turbine sound. There are only few previous studies that have addressed experienced symptoms, and they have not found an association between symptoms and infrasound[38,39]. Infrasound exposure has been shown activate brain regions that associate with stress control[26]. Thus, it was also explored in these experiments whether turbine-related infrasound triggers stress responses.

In the following carefully designed experiments, it was studied whether the presence of infrasound from wind turbines could be detected in sound samples, and whether it was related to annoyance, symptoms or objective physiological stress indicators. Systematically selected samples from real wind turbine sounds from wind power plant areas where inhabitants report symptoms associated with wind turbine infrasound or sound were used as stimuli.

4.2 Participants and Recruitment Procedure

The participants were recruited by 1) an advertisement, posted with the questionnaire study, 2) a call for candidates from activity groups against wind power production Tuulivoima-Kansalaisyhdistys ry and Suomen Ympäristöterveys SYTe ry, and 3) a call for candidates in media coverage in local newspapers and tv-radio interviews in wind power plant areas. Volunteers to participate in the study contacted the research nurses at The Finnish Institute of Occupational Health, received written and oral information of the study and gave an informed consent. Then the participants completed an electronic questionnaire, including a health survey, summarized in Table 4.1. Based on the health criteria, a medical doctor (MS) ensured the eligibility to the study. All the participants (=37) who filled the questionnaire were invited to the laboratory experiments. None met the exclusion criteria, i.e. major hearing deficit, moderate-severe somatic or psychiatric disease. During the time-frame of the study, 26 participants (13 males, 13 females) took part to the provocation experiments.

All participants were compensated for their travel expenses and offered lunch. When required, also accommodation in a hotel adjacent to the laboratory was compensated. Personal feedback was given back on their hearing only, based on audiometry measurements. The experiments were conducted in accordance with the Declaration of Helsinki, and the ethical statement was obtained from the ethical board of the Helsinki University Hospital.

4.3 Questionnaires

Before the invitation to the provocation experiments, the participants filled an electronic questionnaire including a set of validated indicators of health and behavior described in Table 4.1.

The health section was used to evaluate the medical inclusion criteria. Based on the answer to the question "Do wind turbines cause you to feel ill or cause discomfort?", the respondents were divided into two groups: the ones with symptoms related to wind turbines (wind turbine related symptoms, WTRS, n=11) or the ones with not (controls, n=15). The WTRS group reported either quite a bit or very much symptoms from wind turbines related to infrasound and audible sound (n=10), and one individual related symptoms only to audible sound. Ten members of the WTRS group reported moderate, high or extremely high risk to either of the following questions: "How high risk to your health do you consider wind turbine infrasound is in your surroundings? How high risk to health in general do you consider wind turbine infrasound is in Finland?" One individual in the WTRS group, responded similarly but only to audible noise of wind turbines. Related to exposure, the WTSR group reported symptoms, changes of behaviour due to exposure and adverse effects to home, work/study,

Table 4.1: The questionnaire on health and behavior

Items	Reference
Demographics	
Height, weight, sex, education, occupation	
Disease, medication	
Health behavior	
Alcohol Use Disorders Identification Test-Consumption (AUDIT-C)	[40,41]
Smoking	
Work ability, occupational and psychosocial functioning	
Current work ability, Work Ability Score (WAS)	[42]
Own prognosis of work ability two years from now	[42]
Sheehan Disability Scale (SDS)	[43]
Sense of Coherence (SOC-13)	[44]
Single-item measure of stress	[45]
Quality of life	
Two questions used for Adults in Health 2011 Survey	[46]
Wind power plant related questions	
Distance, annoyance, symptoms	[47]
Cognitive and emotional symptoms, thinking style and personality	
Generalized Anxiety Disorder 7-item Scale (GAD-7)	[48]
Patient Health Questionnaire (PHQ-9)	[49]
Insomnia Severity Index (ISI)	[50,51]
Acceptance and Action Questionnaire-II (AAQ-II)	[52,53]
Symptom Checklist-90 (SCL-90) somatization scale	[54]
Toronto Alexithymia Scale (TAS-20)	[55,56]
Short Five (S5) personality inventory	[57]
Intuition subscale	[58,59]
Environmental intolerances, concerns, sensitivity	
Intolerance to environmental factors (indoor air molds, electromagnetic fields, chemicals)	[60]
Environmental-related health concerns	[60]
Weinstein's Noise Sensitivity Scale	[61]
Highly Sensitive Person Scale	[62]

social activities. Only one of the researchers (MS) was aware of the questionnaire data and which participant was assigned to the WTRS group (n=11) or the control group (n=15). The research nurses performing the test day were blind to this information.

4.4 Course of the Experiments

The following procedure was performed in 4 hours. During Baseline A–C, nature videos were shown for 5 to 7 minutes, without audible stimuli.

1. Arrival of the participants to the waiting room
2. Written and oral informed consent
3. Inquiry of the past 24h activities
4. Audiometry
5. Physiological electrode set-up and impedance check
6. Entering to the listening laboratory room
7. Stress inquiry no. 1
8. Baseline A
9. Baseline B
10. Stress inquiry no. 2
11. Listening test 1- Infrasound sensitivity/detection
12. Stress inquiry no. 3
13. Pause
14. Stress inquiry no. 4
15. Listening test 2 - Wind turbine sound annoyance tests
16. Stress inquiry no. 5
17. Pause
18. Baseline C
19. Stress inquiry no. 6
20. 3-min cold pressor test (CPT), stress/pain inquiry at 1, 2, 3 minutes
21. Cognitive instruction test 1 - "infra sound in the background absent/present" on the screen
22. Stress inquiry no. 7
23. Cognitive instruction test 2 - "infra sound in the background absent/present" on the screen
24. Stress inquiry no. 8
25. Removal of the electrodes
26. Instructions to First Beat registration at home
27. Participant received a feedback form and a copy of the audiogram
28. Lunch
29. Calibration of the instruments
30. Data check and save to research files

The order of the presentation of the stimuli was pseudorandomised in the following sections: Baseline A and Baseline B, the blocks of the Sound annoyance tests (Listening test 2), and Cognitive instruction test 1 and 2.

4.5 Audiometry

Before the laboratory measurement, the hearing of the participants was examined by means of automatic audiometry, using Amplivox audiogram device, Amplivox, Oxfordshire, United Kingdom, www.amplivox.ltd.uk. Hearing was tested at 9 different frequencies ranging from 125 Hz to 8000 Hz. The participants were seated on the examination room, with headphones, and the nurse gave the instructions, a brief rehearsal and then initiated the automatic program. After the screening, the audiogram was printed on the paper and inspected by the nurse. Three participants had hearing loss in both ears of 40 dB or more for frequencies higher or equal to 4000 Hz, 6000 Hz and 8000 Hz, respectively. None of the participants were excluded from the study. A copy of the audiogram was given to the participants.

4.6 Infrasound Test Chamber and Apparatus

The size of the room was 2 m $\times$ 3 m with a height of 2.22 m. The infrasound stimuli was produced using a loudspeaker with an infinite baffle, in other words, the listening test subjects were placed inside a closed speaker. An active monitor loudspeaker (Genelec 8130A, SN PM6001655 Nov 06) was used for the upper audible frequency range.

A directly coupled (DC) amplifier (Brüel & Kjær 2721) was used to drive two loudspeaker drivers (Alpine SWR-1522D) attached to the door of the measurement chamber, see Fig. 4.1. The projected area of the driver diaphragm (S_d) of a single driver was 775 cm^2 and the linear excursion (X_max) 21 mm. A DA converter with a frequency response going down to 0.1 Hz

(Nuforce uDAC3 Revision 1) was used and due to some air leaks from this pressure chamber, the frequency response began to drop from 1 Hz down. Therefore the lowest frequencies of the stimuli had to be amplified to get the -3 dB limit down to 0.1 Hz. The maximum pressure in a complete tight chamber (without an acoustic short circuit) would have been 122 dB using the linear excursion value of the driver (132 dB using the X_{mech} value).

Figure 4.1: Loudspeaker drivers attached to the reinforced door of the measurement chamber were hidden behind a curtain during tests.

Experiments were run using Presentation software version 21.1 (Neurobehavioral systems, Berkeley, CA) on a standard Windows 10 based workstation. Responses were collected using a standard keyboard where response keys were labelled with markers.

4.7 Sound Stimuli

The stimuli were selected from the recordings carried out in sound measurements sub-study, see Ch. 2. The objective was to select the samples, which present the worst-case scenario: the selection criteria was to search for the highest infrasound and amplitude modulation levels. In Figure 4.2, as an example, the frequency contents of the selected indoors sample, which was used in the baseline with infrasound test (see Table 4.2). The linear equivalent sound pressure level for that sample was 86 dB, the highest value at the point when the samples had to be selected to the provocation experiments. The L_Z value over the whole measurement period was 67 dB and even higher values were measured later during the long-term measurement campaign (see Fig. 2.12).

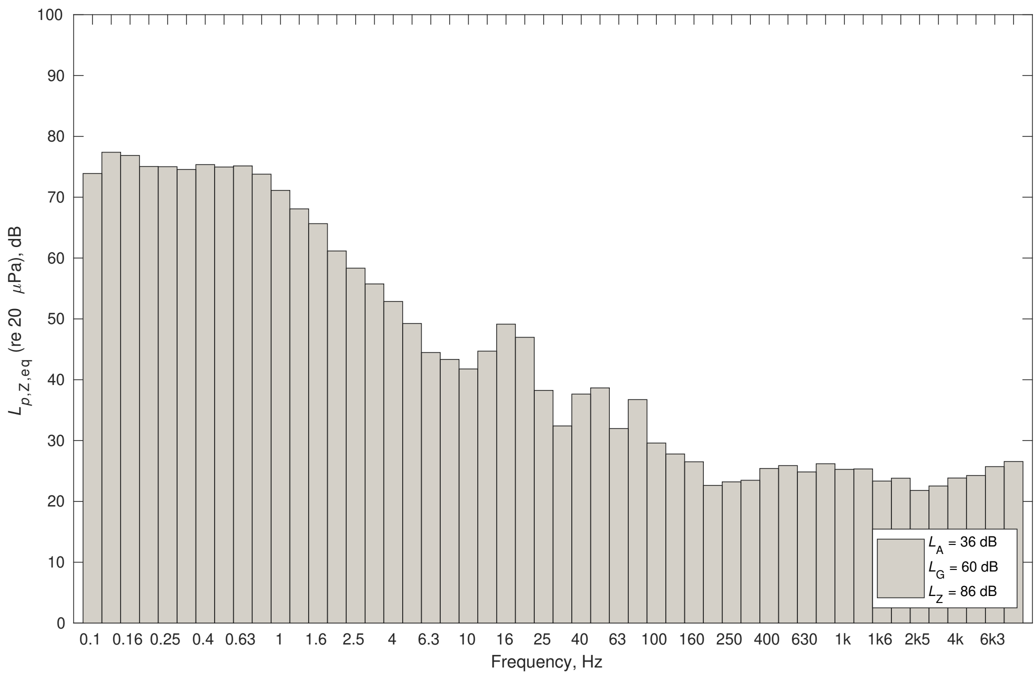


Figure 4.2: Frequency contents of the selected sample from Raahe, indoors data.

The length of the stimuli was selected as long as possible, but still meaningful for the comparison of sound samples. Increasing the length of the sound samples would have led to unbearably tiresome experiments. No experimental data exist to be used as a reference for infrasound stimuli length. However, it is known, that a duration of several periods of sound is needed to create a perception of real pitch of the sound.[63] Pitch was not the subject of research, but this was a known psychoacoustic descriptor with some research information. Extrapolation can always be questioned but in this case it is the only way to estimate the minimum length of the stimuli in the infrasonic frequency range. Based on the extrapolation of the original experimental data shown in Bürck et al. 1935[63], a stimuli length of 3.1 s would be needed for a pitch perception of 1 Hz stimuli (see Fig. 4.3). The dominant frequencies of WTS are around 1 Hz.

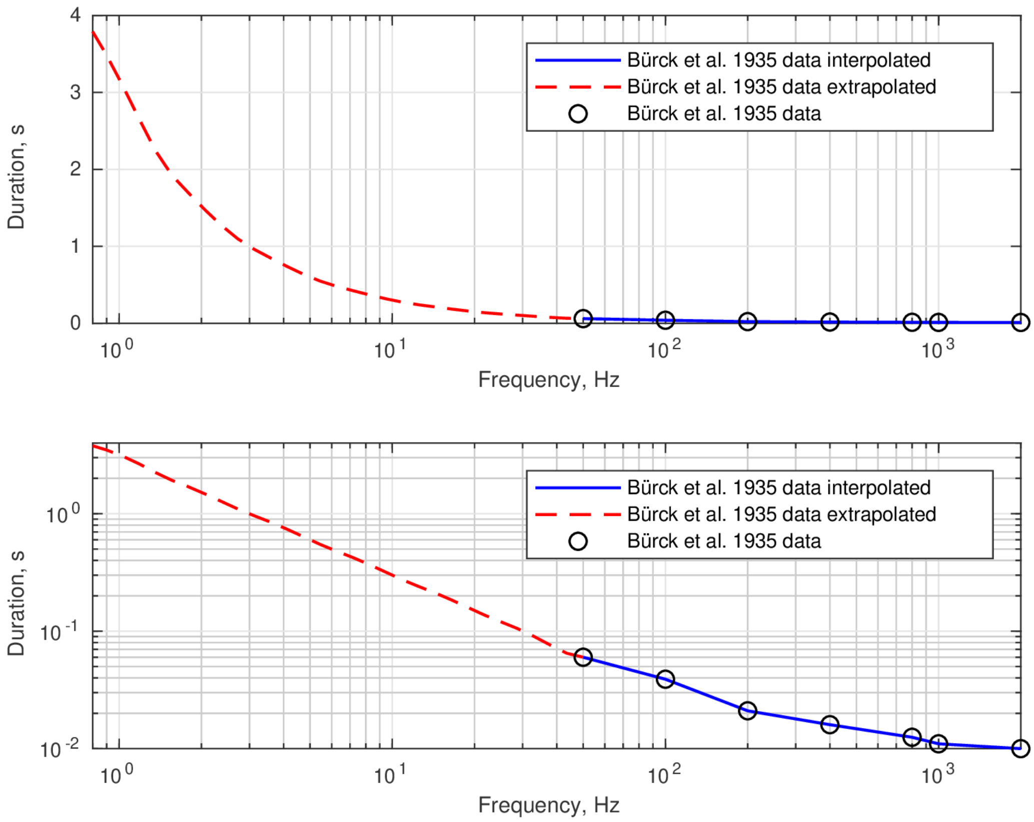


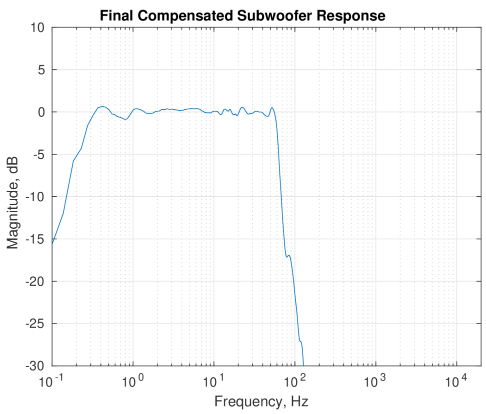
Figure 4.3: The minimum duration of a stimuli required for pitch perception. Semilog and loglog presentations. Adapted from Bürck et al. 1935.[63]

Table 4.2: Sound stimuli in the experiments

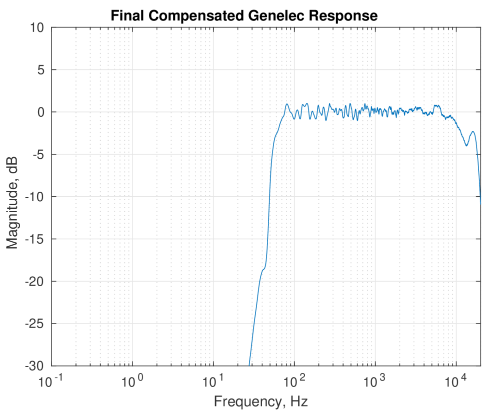
Study condition	Number of samples	Filter	Description
Baseline A	1 / –	LP20Hz	Immission outside (IS only, length 447 s), see Sec. 4.8
Baseline B	1 / –	LP20Hz	Immission outside (IS only, length 447 s), see Sec. 4.8
Detection	10	HP20Hz	Immission inside
	3	HP20Hz	Immission outside maxSPLmaxAM
	2	HP100Hz	Immission outside maxSPLmaxAM
	2	HP20Hz	Immission outside medSPLminAM
	3	HP100Hz	Imission outside medSPLminAM
	3	HP20Hz	Emission maxSPLmaxAM
	2	HP100Hz	Emission maxSPLmaxAM
	2	HP20Hz	Emission medSPLminAM
	3	HP100Hz	Emission medSPLminAM
Annoyance	3	HP20Hz	Immission outside maxSPLmaxAM
	2	HP100Hz	Immission outside maxSPLmaxAM
	2	HP20Hz	Immission outside medSPLminAM
	3	HP100Hz	Immission outside medSPLminAM
	3	HP20Hz	Emission maxSPLmaxAM
	2	HP100Hz	Emission maxSPLmaxAM
	2	HP20Hz	Emission medSPLminAM
	3	HP100Hz	Emission medSPLminAM
	5	HP20Hz	Pleasant control
Baseline C	–	–	No stimuli

4.7.1 Compensating Filters

The frequency responses of the sound sources were measured and compensating filters designed. The subwoofers were responsible for the low frequency range up to 50 Hz and one Genelec loudspeaker took care of the higher frequencies, see Figure 4.4. The digital filters were optimized so that the total sum response from both the Genelec loudspeaker and subwoofers was within 1 dB down to 0.25 Hz (Fig. 4.5) at the listener's ears.



a) Subwoofers



b) Genelec

Figure 4.4: Digitally compensated frequency responses of the sound sources.

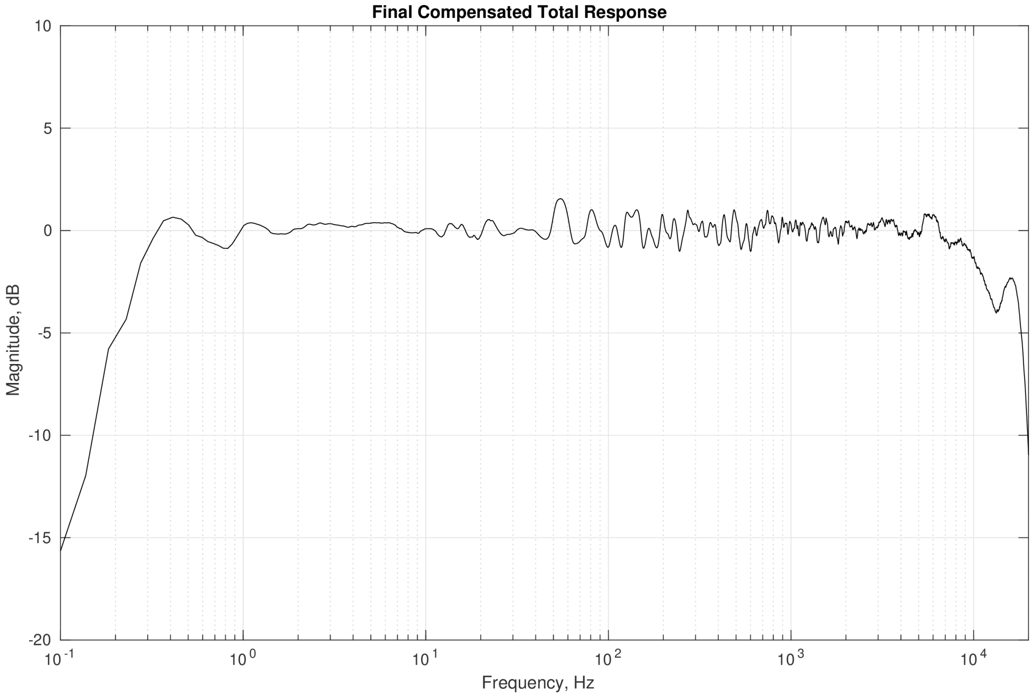


Figure 4.5: Final frequency response of the infrasound laboratory setup.

4.7.2 Preparation of Samples

A software was programmed to prepare the samples for playback in the test chamber. The original, recorded files, an their calibration signals were given as input to the software, and a common calibration signal for all the signals was generated. Further, the software adjusted and filtered the samples for playback in the infrasound test chamber.

The implemented software generates a system calibration signal which contains two frequency components: a 20 Hz and a 200 Hz sinusoidal at a 80 dB sound pressure level. This signal was used to adjust the sound levels in the test chamber to match the original sound levels of the sound samples. Also, the research nurses used this system calibration signal before and after every test in the test chamber to check the signal levels and proper operation of the sound system.

Several IIR (infinite impulse response) and FIR (finite impulse response) filters were designed. The type of the low-pass and high-pass filters was a fourth-order IIR with a 0.5 dB pass-band ripple and the type of all the compensating, inverse, filters was FIR with lengths between $2^{14} - 1$ and $2^{18} - 1$.

A low-pass and a high-pass filter was needed to forward the correct frequency content to the sound sources (see Sec. 4.7.1). For the test plan, a low-pass and a high-pass filter at 20 Hz, and a high-pass filter for 100 Hz was designed. The original sample was filtered to two separate channels, to a low and a high frequency channel. Also, the unideal response during recording was corrected using an inverse filter to compensate the unique microphone and unique AD (analog to digital) converter channel responses. Finally, an inverse room response FIR filter was applied to compensate the unideal responses of the sound system in the test chamber, both signal ends were windowed using a 25 ms Hanning window, and signals were multiplied with unique coefficients based on the original calibration signals of the samples.

All the filters were tested carefully. To estimate the uncertainty and error due to the filters, the whole whole signal path with the filters and windowing was tested by putting pure sinusoidal samples through the signal path. The following attenuations were found at the calibration signal frequencies, 250 Hz and 1000 Hz, see Table 4.3.

Table 4.3: Attenuation due to filters at selected frequencies

Filter	250 Hz	1000 Hz	Description
Left	150.7 dB	201.6 dB	Subwoofer channel filter
Right	−0.5 dB	−1.3 dB	Genelec channel filter
LP20Hz	165.2 dB	196.8 dB	Low-pass at 20 Hz
HP20Hz	121.1 dB	159.5 dB	High-pass at 20 Hz
HP100Hz	−0.5 dB	−0.4 dB	High-pass at 100 Hz

4.8 The Presentation of the Sound Stimuli

For the stimuli in the provocation experiments, see Table 4.2. In the baseline experiments, the infrasound was presented either in the first or the second baseline. The same pseudorandomization applies to the annoyance experiment: the order of infrasound blocks was varied. Infrasound was present in the stimuli in every other block, and the experiment started with either block containing or not containing infrasound.

Figure 4.6: A right-handed person in the listening test. A cross laser scale beam was used in positioning the subject to the optimal location.

Since the sound samples also included audible sound and the frequency response was optimized at one location of the head, the subjects were positioned so that the location of the ears was the same for all. A cross laser scale was used as an aid, see Fig. 4.6.

In the following subsections each of the paradigms is presented in detail.

4.9 Infrasound Detection Experiment

4.9.1 Procedure

A two-interval same-different task was used. In a same trial (50% of trials) observer was sequentially presented with two identical wind turbine sound samples, separated with 500 ms of silence. In a different trial, one of the

Table 4.4: The structure of the laboratory study

Experiment	Duration in minutes	Contains infrasound	Description
Audiometry		no	
Baseline A	7 / 5	yes / no	Baseline with/without infrasound, see Sec. 4.8
Baseline B	7 / 5	yes / no	Baseline with/without infrasound, see Sec. 4.8
Detection 1	9	yes	Infrasound sensitivity/detection experiment
Detection 2		yes	
Detection 3		yes	
Detection 4		yes	
Detection 5		yes	
Annoyance 1	10	no	Annoyance experiment
Annoyance 2		yes	
Annoyance 3		no	
Annoyance 4		yes	
Annoyance 5		no	
Annoyance 6		yes	
Baseline C	5	no	
CPT	3	no	Cold pressure experiment
Cognitive instruction 1		no	Instruction: infrasound present
Cognitive instruction 2		no	Instruction: infrasound not present

samples (chosen randomly) was high pass filtered. Then, a response screen was shown, and the observer's task was to indicate by using the keyboard, whether the sounds were identical or not. After the response there was a random wait of 200–400 ms before the start of the next trial.

Three stimulus conditions were tested: 40 trials had noise samples obtained from a wind power plant (WPP) area, 40 from yards near residential dwellings and 40 were selected from recordings inside the residential houses.

Half of the trials had two identical, unfiltered samples whereas half of the trials had one sample being filtered. In the WPP area and yard conditions, both 20 Hz high pass filter and 100 Hz high pass (in the audible range) were used. In the indoors condition only 20 Hz filter was used. All stimulus conditions were randomly interleaved. The total number of trials per condition was 40. Experiment consisted of 5 blocks of 24 trials and each block lasted about 9 minutes. The order of the blocks and the trials within the blocks was randomized. Observers had possibility to rest between the blocks. Before the actual experiment, a practice block was presented. The practice block contained 3 trials and it was not included in the final data analysis.

4.9.2 Data Analysis

Detectability of infra- and low-frequency wind turbine sound components was analyzed using signal detection theory (SDT) measures[64]. The analysis allows to separate the true sensory-based sensitivity for stimulus (discriminability index d') independently of observer's subjective response criterion (i.e. the bias towards particular response). For the analysis the proportion of "different" responses in the different trials (true positive rate or hit rate, p_{11}) was calculated. This was then compared with the proportion of "different" responses in same trials (false positive rate, or false alarm rate p_{10}). The discriminability index d' is the obtained from the Z-scores of hit and false alarm rates by

$$d' = Z(p_{11}) - Z(p_{10}) \tag{4.1}$$

where Z is the inverse of the standard cumulative normal distribution. d' can be interpreted as true sensory response separation between the same and different trials, divided by the common standard deviation of the response. $d' = 0$ implies no sensitivity (i.e. the observer responds at the chance level) whereas the higher values imply that two stimuli can be more readily discriminated. An unbiased observer would correctly discriminate about 69% of the trials when $d' = 1$ and 84% when $d' = 2$.

4.9.3 Results

Figure 4.7 shows the average sensitivity (d') to 20 Hz and 100 Hz high-pass filtering for wind power plant area, yard and indoors sound samples. It was tested whether average sensitivity in each condition was above chance level ($d' = 0$) by using one sample t-tests. t-tests were corrected for multiple comparisons using false discovery rate correction[65] so that q type I error rate was $q \leq 0.01$.

Average sensitivity for 20 Hz infrasound is very low (wind power plant area: M_{20} = 0.21, SD = 0.44; yard: M = 0.21, SD = 0.45; indoors: M = -0.17, SD = 0.45) and not statistically different from 0. On the other hand, sensitivity for 100 Hz

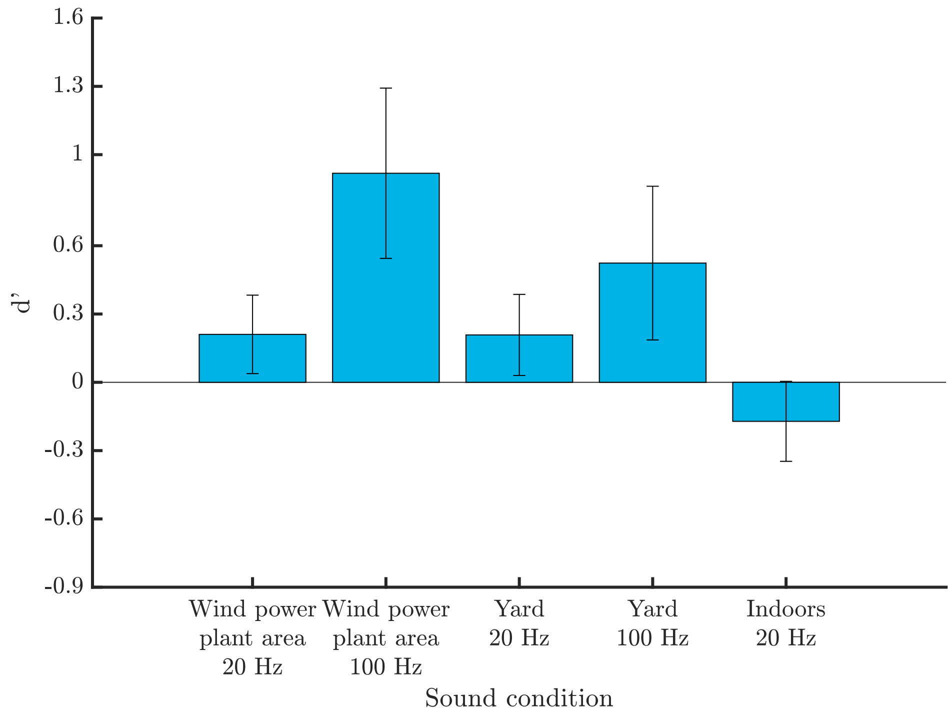


Figure 4.7: Results of infra- and low frequency sound discrimination experiment. d" shows the average sensitivity to low-frequency components in wind turbine noise ($d'' = 0$ is the chance level) recorded in different sites (Wind power plant area, yards, indoors). Sounds were high pass filtered at infrasound cut-off (20Hz) or low frequency audible range (100Hz) range. Error bars show 95% confidence intervals.

filtering samples is larger on average, and wind power plant area 100 Hz condition sensitivity is significantly above the chance (M = 0.92, SD = 0.95). In the yard, 100 Hz samples cannot be discriminated above the chance level M = 0.52, SD = 0.86).

Figure 4.8 shows the average sensitivity separately for the group that has attributed the wind turbine sound as a source of various health symptoms in the questionnaire (WTRS group; "symptoms") compared with participants that did not report health effects ("no symptoms"). Sensitivity for infrasound shows no systematic differences between the groups; on average the group that reported health effects is less sensitive to infrasound recorded in wind power plant area, yard and indoors. The statistical significance of the difference was tested using repeated-measures ANOVA model where stimulus condition was the within-subjects variable, and WTRS group the between-subjects variable. Greenhouse-Geisler correction was used because of the lack of sphericity. A statistically significant effect of stimulus condition $F(2.158, 51.801) = 4.502; p = .044; \eta_p^2 = 0.219$ was found but the difference between the WTRS group and group with no symptoms was not significant ($F(1, 24) = 0.400; p = .533; \eta_p^2 = 0.016$).

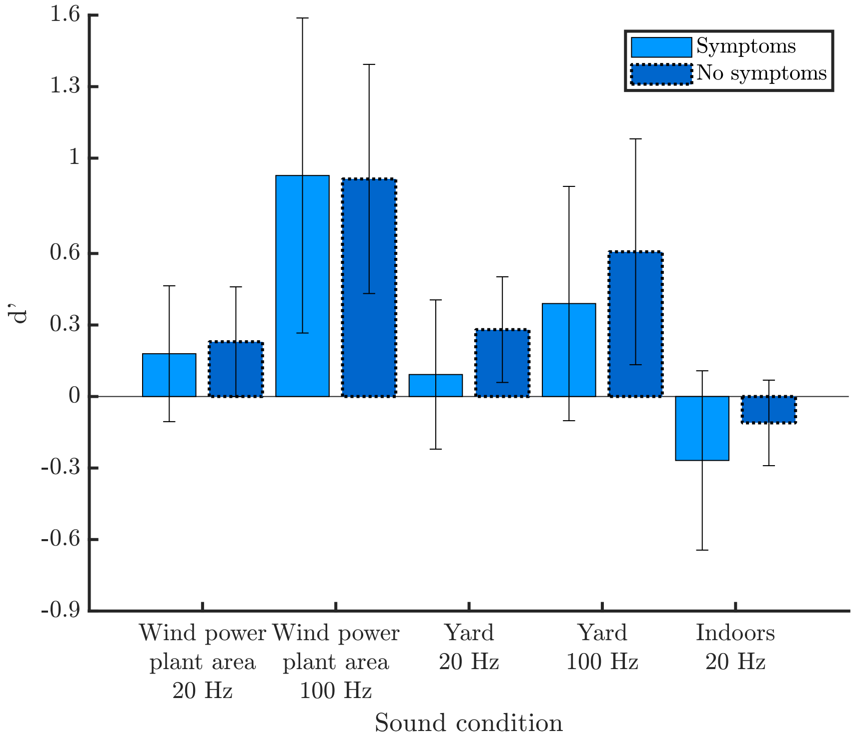


Figure 4.8: Results of infra- and low frequency sound discrimination experiment, analyzed separately for the WTRS group that reported wind turbine related health symptoms (Symptoms) and for the group that reported no health symptoms (No symptoms). The 100 Hz conditions have been filtered at the low frequency audible range and 20 Hz at the infrasound range. Error bars show 95% confidence intervals.

4.10 Wind Turbine Sound Annoyance Experiment

4.10.1 Stimuli and Procedure

The task in this experiment was to rate the annoyance of wind turbine and reference sounds. In each trial, a test sound was presented for 10 seconds followed by a response screen where observer was asked to rate the annoyance of the sound using keyboard numeric keys and 11 – point scale from 0 (not annoying) to 10 (very annoying).

Wind turbine sound recording site (wind power plant area or yard) and amplitude modulation (AM; minimum or maximum) was varied. In addition, a nature sound condition (sea shore sounds) was used as a neutral/pleasant control sound. In half of the experiment blocks, all sounds were filtered to not contain infrasound frequencies, by using 20 Hz high pass filter. In addition, half of the neutral control sounds were presented with infrasound that was extracted from wind turbine sound stimuli, while half of these neutral control sounds were filtered by using 20 Hz high pass filter. Thus, a total of 10 stimulus conditions was tested. Each block consisted of 50 trials where different stimulus conditions were presented with different conditions randomly interleaved. Each block was either filtered or unfiltered. One block took about 10 minutes, and in total experiment consisted of 6 blocks (total time about 1 hour). In the beginning of the experiment, there was a practice block of 10 trials, which was not included in the data analysis.

4.10.2 Results

In Figure 4.9 the average annoyance ratings for sounds in different conditions are shown. Wind power plant area recording sites show the highest annoyance ratings, followed by yard and nature sound. Amplitude modulation seems to have some effect, especially in the yard condition. However, the presence of infrasound does not seem to have any systematic effect on average ratings.

Statistical significance of the ratings was assessed using a repeated-measures ANOVA. Recording site (2 levels), amplitude modulation (2 levels) and presence of infrasound (2 levels) were used as within-subject factors and WTRS as the between-subjects factor (2 levels: symptoms / no symptoms). The effect of recording site was statistically significant ($F(1, 24) = 67.394$; $p < .001$; $\eta_p^2 = 0.737$) as well as the effect of amplitude modulation ($F(1, 24) = 58.853$; $p < .001$; $\eta_p^2 = 0.710$). The presence of infrasound did not have a statistically significant effect on reported annoyance $F(1, 24) = 0.788$; $p = .382$; $\eta_p^2 = 0.032$).

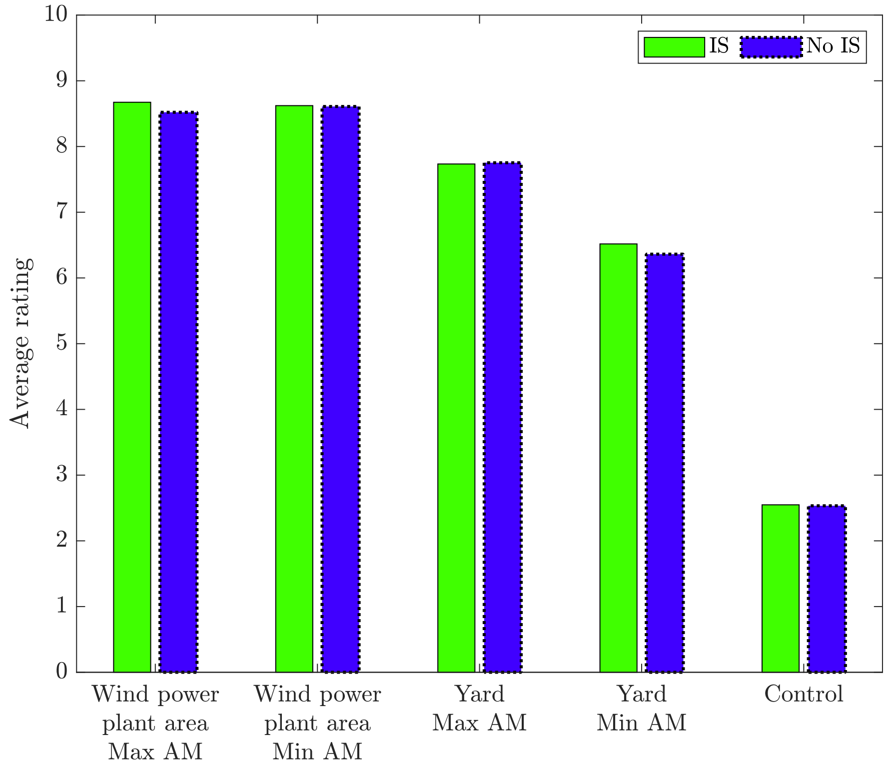


Figure 4.9: Results of wind turbine sound annoyance experiment where participants rated how annoying various wind turbine and reference sounds were (scale: 0 not annoying – 10 very annoying). Bars show average ratings for sounds recorded in wind power plant area, yard and neutral/pleasant control sound (ocean beach). The effect of sound amplitude modulation (AM) was tested by comparing samples gathered from AM maximum and minimum. Green bars show ratings for unfiltered sounds with infrasound frequencies, blue bars show ratings for sounds where infrasound components were filtered (at 20 Hz cut off).

Figure 4.10 shows the average annoyance ratings separately for the WTRS group that reported wind turbine related health symptoms, and for the group who did not report any symptoms. In general, the WTRS group rated the sounds (including the nature sound control) more annoying than the group with no wind turbine sound related symptoms. However, the difference was not statistically significant $F(1,24) = 2.270; p = .145; \eta_p^2 = 0.086$.

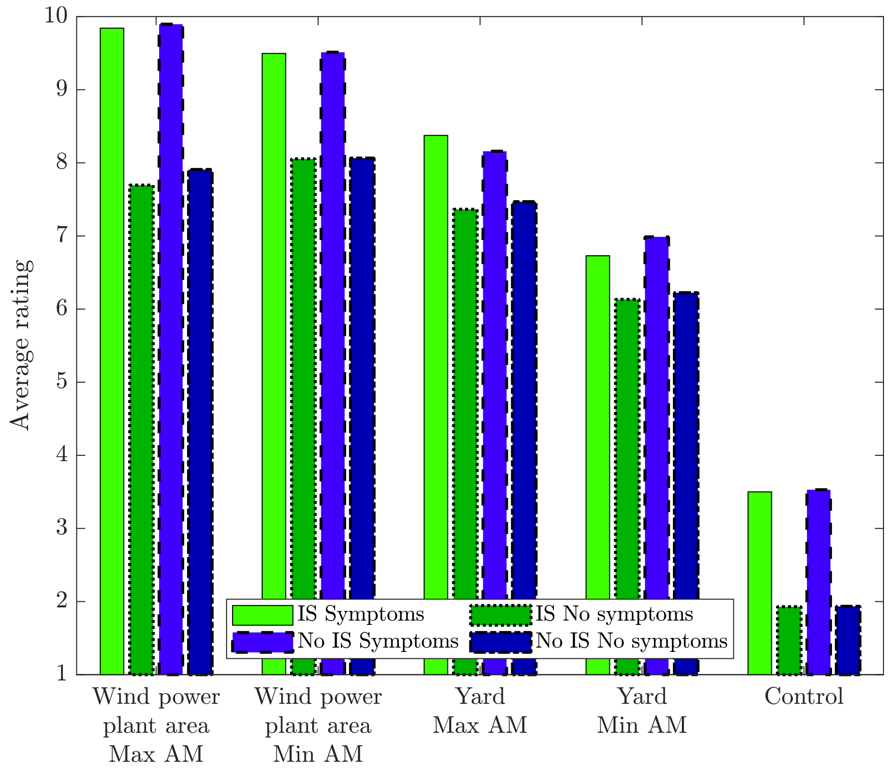


Figure 4.10: Rated annoyance of wind turbine sounds and control sound (ocean beach), analyzed separately for the WTRS group and for the controls Green bars show ratings for unfiltered sounds with infrasound frequencies, blue bars show ratings for sounds where infrasound components were filtered (at 20 Hz cut off).

4.11 Psychophysiological Responses

The purpose of the psychophysiological recordings was to measure the participants' autonomic nervous system (ANS) reactions to the actual and supposed wind turbine noise stimulation, to the potential annoyance of the stimulation, to a well-known controlled stress stimulus (cold pressure test, CPT), as well as baseline physiology. The ANS reactivity was measured during all experimental conditions as changes in both cardiac (electrocardiography, ECG), and electrodermal activity (EDA). This combination allows a partial separation of the sympathetic and parasympathetic activation of the ANS. The EDA is only controlled by the sympathetic nervous system, while the cardiac metrics are mediated by both the sympathetic and the parasympathetic branches.

During the psychophysiological recordings, the participants were seated in a soundproofed measurement chamber. The biosignals were recorded continuously (0–125 Hz, sampling rate 500 Hz) using a NeurOne EXG40 amplifier (Mega Electronics Ltd, Kuopio, Finland). ECG data were collected from 2 disposable Ambu BluSensor electrodes situated at the lower left rib cage and upper right collarbone. EDA were recorded from non-dominant hand, with electrodes placed to the palmar side of the proximal phalanges of the index and the middle fingers. Breathing was measured using an Xrtrace Embla breathing Respiratory Effort Belt (Embla Inc., Broomfield, Colorado, United States). The upper belt was placed around the chest below the arm pit and the lower belt was placed one palm width above the participant's belly button, under the shirt, on bare skin.

We also recorded eye movements by electro-oculography (EOG) and facial muscle activity by electromyography (EMG) using reusable Ambu neuroline cup (REF 72615-M/10) electrodes on the skin. Three of the electrodes were placed around the left eye, two above and one below, while the fourth electrode was placed above the right eye. The ground electrode was placed at left mastoid, and the reference on the forehead. The EOG and EMG data have not yet been analysed and are excluded from the report.

4.11.1 ANS Recordings During the Baselines, and Cognitive Instruction Test

The measurements were done in five blocks (see Table 4.4). During the first two blocks (Baselines A and B) the participants were instructed to watch a silenced video film while their baseline physiology, both the ECG and EDA were recorded. During the 7.5-minute block, wind turbine infrasound was played on the background, while there was no stimulation during the 5-minute block. The order of these two blocks was counterbalanced between the participants. The purpose of these two conditions was to examine whether the ANS responses measured in the presence of the wind turbine infrasound would differ from those measured in the absence of the wind turbine infrasound, when the participants were not aware of the simulation nor the presence of the wind turbine infrasound.

The third block, Baseline C, preceded the cold pressure test and served as a baseline for the CPT. During this 5-minute block the participants again watched a silenced video film, with the instruction that baseline will be recorded. No sound stimulation was presented.

During the last two 5-minute blocks (Cognitive instruction test 1 and 2) there was no sound nor infrasound stimulation, and the blocks differed in the information that was given on the stimulation immediately prior to the measurement. During the other video the participants were informed that there is no infrasound, and during the other they were informed that wind turbine infrasound is in the background. Again, the order of these two blocks was counterbalanced between participants.

4.11.2 ANS Recordings During Detection and Annoyance Experiments

ECG and EDA were also recorded during the two active conditions (Listening tests in Table 4.4): the detection experiment and the annoyance experiment. In the annoyance experiment, the purpose was to compare the ANS responses during those three experimental blocks that were filtered to exclude infrasound frequencies to those blocks that contained infrasound. In the detection experiment, the comparisons were made between groups only, to investigate whether the WTRS group would differ from the control group in their arousal and stress level while evaluating the sound stimuli.

4.11.3 ANS Recordings During the Cold Pressor Test

The purpose of the cold-pressure test (CPT) was to measure the strength of the individually varying autonomic nervous system (ANS) stress response. This could be used to calibrate the individual differences in stress reactivity. Secondly, a widely used and well-known CPT was included to verify the validity of the ANS measurements conducted in the study.

Before the test, baseline physiology was recorded for 5 minutes (Baseline C), while the participant was watching a silenced nature video (edited in order to remove all arousing content). In the cold pressure test, a bucket of water that was kept at 4–5 degrees Celsius, was brought to the measurement chamber. The participants were asked to immerse their dominant hand up to the wrist in the water for three minutes. The participants gave their stress and pain level from 1–10 (1= no stress/pain at all, 10 = extreme stress/intolerable pain) before (at baseline) immersing their hand, after every minute during the test (three times), and 5 minutes after (recovery) the test. The participants gave their rating orally, and the research nurse marked the rating.

4.11.4 Data Processing

For data processing, the different biosignals were separated from the recording files and the parameters were individually extracted for each stimulation block.

The cardiac activity was analyzed via MATLAB® [35]. Mean heart rate (HR) and the most commonly used metric for heart rate variability (HRV), root mean square of successive inter-beat-intervals (RMSSD) during each stimulation block were extracted for statistical analysis. Heart rate (HR), measured as number of beats per minute (bpm) increases with increasing stress[66,67], whereas the RMSSD decreases as a consequence of stress[66–68].

The electrodermal activity was analyzed using the Ledalab-toolbox (v.3.4.8) for MATLAB. The analysis produced two skin conductance variables: the skin conductance response (SCR) and the skin conductance level (SCL) for each stimulation block. The slowly varying SCL represents the overall state of the parasympathetic arousal and is modulated by internal factors but also external factors, such as room temperature. SCRs, on the other hand, can be elicited by direct orientation to external stimuli[69] or by non-specific responses to emotionally arousing conditions[70]. The SCR are caused by the burst-like activation of the postganglionic sudomotor fibres of the sweat glands. SCR component is thus generally considered to be more useful indicator for emotional arousal like stress than the SCL or the raw SC signal. Thus, the SCR was selected for further statistical analysis.

4.12 Statistical Analyses of the ANS Responses

4.12.1 Cardiac Features HR and RMSSD

For the cardiac features HR and RMSSD two-tailed t-tests were conducted to compare differences between groups (two-sample t-tests assuming unequal variances) and between conditions (paired t-tests).

First, it was examined whether the HR and the RMSSD differed during the passive conditions with respect to the presence of infrasound (infrasound present vs. infrasound not present; Baseline A & Baseline B) or with respect to the instruction given (instruction when no sound was played: infrasound vs. no infrasound; Cognitive instruction test 1 & 2). The within-participant comparisons were conducted for the two groups (WTRS and controls) separately, but also for the entire participant group including both WTRS and controls.

Second, the effect of infrasound on HR and RMSSD during the annoyance experiment was examined, again, both by combining all participants to a single group and also for the two groups (WTRS and controls) separately. The HR and the RMSSD during those three blocks that included infra sound were compared to those three blocks that did not include infra sound.

Third, the HR and RMSSD during the detection experiment were compared between the WTRS group and the control group in order to investigate whether the WTRS group would exhibit increased stress while evaluating the sound stimuli.

Finally, the HR and the RMSSD during the baseline recording before the CPT (Baseline C) test were compared to those during the CPT, separately for the WTRS and the control group. Also, the HR and the RMSSD during the the baseline preceding the CPT were compared between the control and the WTRS group, and the HR and RMSSD during the CPT were compared between groups.

4.12.2 Skin Conductance Responses

For the EDA, the number of spontaneous SCR spikes, and the sum amplitude of those spikes within each block were used as the metrics for electrodermal activity, as there were no clear stimulus-response reactions to which the analysis windows for electrodermal responses could be tied to.

The first comparison was between the first two passive listening conditions (watching silent nature video with or without infrasound stimulation; Baseline A and B), with the passive baseline condition (silent nature video; Baseline C) with no infrasound stimulation, and the CPT condition as control conditions for electrodermal reactivity. The second comparison was made to investigate whether the presence of infrasound had any effect in the annoyance experiment. The third comparison compared the difference between the two instructions (infrasound present or not present) in the Cognitive instruction test.

A two-way Anova compared the test condition and symptom group as the independent variables, and the test metric (number of SCR spikes / sum amplitude of SCR spikes) as the dependent variable in each phase.

4.12.3 Rating of Stress and Symptoms

Between the experiments the participants were asked to report their stress level (Stress inquiry) at eight occasions with a scale from 0 (not at all) to 10 (very much). Stress and pain were also inquired at 1 min, 2 min and 3 min of the cold pressure test (CPT). During the experiment day, the participants were encouraged to report if they experienced symptoms. At the end of the day, the participants evaluated, how strainful the experiments had been and gave overall feedback.

4.13 Results

4.13.1 Cardiac Features HR and RMSSD

No statistically significant differences were found in any of the comparisons, except for the cold pressure test (CPT). In the CPT, the mean HR increased significantly from the preceded baseline measurement (Baseline 3) for both the control group (mean HR during baseline 64 bpm vs. mean HR during water immersion 73 bpm, $t17 = -5.25$, $p < 0.001$) and for the participants of the WTRS group (mean HR during baseline 69 bpm vs. mean HR during water immersion 75 bpm, $t9 = -4.82$, $p < 0.001$).

4.13.2 Skin Conductance Response

No significant difference between the symptom groups was detected during the baseline and the CPT conditions (number of spikes: F(1)=0.019; p=.893; amplitude sums: F(1)=0,033; p=.856), see Figure 4.11. The difference between the conditions was highly significant for both measures (number of spikes: F(3)=20.207, p<.000; amplitude sums: F(3)=10.629, p<.000), but no interaction between these two was found (number of spikes: F(3,1)=0.118, p=.949; amplitude sums:F(3,1)=0.185, p=.906). A post-hoc Tukey test revealed that the CPT condition differed significantly from the baseline conditions for both

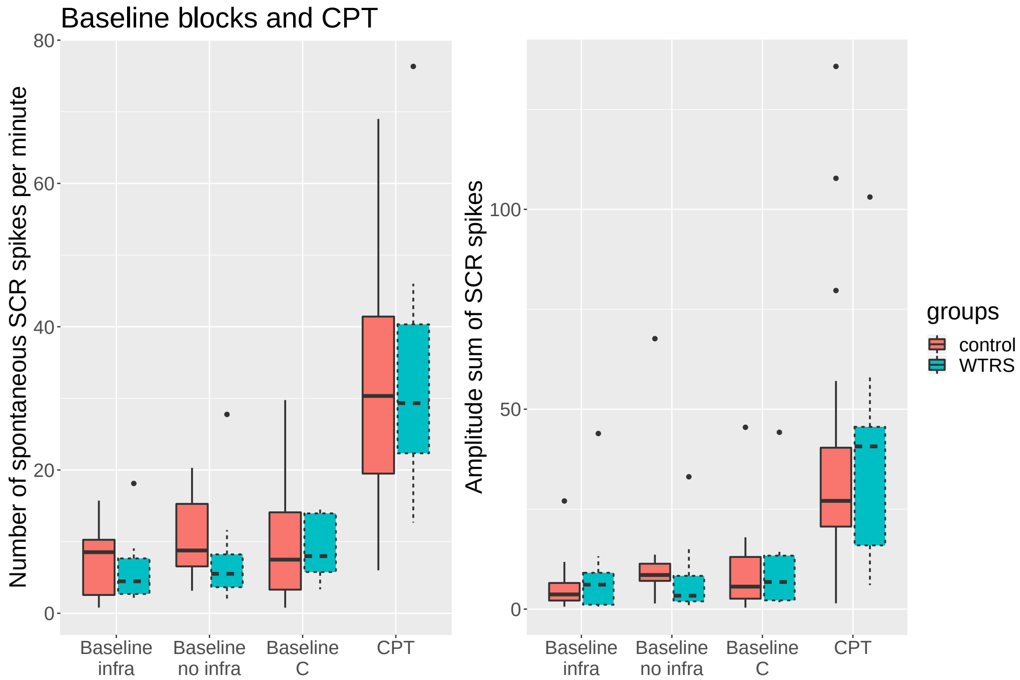


Figure 4.11: The number and sum amplitude of SCR peaks between the baseline and the CPT conditions. Baselines A and B are reclassified based on whether infra sound was presented during the block.

measures (p<.000), but there was no difference between the different baseline conditions.

In the annoyance experiment (see Figure 4.12), no statistically significant differences were found for any of the comparisons or their interactions. The same applies to the cognitive instruction test (see Figure 4.13): the EDA metrics showed no statistically significant differences between the instruction conditions in either of the symptom groups.

4.13.3 Reported Stress and Symptoms

It was observed during the whole course of the experiment that self-reported stress levels elevated in WTRS group. As can be seen in Figure 4.14, the two groups reported similar stress levels until the WTN annoyance task. From there onward, the symptomatic group reported greater stress than the asymptomatic group. There was a statistically significant interaction between time and group

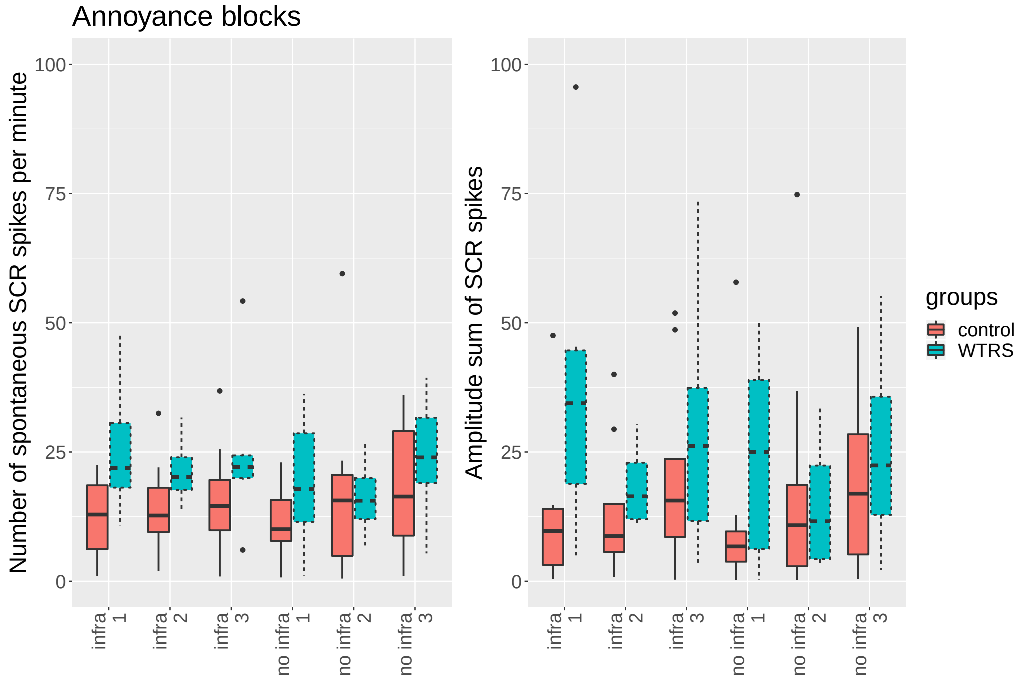


Figure 4.12: The number and sum amplitude of SCR peaks in different phases of the annoyance test, classified based on the presence of infrasound.

in ($F(1, 214.0) = 10.56, p = 0.001$). The main effect of group was not significant ($F(1, 64.237) = 0.09, p = 0.76$) while the main effect of time was significant ($F(1, 214.0) = 32.76, p < 0.001$), although these results should be interpreted with caution in light of a significant interaction.

Moreover, the WTRS group, six out of 11 individuals reported symptoms during the sections, compared to no symptoms but minor sensations in two out of 15 controls. Out of all 19 separate symptoms/sensations in 8 individuals, only five was during infrasound exposure. During the Cognitive instruction test, 6 separate symptom reports were given by the WTRS goup and 1 sensation by the control group.

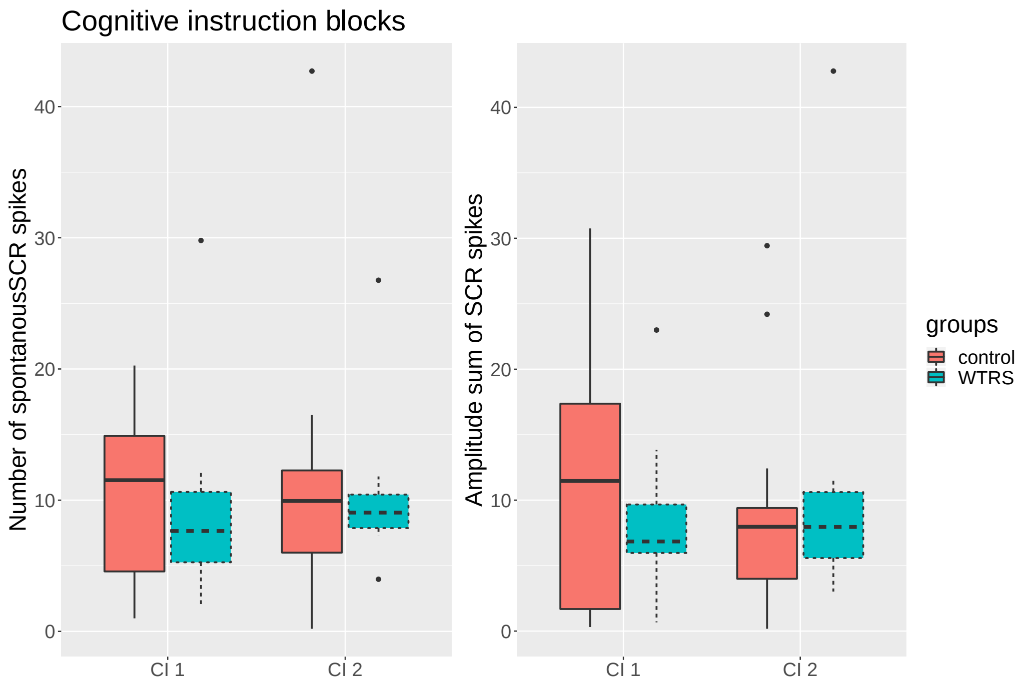


Figure 4.13: The number and sum amplitude of SCR peaks in the cognitive instruction test, classified based on whether the subject was/was not told whether infra sound would be presented during the block.

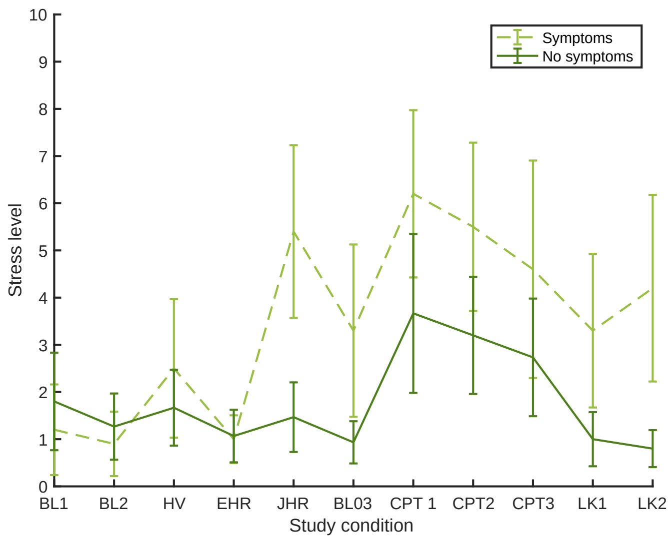


Figure 4.14: Self reported stress level during the course of the experiment. Symptoms: WTRS symptoms group; No symptoms: participants that reported no WTRS symptoms. Error bars show 95% confidence interval.

5 Discussion

Some people living near wind power plants have reported symptoms which they have intuitively associated to wind turbine infrasound. The aim of this project was to find out whether wind turbine infrasound has harmful effects on human health. Long-term field measurements were conducted to characterize wind turbine noise as an exposure also indoors. The questionnaire study aimed at describing symptoms intuitively associated with infrasound from wind turbines. The provocation experiments were performed to study how infrasound produced by wind turbines affects humans, in particular, perception, annoyance, and physiological responses.

5.1 No Standards or Guidelines

There is no guidance for WTS measurements in the infrasound frequency range. The international standard for measuring emission levels of wind turbines IEC 61400-11:2012[34] gives some criteria which are possible to apply to some extent. The standard is for audible frequency range, from 20 Hz to 10 kHz. Annex A.2 of the standard mentions the measurement of infrasound and recommends the use of sound pressure levels when calculating the G weighting. The G weighting is the weighting for infrasound according to standard ISO 7196:1995[71]. However, the physical basis of the requirements or instructions for measuring equipment and methods do not directly extend to the infrasonic range. In infrasound measurements, taking into account the physical requirements, would cause major practical difficulties, for example in positioning sensors.

According to the standard[34], the microphone should be placed on a plate at least one meter in diameter and if the plate would be extended in relation to the wavelength, it would become impractically large (the wavelength of a 0.1 Hz sound is over 3 km). On the other hand, there is no need for the plate because the lower the frequency, this boundary condition is approaching to the plate. It is straightforward to see this e.g. from the most widely used model for complex surface impedances, the Delany–Bazley equation[72], involving a direct and a reflected wave (5.1):

$$Z = 1 + 0.0571 \left(\frac{\rho_0 f}{\sigma_\mathrm{r}}\right)^{-0.754} + i0.087 \left(\frac{\rho_0 f}{\sigma_\mathrm{r}}\right)^{-0.732}, \tag{5.1}$$

where σ_r is the flow resistivity in Pa·s/m^2, f is the frequency, and ρ_0 is the static air density. In real life the value for flow resistivity of the surface is always greater than one (ideal, perfect absorption, no such exists), so the absolute value of the impedance Z increases, which means reflection to a incident wave — the function of the reflector plate.

Embleton et al. refined[73] the work of Delany and Bazley by taking into account also the ground wave, but the above also applies in his model (5.2):

$$Z = 1 + 9.08 \left(\frac{f}{\sigma_\mathrm{r}}\right)^{-0.75} - i11.9 \left(\frac{f}{\sigma_\mathrm{r}}\right)^{-0.73}. \tag{5.2}$$

Hansen et al. (2019) showed, that the measured sound levels could be up to 7 dB higher in measurements on the ground plate compared to a microphone at 1.5 m from the ground. However, they concluded, that measurements at ground level are advantageous at 1/3-octave frequencies below 50 Hz due to wind-induced noise.[74] In this report, a ground reflection correction would be justified for the A-weighted sound levels, but in the interests of consistency, the ground reflection corrections were omitted in all the results. At infrasound frequencies, it does not make sense to reduce the ground reflection from the final result, because the area of influence of the ground reflection extends high above the ground due to the large wavelength — from tens of meters to kilometers.

5.2 Evaluation is Different

Wind turbine sound is never a deterministic signal, instead, it is a random signal which only can be estimated by statistical means. In the statistical signal analysis theory the minimum time history of the samples as a function of frequency can be defined in terms of measurement uncertainty. Especially, when estimating infrasound levels below 1 Hz, the time history (calculation window length) have to be much longer than for higher frequencies. Because there was a need to estimate sound levels down to 0.1 Hz, a 10-minute calculation window was utilized. This time history comprises 60 waves, which is in a statistical sense equivalent to a 0.06 seconds time history for a 1 kHz signal. Respectively, the shortest typical time history for a proper estimate of a 1000 Hz signal is 10 seconds, which is equivalent to about 28-hour time history for a 0.1 Hz signal. Next, just for comparison purposes, also results from a shorter, very common 60-second equivalent level analysis is shown. For the Raahe indoors data, in Figure 5.1, the $L_{Z,60\ s}$ values are 14 dB lower than $L_{Z,600\ s}$ values in Figure 5.2. In G weighting the difference is only 1 dB and the A weighted values are similar, as it should be.

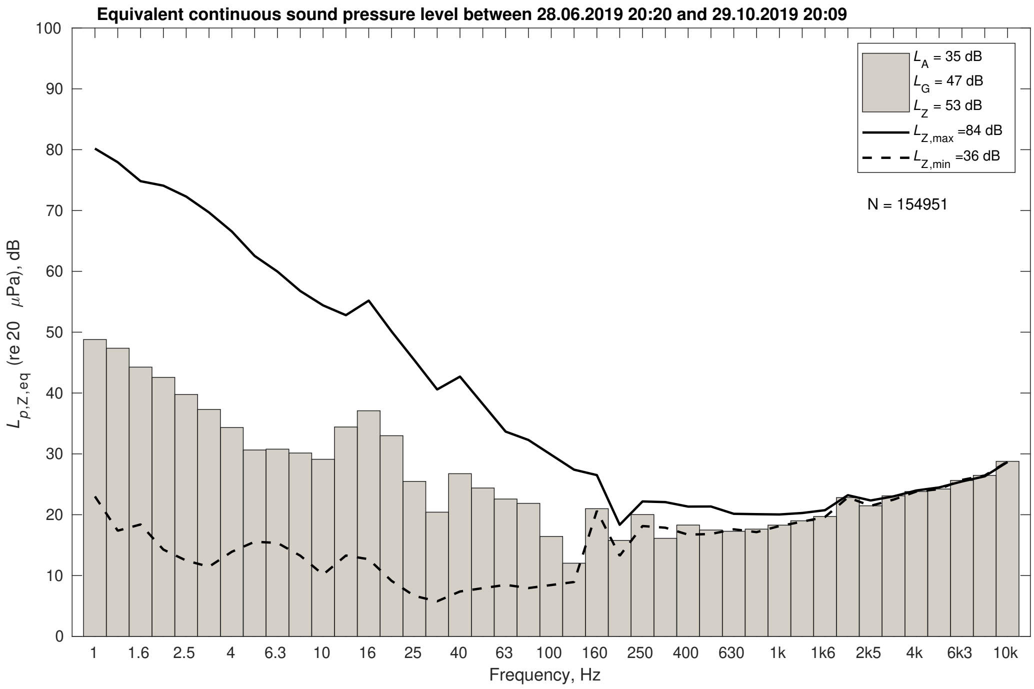


Figure 5.1: Raahe , indoors, third octave bands for all the validated data based on 60 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

5.3 Question About Data Validation

The analysis of a long-term measurement is always challenging. In reporting, the goal is always to use only valid data and to achieve this, each measurement should be carefully evaluated and validated. In this study, due to the large

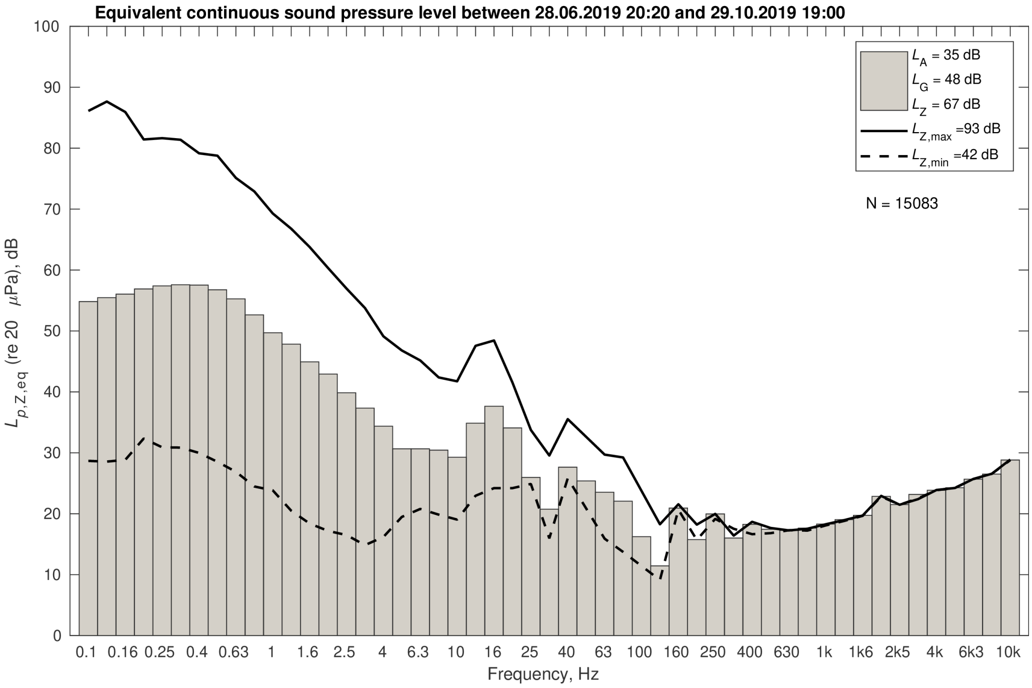


Figure 5.2: Raahe, indoors, third octave bands for all the validated data based on 600 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

amount of data, the evaluation was forced to be done as automatically as possible. All the automatic validation methods have their pros and cons. Algorithms based on machine-learning and artificial intelligence (AI) are considered to be the state-of-the-art and to become as standard validation methods in all environmental noise measurements[75]. However, in this study no AI algorithms for WTS was at hands and only a few rough evaluation algorithms were utilized, described in Section 2.3.1. It is very likely that the use of these algorithms eliminated some correct but also left erroneous measurements distorting the results.

5.4 Symptoms were Relatively Common

In the questionnaire study within 20 km around four wind power plants in Finland, the prevalence of symptoms intuitively associated with wind turbine infrasound was 5% (n=70) in the whole study population and 15% (n=34) within 2.5 km from the closest turbine. One third of the symptomatic respondents had consulted a doctor because of the symptoms. Similarly, one third considered their symptoms severe or affecting a lot on working capacity. The symptom spectrum was very broad covering several organ systems. Many of the symptomatic respondents reported being annoyed by audible wind turbine sound and associated their symptoms also with vibration or electromagnetic field from wind turbines.

It should be noted that in this study, the respondents' interpretation of the symptoms and their cause was of interest. The intention of this questionnaire was not masked and the evident emphasis on health problems could have led to higher reporting of symptoms than in questionnaires of more general nature. To our knowledge, there are no prior studies that have focused on the respondents' interpretation of the symptoms. Relatively high prevalence can also be explained by the selection of study areas. Areas assessed to have the most problems intuitively associated with wind turbine infrasound were identified based on a prior survey among interest groups. This allows us to characterize the magnitude of the problem as its worst but on the other hand, the results are not generalizable to all wind power plant areas in Finland. Since the reported results represent the worst case scenario, it can be assumed that the symptom prevalence is not higher in other wind power plant areas in Finland.

Another special feature of the study is that the number of inhabited dwellings and therefore also the number of individuals in the sample is low in the closest distance zone ($\leq$ 2.5 km from the closest turbine), and the number of respondents is even lower. This means that even one respondent can have notable effect on prevalence. For this reason it is useful to acknowledge the numbers of cases in addition to prevalence.

It could be speculated that the prevalence estimation is not reliable due to high non-response. However, in a telephone interview among 10% of non-respondents, symptom prevalence was not any higher when compared with the questionnaire study. In addition, it is typically seen in questionnaire studies that aged individuals and women are more eager to volunteer. This did not seem to distort the results here since telephone interview respondents were somewhat younger and a larger proportion of them were men.

Regarding symptom severity, half of the symptomatic respondents reported having symptoms often (at least several times per week) but only one third rated their symptoms difficult or had visited a doctor because of the symptoms. Further, only five individuals reported having difficult symptoms often. Regarding harmful effects on different aspects of life, the effects on mental well-being, health and working capacity were the most prevalent. However, less than 20% of the symptomatic respondents had been on a sick leave because of symptoms. It appears that although symptoms intuitively associated with wind turbine infrasound were relatively common, it was much less common to rate these symptoms severe. Thus, the results do not support impression from public discussions where health problems intuitively associated with turbine infrasound have mostly been described serious and even fatal.

5.5 Many Factors were Associated with Symptoms

With regard to multivariate modelling, it should be noted that the number of symptomatic respondents (cases) was relatively low in the whole data (n=70). In the combined model (n=62), the numbers of cases in four distance zones were only 28, 12, 14, and 8. This, together with the fact that the responses among symptomatic respondents were typically at extreme ends of the response spectrum, the size of the odds ratio (OR) estimates cannot be interpreted as absolute. However, the size of the estimate does reflect the strength of the association.

Living close to a wind power plant was associated with increased probability of having wind turbine infrasound related symptoms, and the association was especially strong in the closest distance zone. Distance to the closest turbine is a proxy for actual exposure to both audible sound and infrasound from wind turbines but it is also a proxy also for all the phenomena that are associated with high exposure. In this data, annoyance caused by different aspects of wind turbines, wind turbine infrasound related symptoms, negative experiences and opinions as well as a perception of high risk for health were emphasized close to the wind power plant.

Instead of audible noise, being annoyed by audible sound and different visual stimulus from wind turbines has been recognized as one of the explanatory variables for sleep disturbance and symptoms associated with wind power[10,76–78], and could be speculated to explain also some of the symptoms intuitively associated with infrasound. In this study, being highly or extremely annoyed indoors by audible sound from wind turbines and being at least slightly annoyed by wind turbine lights were associated with an increased probability of having symptoms intuitively associated with wind turbine infrasound but not in the combined model. Introducing distance to the model made these associations disappear. In the combined model, annoyance caused by shadow flicker had increased but statistically non-significant risk estimate.

Regarding opinions and risk perceptions, the effect of wind turbines on landscape, opinion about wind power as a form of energy production, opinion about decision making at home municipality, and trust in public sector and wind power companies regarding the health effects of wind power production were not associated with the probability of being symptomatic. Not receiving enough information regarding realized wind power projects in home municipality had increased but statistically non-significant risk estimate. This is understandable since people can have different opinions about wind power production regardless of personal experiences on the topic. Especially public discussions typically have an effect on people's opinions and attitudes. Indeed, variables dealing with health problems, risk perceptions and opinions around the same topic are different aspects of the same phenomena and often inherently dependent on each other. This could cause problems in statistical analyses. In this study, multicollinearity was not a problem and the models were stable regardless of interrelations between the variables. However, internal correlations should be kept in mind when interpreting the results. Depending on the set of variables, different combinations reach statistical significance.

Experimental studies have shown that negative expectations such as worry are associated with increased symptom reporting[29,30]. In this study, considering wind turbine infrasound as a personal health risk, considering wind power production as a health risk in general and considering wind turbine infrasound as a major risk factor for deteriorated health were strongly associated with an increased probability of having symptoms intuitively associated with wind turbine infrasound. However, cross-sectional setting does not allow inferences on temporal order. Negative opinions and risk perceptions can lead to symptoms but the direction of the association can also be the opposite.

Having at least two chronic diseases or at least one functional disorder was associated with an increased probability of having wind turbine infrasound related symptoms. However, many of the symptoms that have been intuitively associated with wind turbine infrasound are very common in the population and are also typically associated with many chronic diseases and stress. Due to this complexity, it is usually not possible to pinpoint one single reason for a symptom. The probability of having wind turbine infrasound related symptoms was lower among pensioners. That could be explained by the fact that although older people typically have more health problems when compared with younger persons, they might consider these health problems as a part of aging process and do not associate them with some external exposures.

Impaired hearing and noise sensitivity were associated with an increased probability of having symptoms intuitively associated with wind turbine infrasound but only in a model without annoyance, opinions and risk perceptions. The association with impaired hearing could be explained by the fact that it typically causes physiological sensitivity to sounds and is often associated with ear symptoms such as tinnitus. Further, noise sensitive persons perceive noise more annoying and threatening, have stronger psychological and physiological reactions to noise, and habituate less than persons not sensitive to noise. It has been observed that those who report to be highly sensitive to noise have also, for example, high prevalence of non-specific symptoms[79]. In this study, the association with impaired hearing and noise sensitivity disappeared when they were included into the same with annoyance, opinions and risk perceptions.

Individual characteristics such as age, sex and life habits, and building characteristics such as main material for building structure or window structure and were not associated with the probability of having wind turbine infrasound related symptoms. There are some unofficial theories that certain building materials such as timber could be associated with increased risk of health effects but this was not supported in this study.

A large array of symptoms were intuitively associated with wind turbine infrasound. The most common were ear symptoms, sleep disturbance, cardiac symptoms, headache, dizziness, anxiety, high blood pressure, fatigue, nausea and problems in concentrating. A few respondents reported also eye problems, skin irritation, gastrointestinal problems, asthma, irritable bowel syndrome, low body temperature, stress, irritation, depression, stroke, fibromyalgia, cataract, numbness in limbs, brain fog, and pressure sensation in the brain. Some of these symptoms such as ear sensations, dizziness, nausea and fatigue are known to result infrasound exposure but the sound pressure levels are extreme and way above perception threshold[80]. Exposure levels in the vicinity of wind power plants and in living environments in general are much lower. It is biologically implausible that one exposure such as infrasound from wind turbines could cause all those symptoms across different organ systems especially since exposure levels even at close distances are low. Similar symptoms at low exposure levels have been reported also in association with other environmental exposures such as electromagnetic fields and odors[81]. Also, such symptomatology is characteristic to functional symptoms, disorders and syndromes[82]. In this study, many of those who reported wind turbine infrasound related symptoms also reported symptoms because of vibration and electromagnetic field from wind turbines. However, sensitivity to environmental exposures was not associated with the risk of symptoms in multivariate models.

5.6 Detection and Annoyance in Laboratory

In laboratory conditions, perception and annoyance of infrasound in wind turbine noise was studied. Only few studies investigating perception of infrasound have previously used real wind turbine sound samples as stimuli, reproduced in high precision in an controlled infrasound laboratory[20,21]. In addition, studies investigating influence of turbine infrasound on annoyance are lacking. Further, modern signal detection theory measures were used to analyze the auditory sensitivity to infrasound, minimizing any possible effect of subjective response biases or preferences.

The results of detection experiment show minimal sensitivity to the presence of infrasound in any of the stimulus conditions (wind power plant area, yard, indoor sounds). On the other hand, sensitivity for audible low-frequency sound was well above the chance level at least in wind power plant area samples, showing that participants could perform the discrimination task correctly when stimuli had audible low frequency components.

The detectability results were further analyzed by investigating separately the group that had reported wind turbine related health symptoms (WTRS group) and the rest of the participants. The sensitivities did not differ between the groups. The WTRS group did not express any signs of increased sensitivity for infrasound or low-frequency sound.

Regarding the experiment that investigated annoyance related to various characteristics of wind turbine sound (i.e., presence of infrasound, level of amplitude modulation, and recording site), presence of infrasound had no systematic effect on rated annoyance. The ratings were highly similar with and without infrasound. However, an effect of recording site and AM was found: wind power plant area stimuli were rated more annoying than yard stimuli and maximum AM stimuli were rated more annoying than minimum AM stimuli. This finding is in line with previous studies that have suggested that amplitude modulation of wind turbine noise increases annoyance[25][24]. This is likely due to the fact that the plant area stimuli provided more salient and intensive turbine noise that the yard stimuli and hence they were rated more annoying. When annoyance ratings were analyzed separately for the WTRS group and the rest of the participants, the ratings were highly similar in both groups, both when infrasound was present and not.

Taken together, the behavioral findings of the current study suggest that wind turbine infrasound cannot be reliably perceived and it does not result in increased annoyance. Participants that showed health effects did not show signs of increased infrasound sensitivity and did not rate wind turbine sounds more annoying. These findings do not support the hypothesis that infrasound is the element in turbine sound that causes annoyance. Instead, they suggest that people who have health symptoms which they associate with wind turbine sound are not likely to have these symptoms because they perceive turbine sound more annoying than controls, at least in laboratory settings. It is more likely that these symptoms are triggered by other factors such as symptom expectancy as proposed by Crichton et al.[29] and Tonin et al.[30].

The behavioral findings were supported by the psychophysiological recordings of the autonomic nervous system (cardiac and electrodermal) activity. There were no differences between the infrasound and no-infrasound conditions, nor between the conditions with the instruction that infrasound was present or not present. Also, no significant differences were found between the WTRS groups and the rest of the participants. No support was found for the proposition[83,84] that wind turbine infrasound could increase arousal and elicit physiological stress responses even in situations when the infrasound is not perceived.

As expected, during the cold pressure test, elevated cardiac and electrodermal responses, reflecting increased physiological stress and arousal, were found for both study groups. Moreover, these responses were comparable between the WTRS group and rest of the participants. This suggests that there is no increased or decreased sensitivity to stress in neither one of the groups. It appears, that despite their symptom history, also the WTRS group has normal physiological reactivity to stress, at least to this type of a stressor. In spite of small sample size, the result may be informative. With larger sample size, that is with larger study groups, one might have been able to detect physiological reactions of smaller magnitude. Yet, the very high statistical significance of the difference between the baseline preceding the cold pressor test and the responses during the test indicates, that also considerably milder stress responses would have been detected in this sample.

As already mentioned in the Introduction, laboratory studies have been criticized for the short duration of the exposure to wind turbine sound and infrasound. Indeed, previous studies have used exposure duration of few seconds[85,86]. In this study, infrasound blocks lasted up to 10 minutes. Infrasound had a negligible effect on rated annoyance, even when annoyance was heavily affected by other factors (distance, AM). Although, the participants were recruited from regions with high density of wind power plants and had a history of long-term exposure to wind turbine sound, and still no evidence of hypersensitivity or increased annoyance to wind turbine infrasound was observed.

5.7 Participants and Their Symptoms in the Provocation Experiment

The recruitment procedure caught individuals who were either bothered by wind turbines or interested in the study paradigm. No clinical evaluation of the participants was performed nor diagnostics of adverse health effects in the environs of industrial wind turbines[87]. However, the reporting of the symptoms of the WTRS group resembled the probable diagnostic criteria presented by McMurthy (2014)[87]. Majority of the participants in the WTRS group experienced symptoms and discomfort inconsistently during the course of the experiments, which were not reported by the rest of the participants. Also, the increased stress levels rated by the WTRS group as the experiment day went further suggest that they were more bothered of the testing without association to sound or infrasound exposure. Similar symptom arousal has been demonstrated in provocation experiments to infrasound and electromagnetic fields, without real exposure, which initiates when subjects presume that they are exposed[88–90].

In our study participants, nocebo reactions were present in those who had reported symptoms related to wind turbines. This is a plausible explanation to the differences in the reactions in the population living in the same environment.

Several psychological mechanisms may account for symptoms attributed to wind turbines. First, the nocebo effect is a well-recognized phenomenon in which the expectation of adverse effects or symptoms can become self-fulfilling. Second, mis-attribution of pre-existing or new symptoms to a novel technology can also occur. Third, worry about a modern technology increases the chances of someone attributing symptoms to it. Fourth, social factors, including media reporting and interaction with lobby groups can increase symptom reporting.[90]

Non-specific symptoms related to environmental factors at low levels without evidence of health effects have been demonstrated in idiopathic environmental intolerance and noise sensitivity[79]. Annoyance and reactions can be induced at the levels of sensory detection threshold or when exposure is not present but it is anticipated to be present[88,91,92]. Environmental intolerance is not infrequent, also in Finland[93]. Although the prevalence of intolerance to wind turbines has not been studied in Finland, it is presumable that it occurs and co-occurs with other intolerances, i.e. to multiple chemicals, buildings, electromagnetic fields and sounds, which has been shown in other environmental intolerances[60,94]. The more severe the intolerance, the more co-occurrence of different intolerances is seen[60]. The strongest evidence of nocebo mechanisms and negative expectations explaining symptoms and reactions has been shown for environmental intolerance to electromagnetic fields[95]. The brain mechanism of expectations and priming of sensations seem to be part of the central nervous system processing and occur constantly[91]. Also, in symptoms related to wind turbine noise, nocebo effects have been shown to play a major role[29,89]. Tonin et al.[30] showed that in listening experiments with simulated infrasound, there was no significant effect on the symptoms reported by volunteers, but in volunteers with prior concerns about negative effects of infrasound a significant influence on the symptoms was seen supporting nosebo effect hypothesis.

6 Conclusions

In this project, multidisciplinary methods were used to study the health effects of wind turbine infrasound. The work was divided into three independent sub-studies: sound measurements, a questionnaire study, and provocation experiments. The first sub-study characterized wind turbine infrasound as an indoor exposure and also provided the sound samples to the exposure provocation study. The second sub-study aimed at characterizing symptoms intuitively associated with wind turbine infrasound by those living in the vicinity of wind power plants. The third sub-study was based on an extensive provocation experiment involving both the psychoacoustical and psychophysiological measurements of the autonomic nervous systems. The provocation experiment participants consisted of a group who had reported symptoms related to the sound and infrasound of wind power production (Wind Turbine Related Symptoms, WTRS) and a group without symptoms.

The main findings of the project are the following:

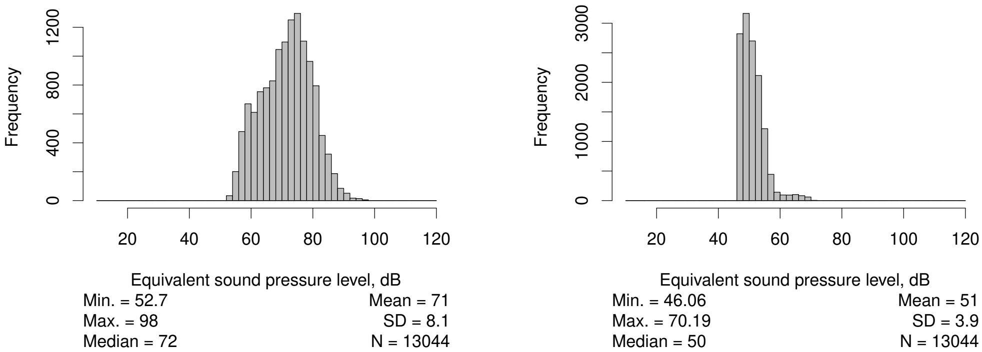
- Wind power plants changed the sound environment of dwellings in an urban direction: the long-term immission measurements in houses located near (approximately 1.5 km away) wind power plants showed that both the infrasound levels and the relative loudness perceived by the human ear were similar to the levels occurring typically in an urban environments.
- Unique and rare sound data was captured: infrasound and audible sound from a uniform period, throughout all the seasons from residential buildings that were not occupied during the measurements. According to the equivalent continuous sound pressure levels, the most important frequencies were less than 2 Hz. The human infrasound detection threshold is unique, and the experimentally determined thresholds extend down to 4 Hz (threshold 107 dB). It is possible, that some people could detect the highest infrasound levels (in this study 102 dB) originated from wind turbines, although this could not be demonstrated in this study.

- At immission measurement points, the average indoors sound levels for frequencies below 2 Hz were 20 dB higher than in other quiet areas, such as in our earlier measurements in a natural forest. Although the infrasound level in immission measurements was below the known human detection threshold, it was still considerably much higher than typically in natural areas.
- The long-term emission measurement confirmed the previously found understanding: the equivalent continuous sound pressure level, $L_Z = 74$ dB ($L_A = 52$ dB), was of the same order of magnitude as in our previous shorter period emission measurement campaign.
- Symptoms intuitively associated with wind turbine infrasound were relatively common (15%, 34 individuals reporting symptoms) within 2.5 km from the closest wind turbine and less common (5%, 70 individuals reporting symptoms) in the whole study population. One third of those reporting symptoms rated their symptoms severe. The reported symptoms had a broad spectrum across different organ systems.The questionnaire study was conducted around wind power plants that were assessed to have the highest prevalence of symptoms intuitively associated with wind turbine infrasound.
- Many of the symptomatic respondents reported being annoyed by audible wind turbine sound and associated their symptoms also with vibration or electromagnetic field from wind turbines.
- The symptomatic respondents lived, on average, closer to wind turbines than those without symptoms. Having impaired health status, being annoyed by different aspects of wind turbines and considering wind turbines as a health risk were more common among the symptomatic respondents. However, cross-sectional questionnaire study does not allow causal inference.
- The detection experiment showed no evidence for sensitivity for infrasound in wind turbine noise, or increased sensitivity for infrasound in the WTRS group.
- The annoyance experiment indicated that infrasound is not causing increased annoyance associated with wind turbine sound. Instead, potential annoyance is more related to intensity and amplitude modulation of turbine sound.
- Physiological measurements of cardiac function and electrodermal activity revealed no evidence on the effects of wind turbine infrasound or wind

turbine sound annoyance on heart rate (HR), heart rate variability (RMSSD) and skin conductance responses (SCR). The same result was seen when the WTRS and the control groups were examined separately, and when all the participants were examined all together as one group, as well as for the active and passive listening conditions.

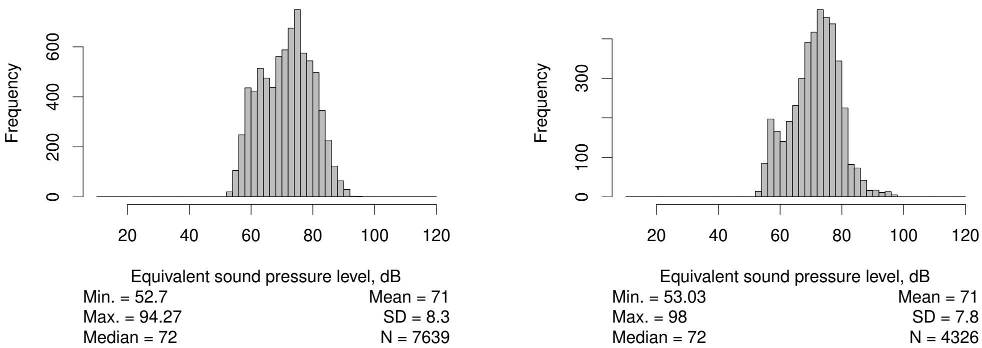
- During a stressful exposure to cold water (CPT) both groups, the WTRS and the control, experienced elevated stress as indicated by an increase in HR and SCR. The groups did not differ in their stress reactivity, as their ANS responses (HR, RMSSD, SCR) did not differ during the baseline preceding the CPT nor during the CPT.

A Measurement statistics



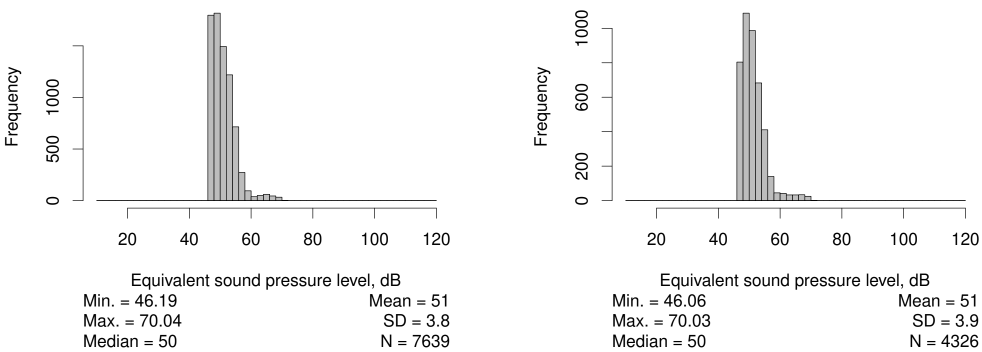
a) $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) $L_{p,\mathrm{A},600\ \mathrm{s}}$

Figure A.1: Histograms for Santavuori wind power plant area equivalent sound pressure levels.



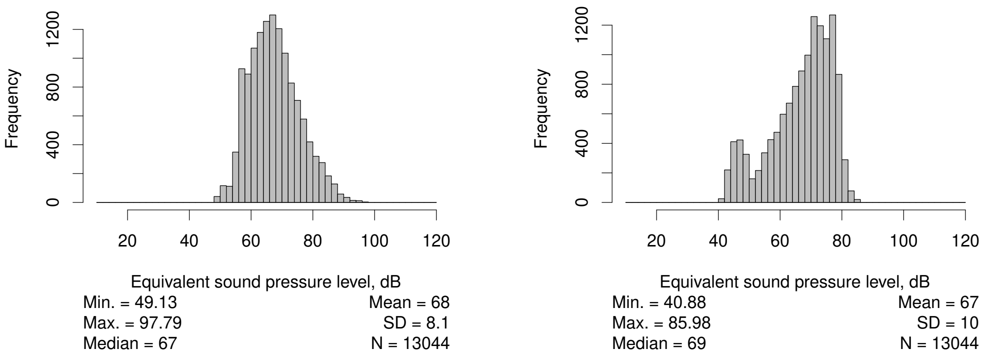
a) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.2: Histograms for Santavuori wind power plant area day and night time equivalent sound pressure levels.



a) $L_{p,\mathrm{A},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{A},600\ \mathrm{s},\ 22\text{-}7}$

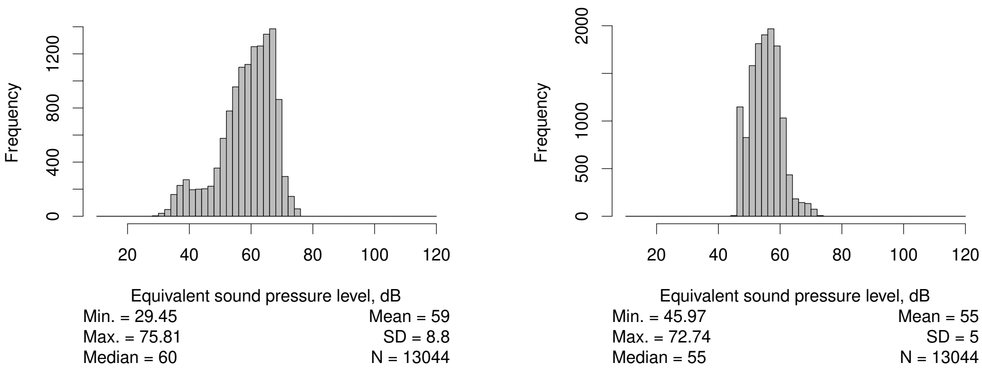
Figure A.3: Histograms for Santavuori wind power plant area day and night time equivalent sound pressure levels.



a) 0.1–2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

b) 2–20 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

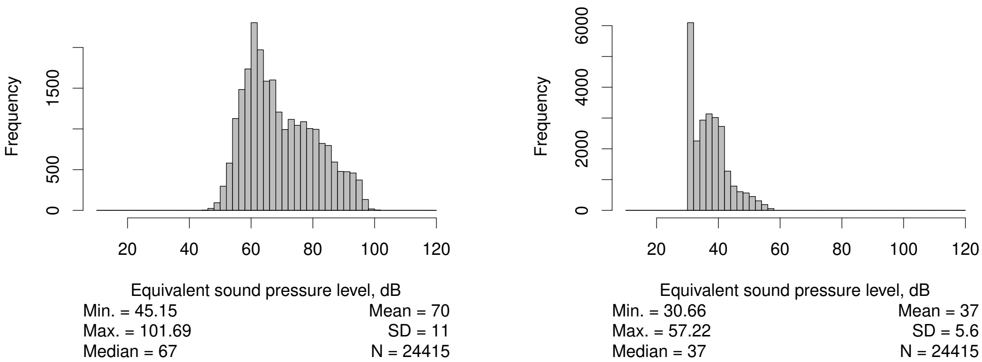
Figure A.4: Histograms for Santavuori wind power plant area equivalent sound pressure levels for selected frequency bands.



a) 20–100 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

b) 100–10 000 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

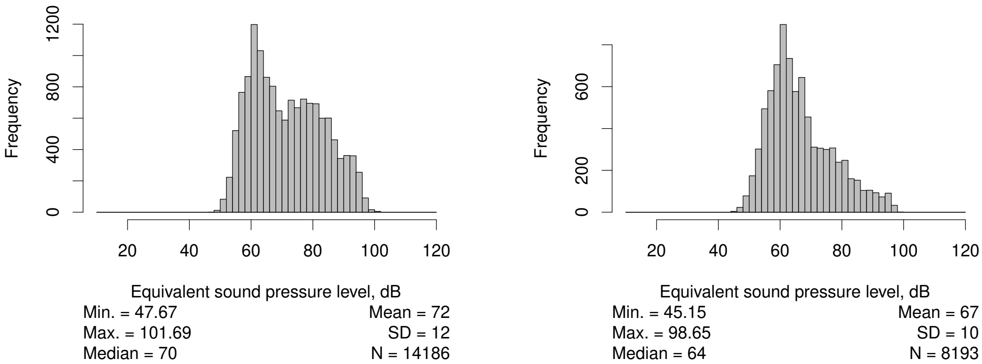
Figure A.5: Histograms for Santavuori wind power plant area equivalent sound pressure levels for selected frequency bands.



a) $L_{p,\mathrm{Z},600\ \mathrm{s}}$

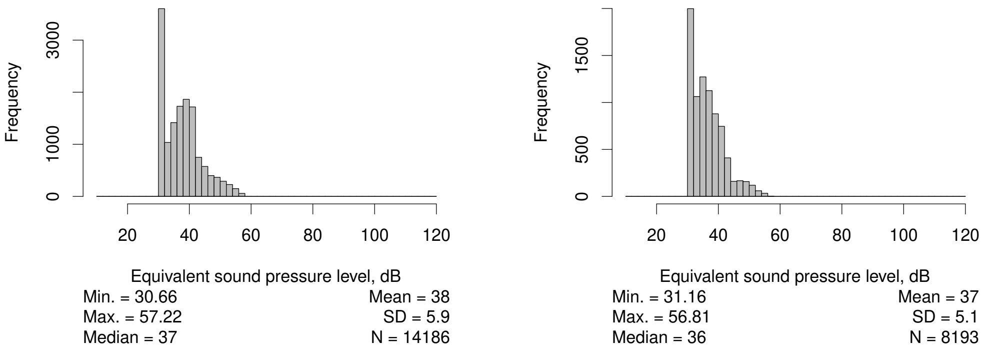
b) $L_{p,\mathrm{A},600\ \mathrm{s}}$

Figure A.6: Histograms for Kurikka outdoors equivalent sound pressure levels.



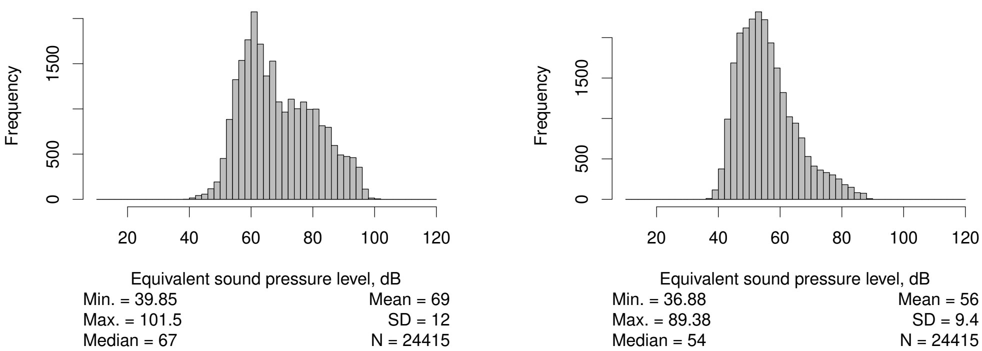
a) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.7: Histograms for Kurikka outdoors day and night time equivalent sound pressure levels.



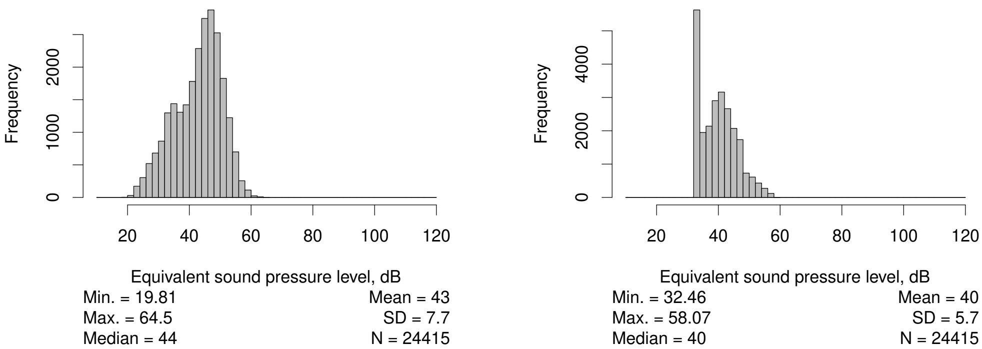
a) $L_{p,\mathrm{A},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{A},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.8: Histograms for Kurikka outdoors day and night time equivalent sound pressure levels.



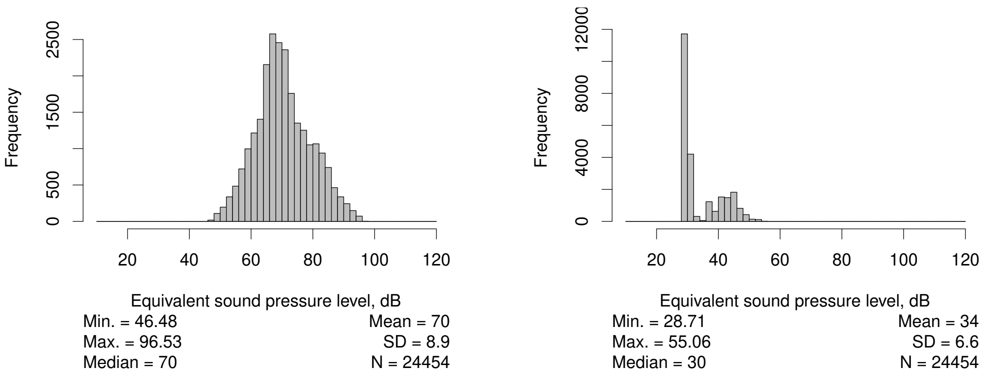
a) 0.1–2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 2–20 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.9: Histograms for Kurikka outdoors equivalent sound pressure levels for selected frequency bands.



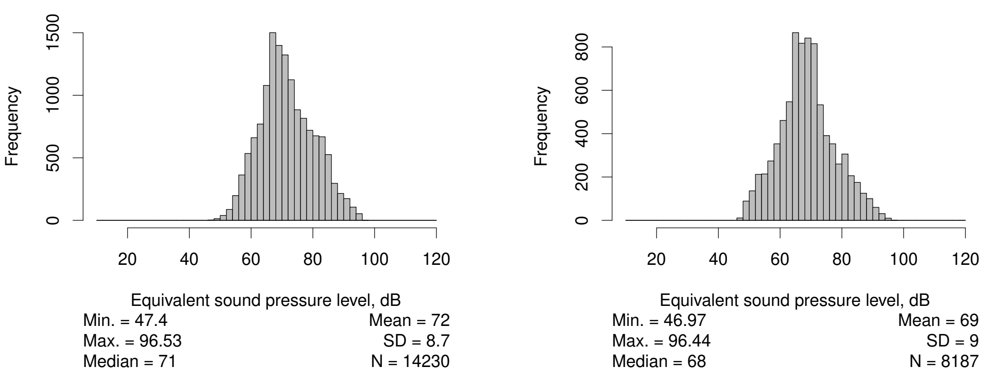
a) 20–100 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 100–10 000 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.10: Histograms for Kurikka outdoors equivalent sound pressure levels for selected frequency bands.



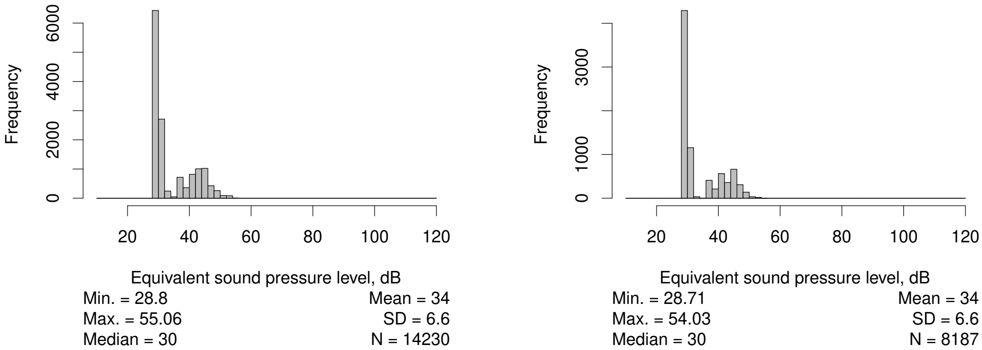
a) $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) $L_{p,\mathrm{A},600\ \mathrm{s}}$

Figure A.11: Histograms for Kurikka indoors equivalent sound pressure levels.



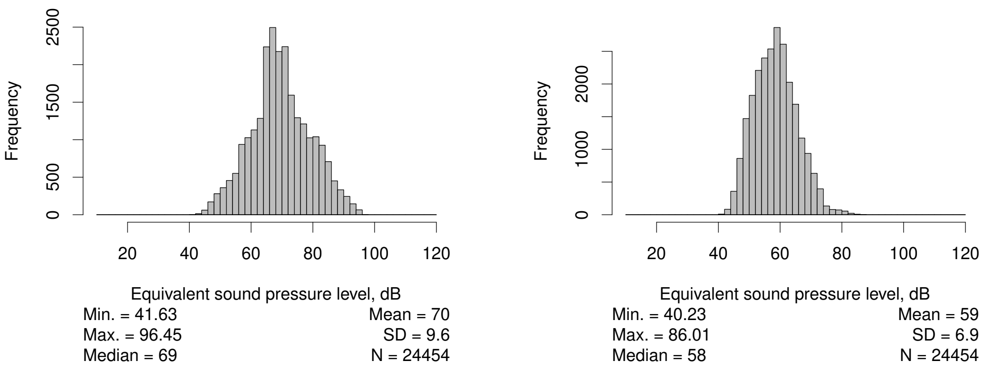
a) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.12: Histograms for Kurikka indoors day and night time equivalent sound pressure levels.



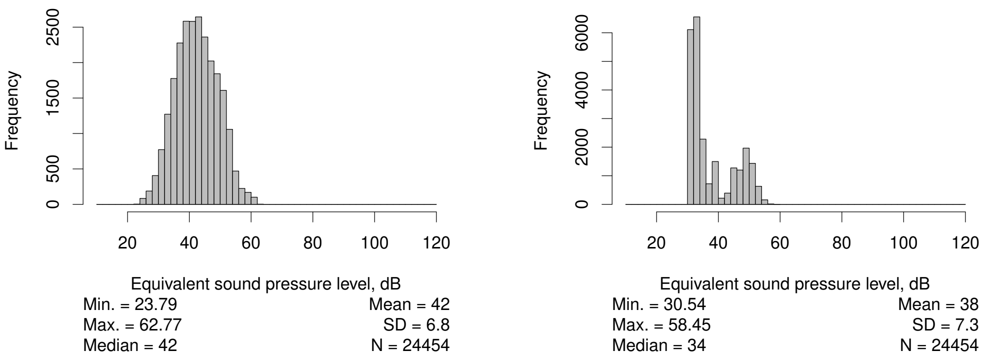
a) $L_{p,\mathrm{A},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{A},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.13: Histograms for Kurikka indoors day and night time equivalent sound pressure levels.



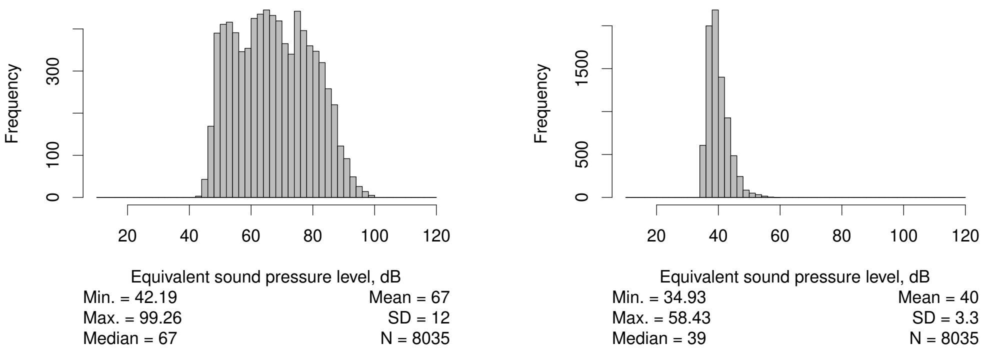
a) 0.1–2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 2–20 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.14: Histograms for Kurikka indoors equivalent sound pressure levels for selected frequency bands.



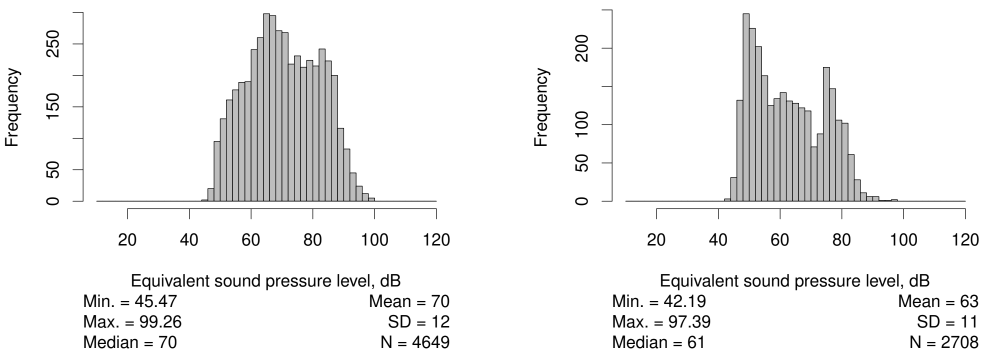
a) 20–100 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 100–10 000 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.15: Histograms for Kurikka indoors equivalent sound pressure levels for selected frequency bands.



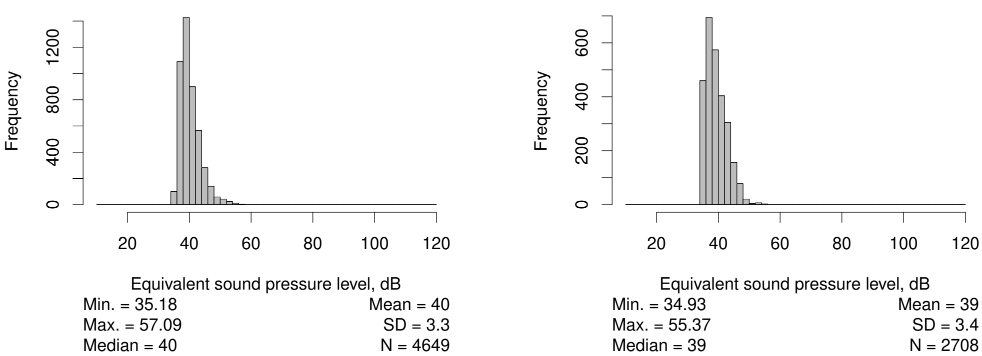
a) $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) $L_{p,\mathrm{A},600\ \mathrm{s}}$

Figure A.16: Histograms for Raahe outdoors equivalent sound pressure levels.



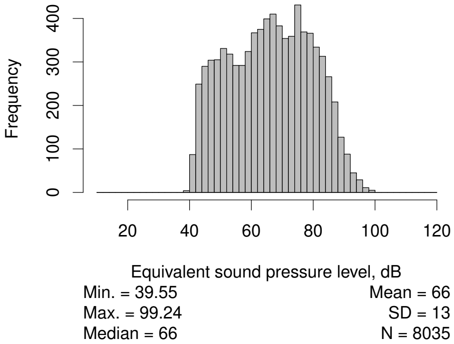
a) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.17: Histograms for Raahe outdoors day and night time equivalent sound pressure levels.

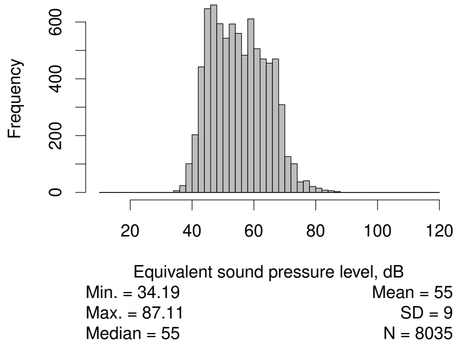


a) $L_{p,\mathrm{A},600\ \mathrm{s},\ 7\text{-}22}$ b) $L_{p,\mathrm{A},600\ \mathrm{s},\ 22\text{-}7}$

Figure A.18: Histograms for Raahe outdoors day and night time equivalent sound pressure levels.

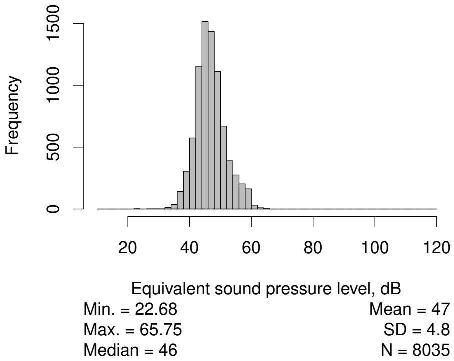


a) 0.1–2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

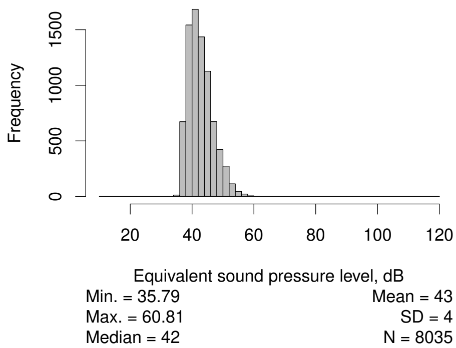


b) 2–20 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.19: Histograms for Raahe outdoors equivalent sound pressure levels for selected frequency bands.

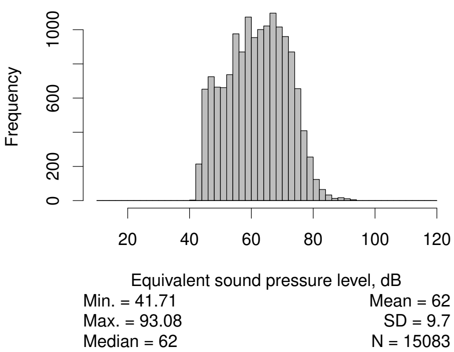


a) 20–100 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

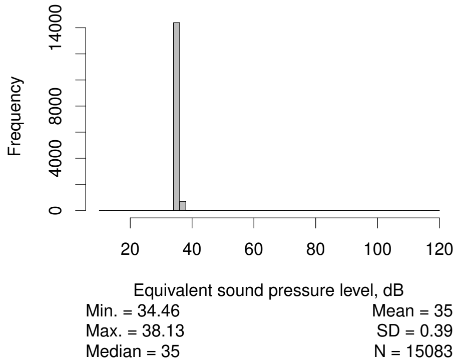


b) 100–10 000 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.20: Histograms for Raahe outdoors equivalent sound pressure levels for selected frequency bands.

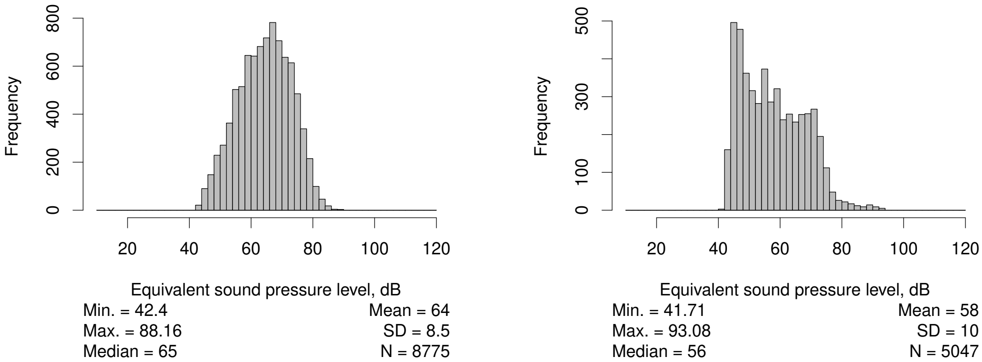


a) $L_{p,\mathrm{Z},600\ \mathrm{s}}$



b) $L_{p,\mathrm{A},600\ \mathrm{s}}$

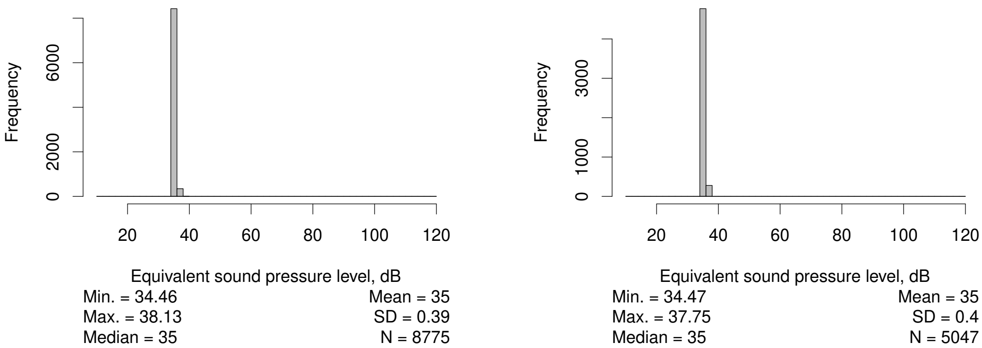
Figure A.21: Histograms for Raahe indoors equivalent sound pressure levels.



a) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 7\text{-}22}$

b) $L_{p,\mathrm{Z},600\ \mathrm{s},\ 22\text{-}7}$

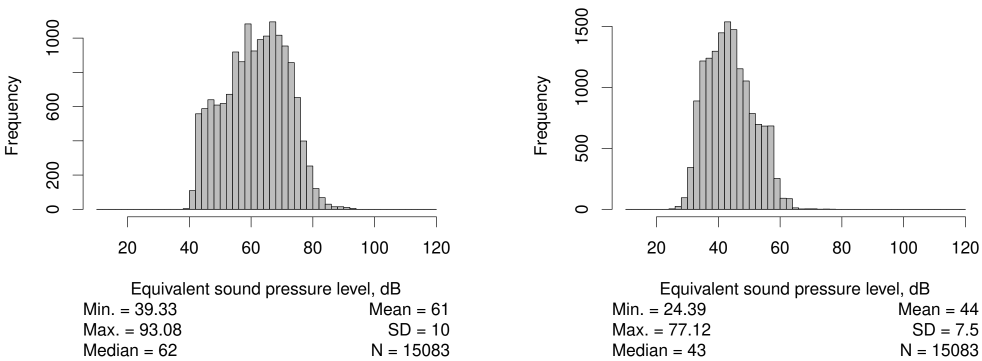
Figure A.22: Histograms for Raahe indoors day and night time equivalent sound pressure levels.



a) $L_{p,\mathrm{A},600\ \mathrm{s},\ 7\text{-}22}$

b) $L_{p,\mathrm{A},600\ \mathrm{s},\ 22\text{-}7}$

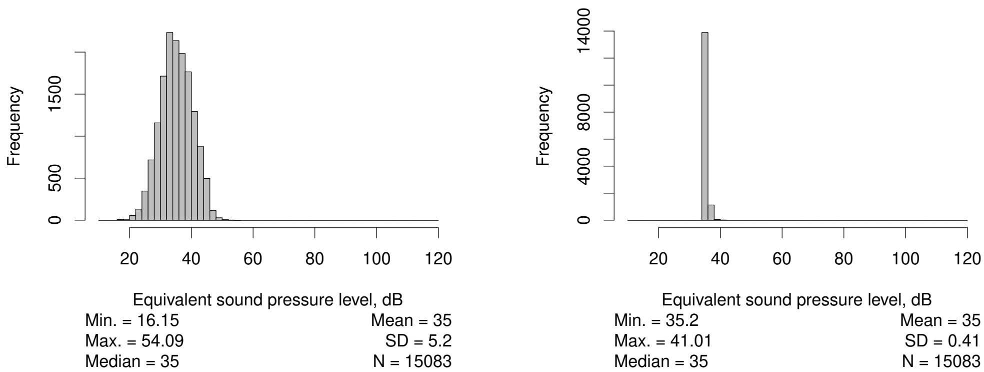
Figure A.23: Histograms for Raahe indoors day and night time equivalent sound pressure levels.



a) 0.1–2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

b) 2–20 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

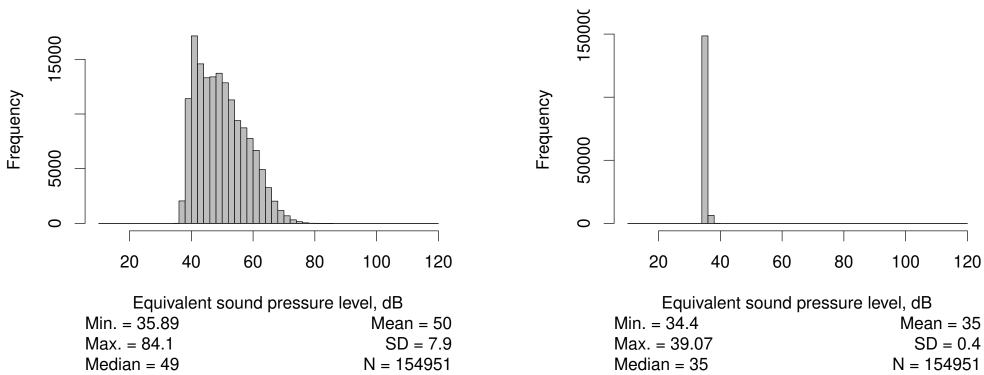
Figure A.24: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



a) 20–100 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

b) 100–10 000 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

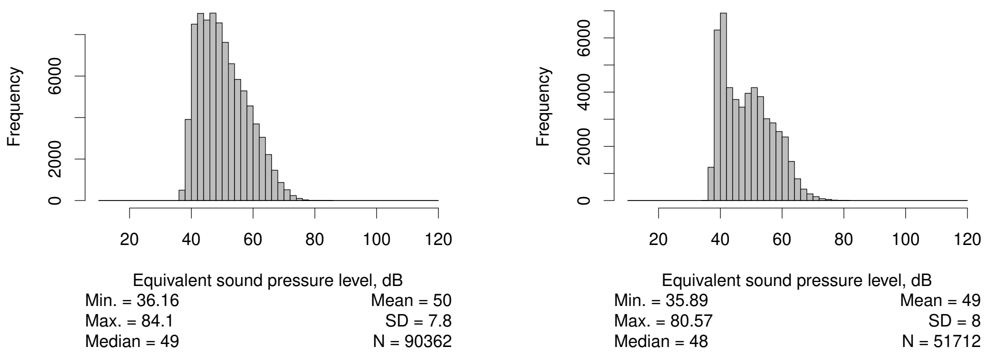
Figure A.25: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



a) $L_{p,\mathrm{Z},60\ \mathrm{s}}$

b) $L_{p,\mathrm{A},60\ \mathrm{s}}$

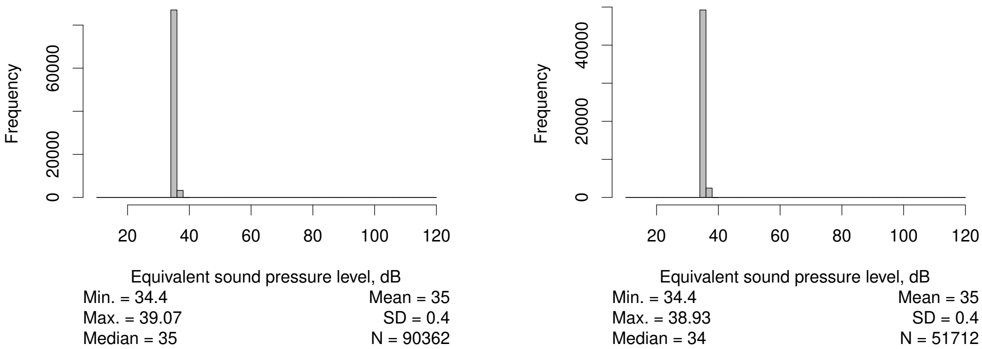
Figure A.26: Histograms for Raahe indoors equivalent sound pressure levels.



a) $L_{p,\mathrm{Z},60\ \mathrm{s},\ 7\text{-}22}$

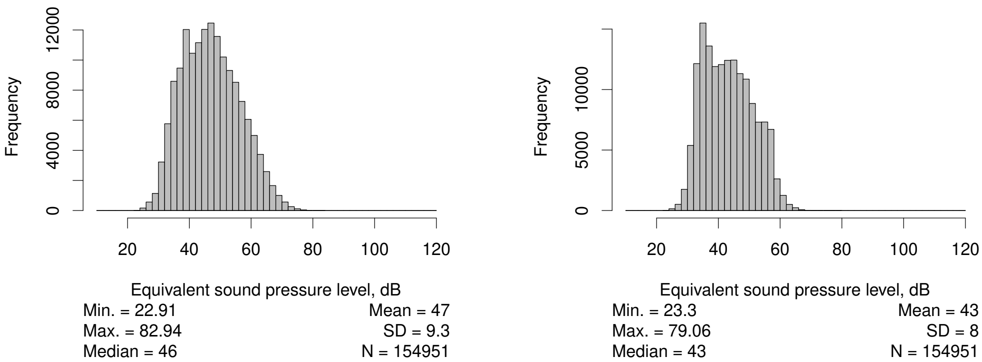
b) $L_{p,\mathrm{Z},60\ \mathrm{s},\ 22\text{-}7}$

Figure A.27: Histograms for Raahe indoors day and night time equivalent sound pressure levels.



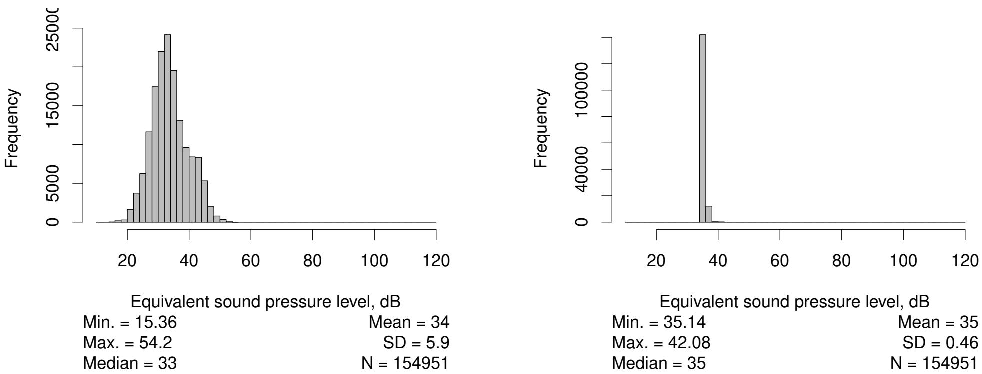
a) $L_{p,\text{A},60\text{ s},7\text{-}22}$ b) $L_{p,\text{A},60\text{ s},22\text{-}7}$

Figure A.28: Histograms for Raahe indoors day and night time equivalent sound pressure levels.



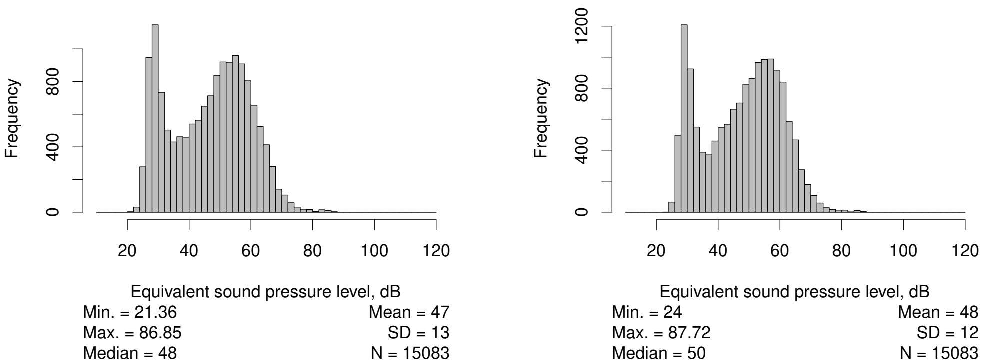
a) 0.1–2 Hz, $L_{p,\text{Z},60\text{ s}}$ b) 2–20 Hz, $L_{p,\text{Z},60\text{ s}}$

Figure A.29: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



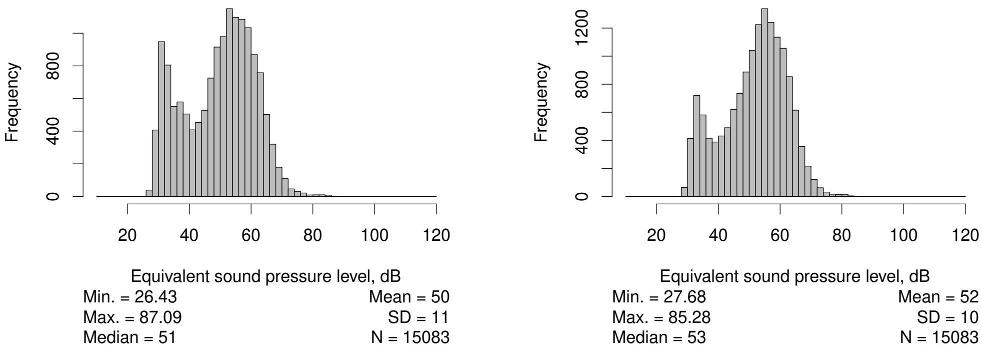
a) 20–100 Hz, $L_{p,\text{Z},60\text{ s}}$ b) 100–10 000 Hz, $L_{p,\text{Z},60\text{ s}}$

Figure A.30: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



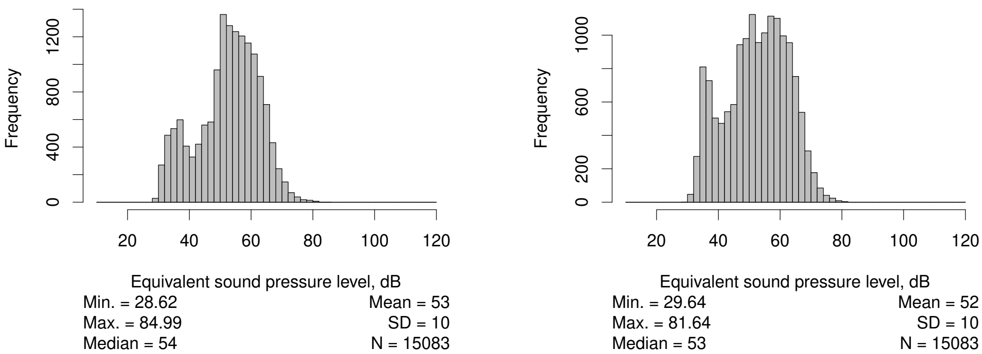
a) 0.1 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 0.125 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.31: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



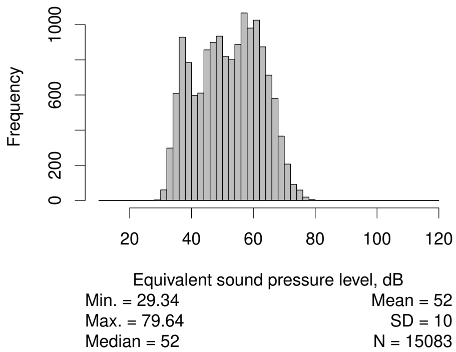
a) 0.16 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 0.2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.32: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.

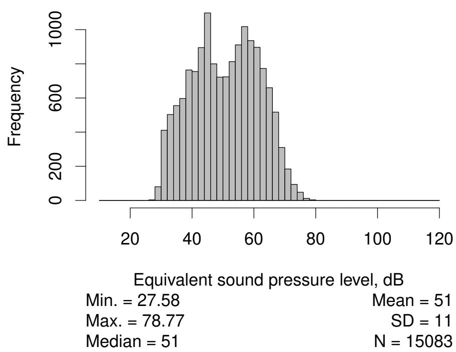


a) 0.25 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 0.315 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.33: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.

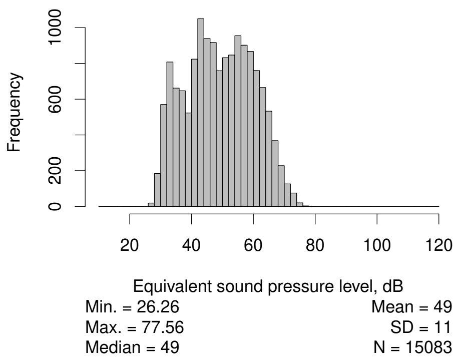


a) 0.4 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

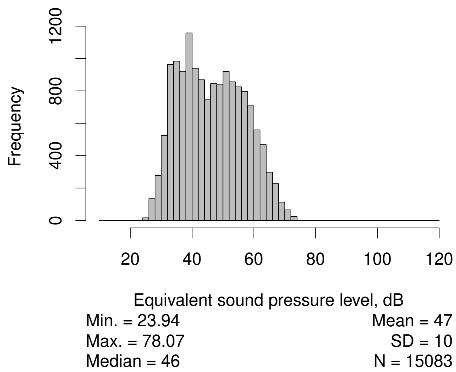


b) 0.5 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.34: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.

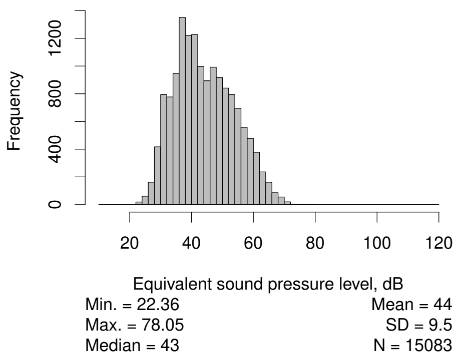


a) 0.63 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

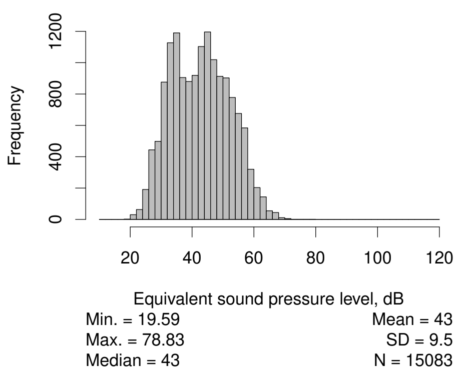


b) 0.8 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.35: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.

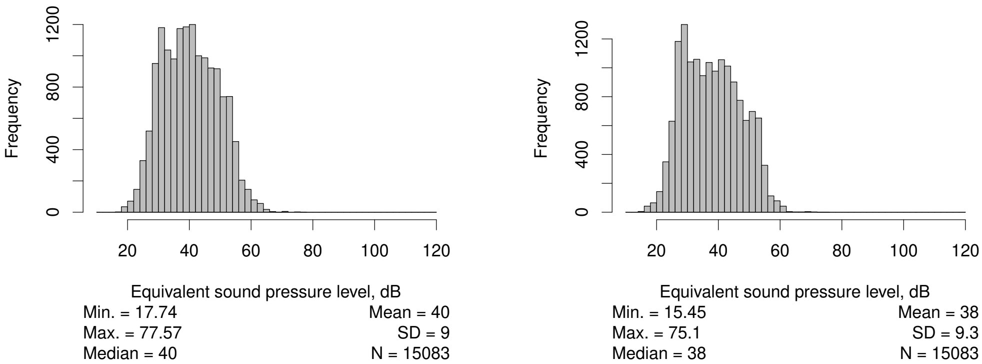


a) 1 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$



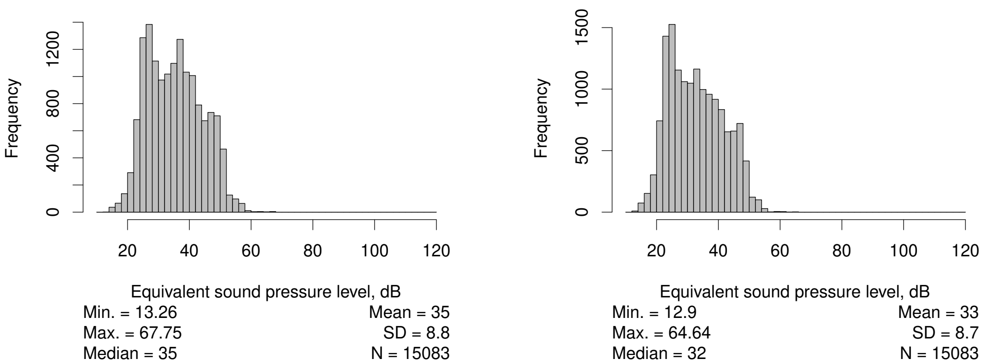
b) 1.25 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.36: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



a) 1.6 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 2 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.37: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.



a) 2.5 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$ b) 3.15 Hz, $L_{p,\mathrm{Z},600\ \mathrm{s}}$

Figure A.38: Histograms for Raahe indoors equivalent sound pressure levels for selected frequency bands.

B Descriptive WTS Data

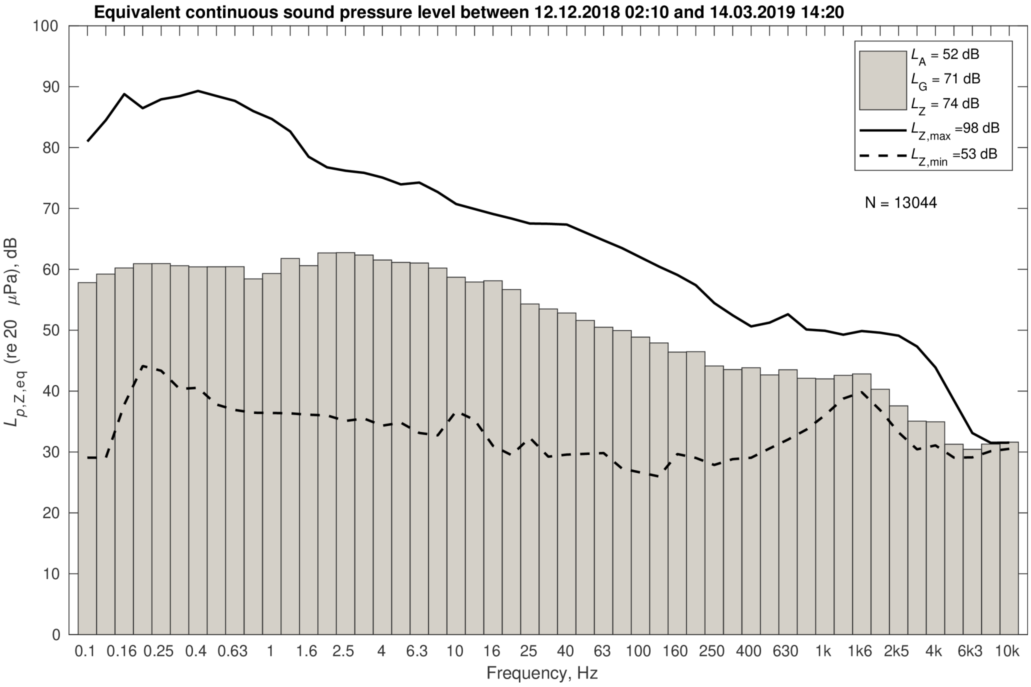


Figure B.1: Santavuori, emission measurement, equivalent sound pressure level.

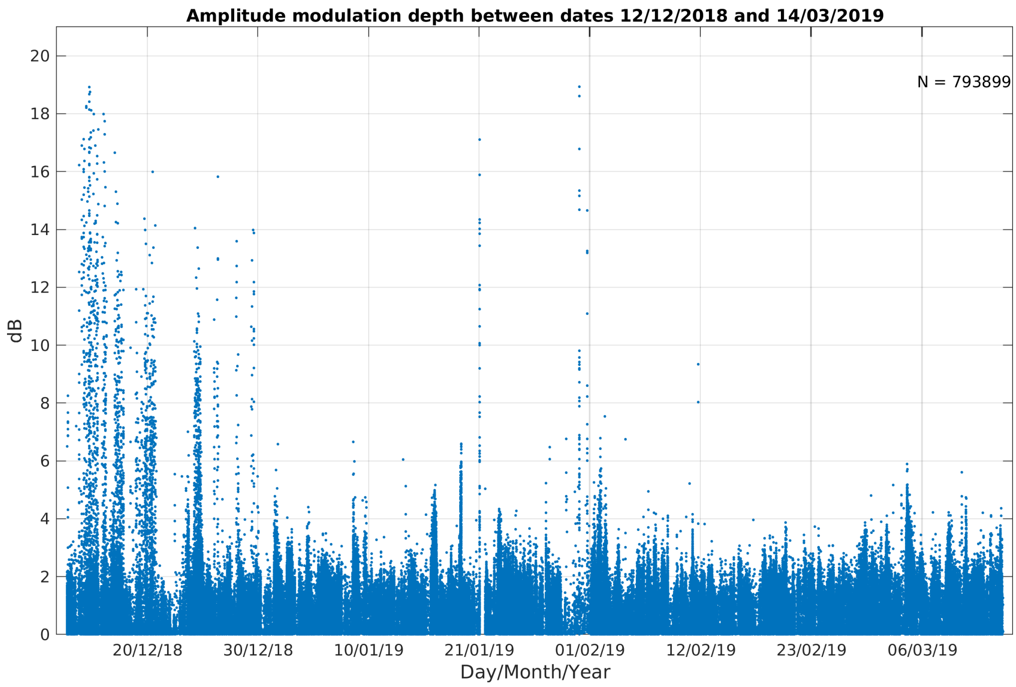


Figure B.2: Santavuori, emission measurement, amplitude modulation depth.

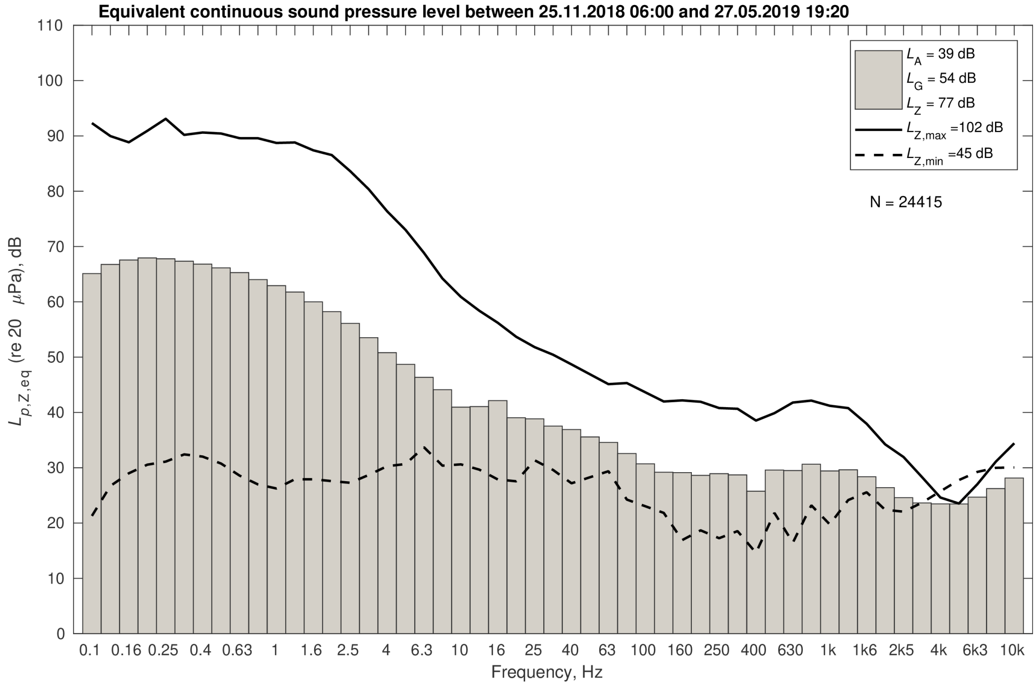


Figure B.3: Kurikka, outdoors, third octave bands for all the validated data based on 600 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

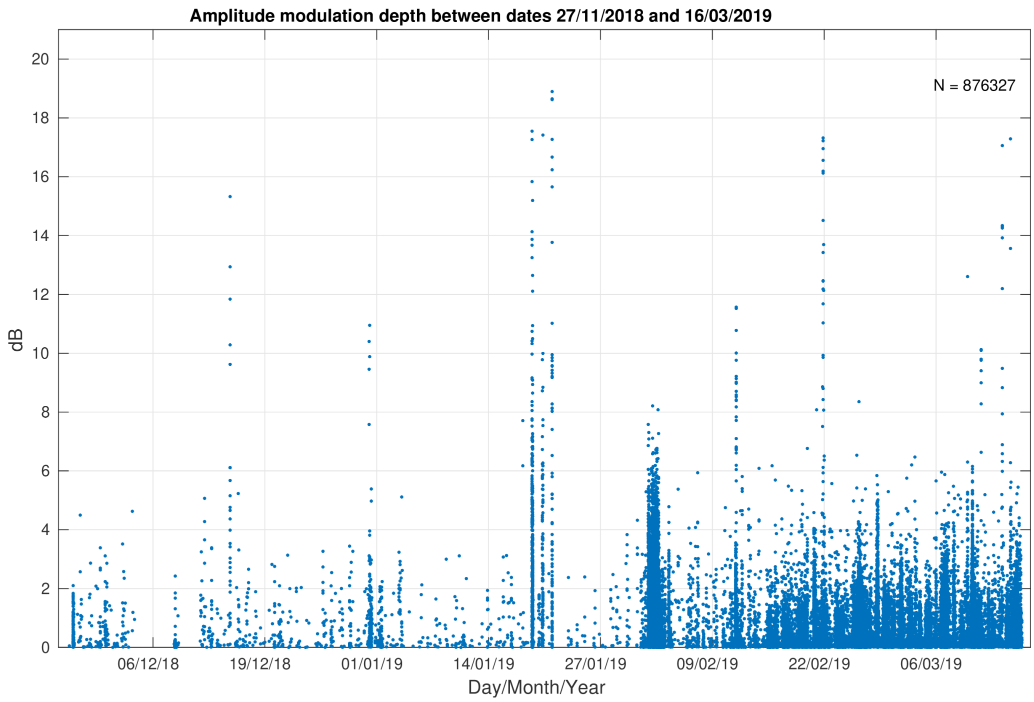


Figure B.4: Kurikka, outdoors, amplitude modulation depth.

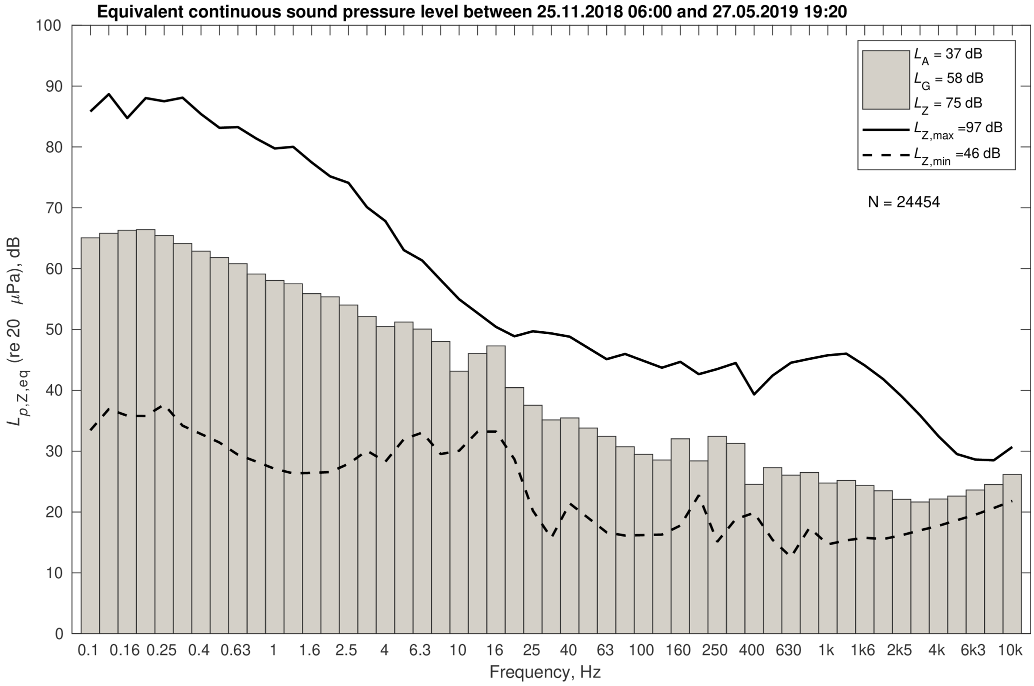


Figure B.5: Kurikka, indoors, equivalent sound pressure level.

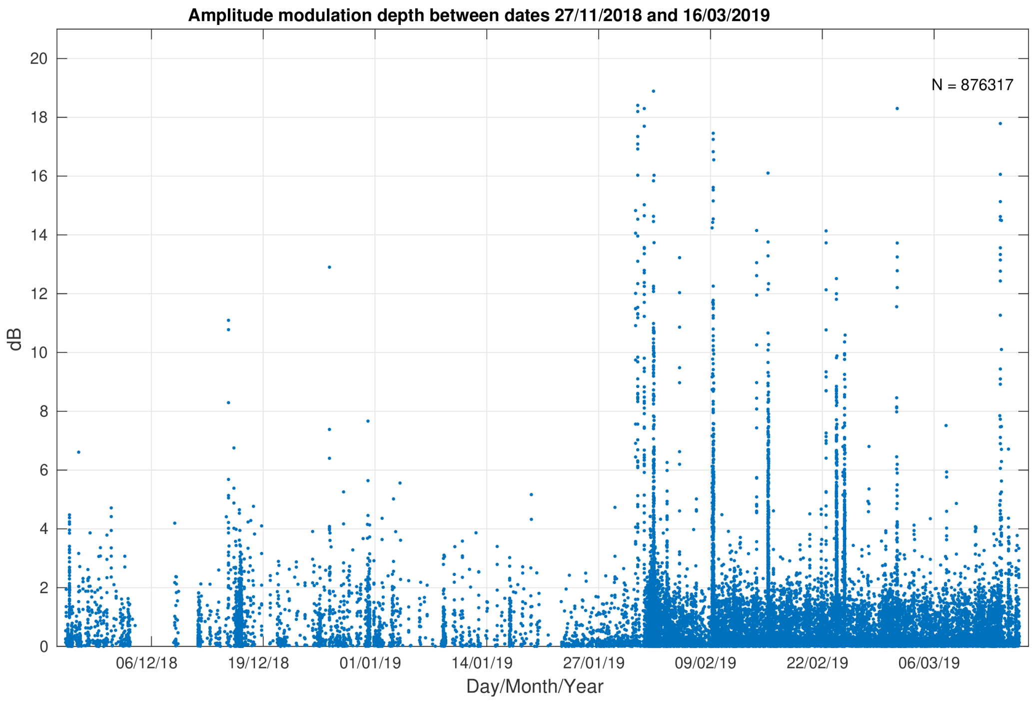


Figure B.6: Kurikka, indoors, amplitude modulation depth.

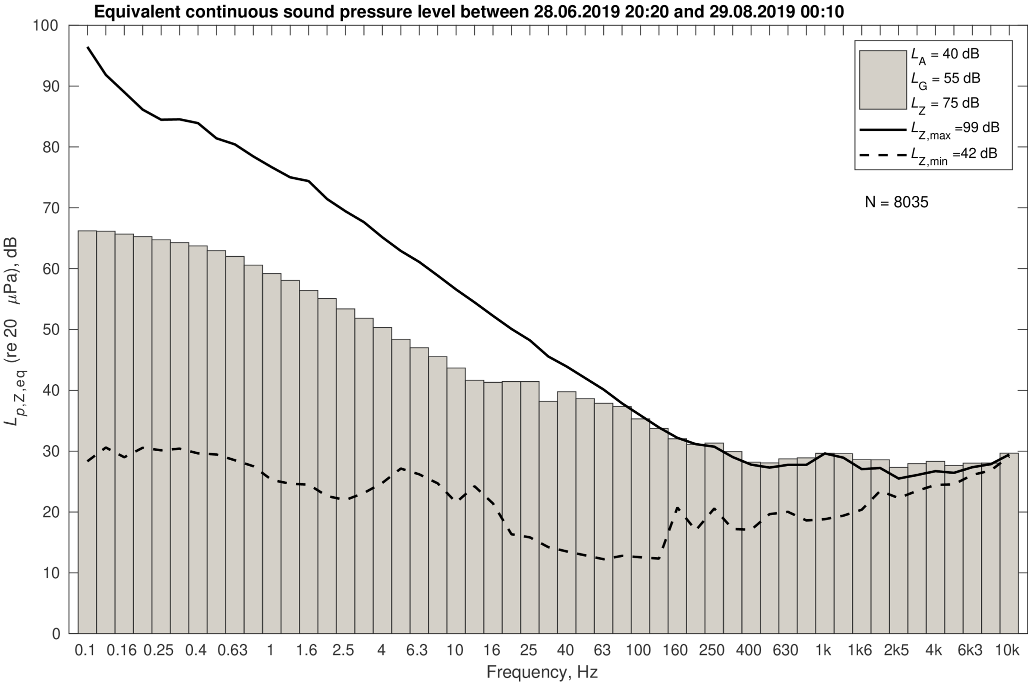


Figure B.7: Raahe, outdoors, third octave bands for all the validated data based on 600 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

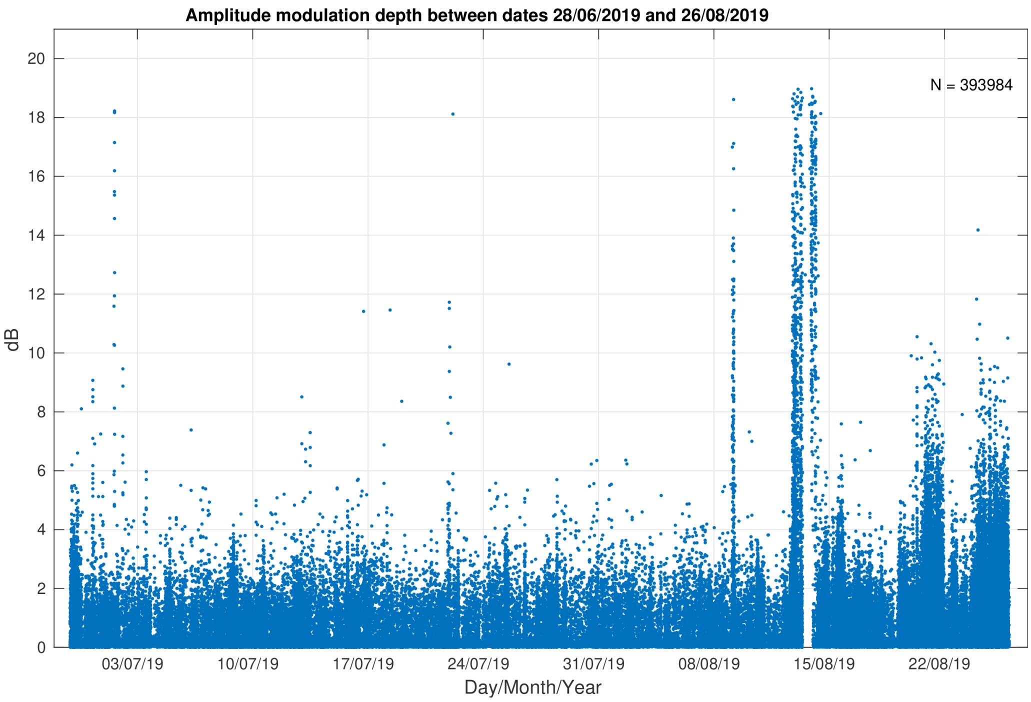


Figure B.8: Raahe, outdoors, amplitude modulation depth.

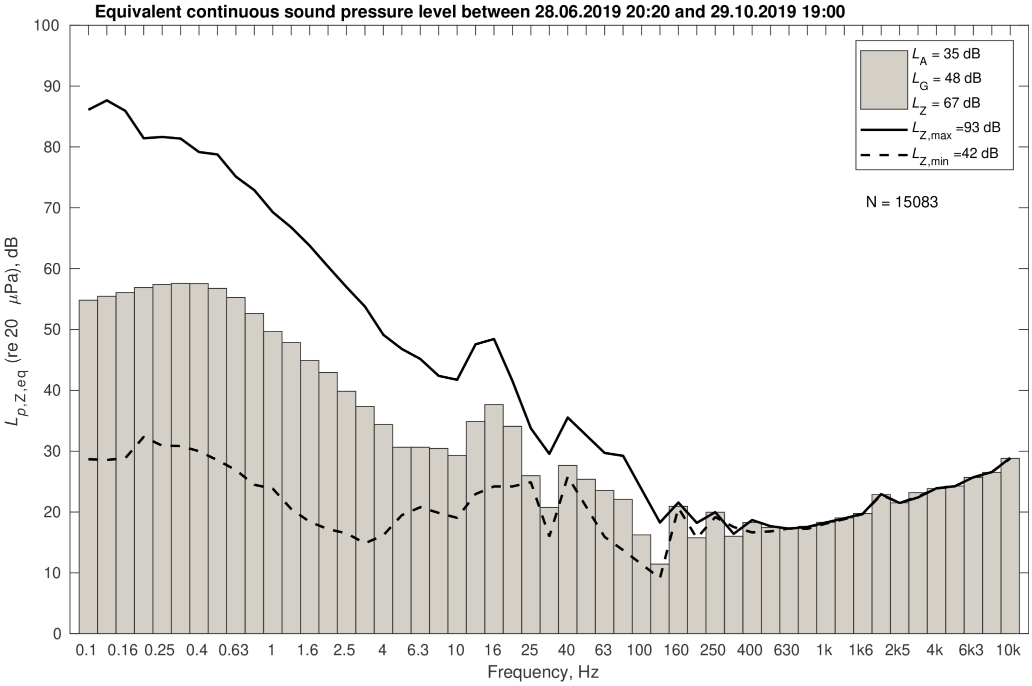


Figure B.9: Raahe, indoors, third octave bands for all the validated data based on 600 seconds equivalent sound pressure levels. Also, the minimum and maximum L_Z curves are shown.

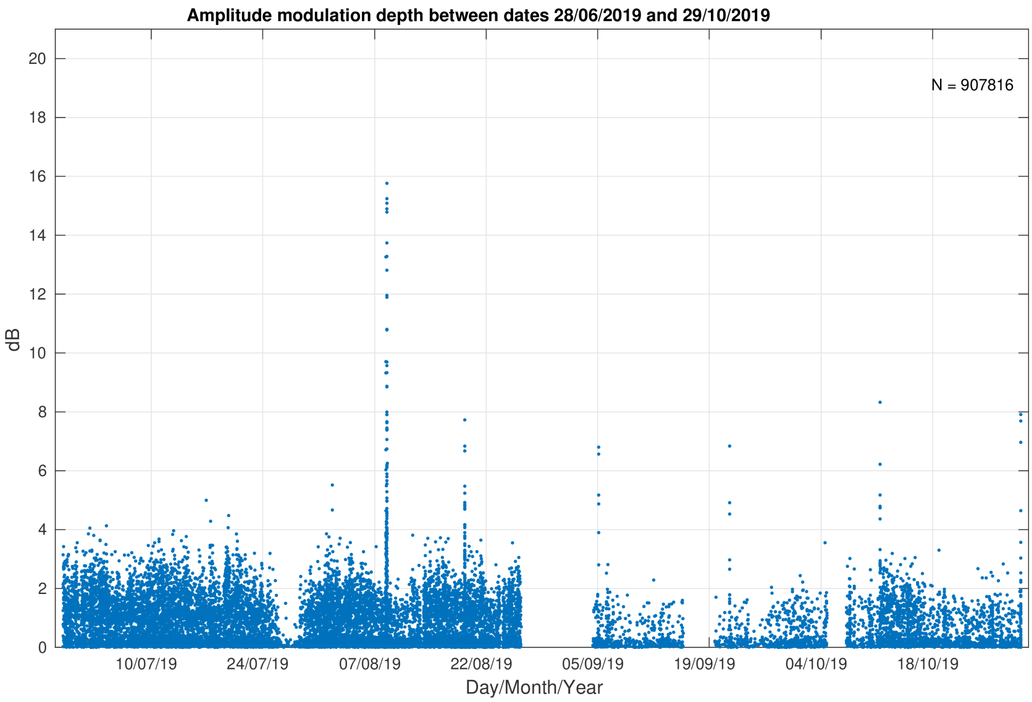


Figure B.10: Raahe, indoors, amplitude modulation depth.

C Tables of the Questionnaire Study

Table C.1: The prevalence and severity symptoms caused by infrasound, vibration and electromagnetic field from wind turbines among all questionnaire respondents, their spouses and their children at different distance zones. Numbers of responses to each question are given in the footnote.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
	%	n	%	n	%	n	%	n	%	n
Infrasound from wind turbines										
Respondent has symptoms[1]	15	34	5	14	3	14	2	8	**5**	**70**
Spouse has symptoms[2]	14	23	6	12	2	7	2	4	**5**	**46**
Spouse examined/treated by a doctor[3]	3	5	2	4	2	5	1	2	**2**	**16**
Spouse on a sick leave[4]	1	2	2	4	1	2	1	2	**1**	**10**
Child has symptoms[5]	8	7	2	3	1	3	2	4	**3**	**17**
Child examined/treated by a doctor[6]	1	1	1	1	2	3	1	2	**1**	**7**
Child away from day care or shcool[7]	0	0	2	2	1	2	1	2	**1**	**6**
Vibration from wind turbines										
Respondent has symptoms[8]	5	11	1	3	1	5	1	2	**2**	**21**
Electromagnetic field from wind turbines										
Respondent has symptoms[9]	4	8	3	8	2	9	2	6	**2**	**31**

1 In your own opinion, have you ever had any symptoms that you have associated with wind turbine infrasound in your current home? n=1293

2 Has your spouse had any symptoms associated with wind turbine infrasound? n=910

3 Has your spouse been examined or treated by a doctor because of symptoms or diseases that have been suspected to result from wind turbine infrasound? n=890

4 Has your spouse been on a sick leave because of symptoms or diseases that have been suspected to result from wind turbine infrasound? n=888

5 Has any of your children had any symptoms associated with wind turbine infrasound? n=583

6 Has any of your children been examined or treated by a doctor because of symptoms or diseases that have been suspected to result from wind turbine infrasound? n=567

7 Has any of your children been away from day care or school because of symptoms or diseases that have been suspected to result from wind turbine infrasound? n=564

8 In your own opinion, have you ever had any symptoms that you have associated with vibration from wind turbine in your current home? n=1290

9 In your own opinion, have you ever had any symptoms that you have associated with electromagnetic field from wind turbines in your current home? n=1298

Table C.2: Frequency and severity of wind turbine infrasound related symptoms and their effects on well-being among respondents with wind turbine infrasound related symptoms (n=64–68) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
	%	n	%	n	%	n	%	n	%	n
Infrasound from wind turbines										
Visited a doctor[1]	33	11	62	8	31	4	0	0	**35**	**23**
Been on a sick leave[2]	16	5	31	4	17	2	0	0	**17**	**11**
Symptom frequency[3]										
Once per month or less	15	5	0	0	15	2	14	1	**12**	**8**
Several times per month	26	9	23	3	15	2	14	1	**22**	**15**
Once per week	18	6	8	1	8	1	0	0	**12**	**8**
Several times per week	20	7	38	5	31	4	43	3	**29**	**19**
Almost every day	15	5	23	3	23	3	29	2	**19**	**13**
Every day	6	2	8	1	8	1	0	0	**6**	**4**
Symptom severity[4]										
Mild	15	5	15	2	15	2	57	4	**19**	**13**
Moderate	53	18	62	8	47	6	43	3	**53**	**35**
Difficult	20	7	23	3	23	3	0	0	**19**	**13**
Extremely difficult	12	4	0	0	15	2	0	0	**9**	**6**
Effect on relationships[5]										
No	44	13	77	10	46	6	64	5	**53**	**34**
Small	33	10	8	1	31	4	12	1	**25**	**16**
Moderate	10	3	15	2	8	1	12	1	**11**	**7**
Quite large	10	3	0	0	15	2	0	0	**8**	**5**
Very large	3	1	0	0	0	0	12	1	**3**	**2**
Effect on financial situation										
No	56	17	77	10	62	8	62	5	**62**	**40**
Small	20	6	15	2	15	2	25	2	**19**	**12**
Moderate	10	3	8	1	23	3	13	1	**13**	**8**
Quite large	7	2	0	0	0	0	0	0	**3**	**2**
Very large	7	2	0	0	0	0	0	0	**3**	**2**
Effect on mental wellbeing										
No	6	2	23	3	31	4	37	3	**18**	**12**
Small	25	8	46	6	31	4	13	1	**29**	**19**
Moderate	41	13	8	1	8	1	37	3	**27**	**18**
Quite large	22	7	15	2	22	3	13	1	**20**	**13**
Very large	6	2	8	1	8	1	0	0	**6**	**4**
Effect on living arrangements										
No	52	16	46	6	54	7	62	5	**52**	**34**
Small	20	6	31	4	15	2	25	2	**22**	**14**
Moderate	16	5	15	2	15	2	13	1	**15**	**10**
Quite large	6	2	8	1	8	1	0	0	**6**	**4**
Very large	6	2	0	0	8	1	0	0	**5**	**3**
Effect on health										
No	6	2	8	1	8	1	25	2	**9**	**6**
Small	9	3	39	5	31	4	13	1	**19**	**13**
Moderate	41	14	15	2	8	1	62	5	**32**	**22**
Quite large	29	10	15	2	22	3	0	0	**22**	**15**
Very large	15	5	23	3	31	4	0	0	**18**	**12**
Effect on working capacity										
No	19	6	23	3	15	2	38	3	**21**	**14**
Small	22	7	39	5	15	2	38	3	**26**	**17**
Moderate	28	9	15	2	23	3	24	2	**24**	**16**
Quite large	22	7	15	2	23	3	0	0	**18**	**12**
Very large	9	3	8	1	23	3	0	0	**11**	**7**

1 Have you visited a doctor because of symptoms or diseases that you have suspected to result from wind turbine infrasound?
2 Have you been on a sick leave because of symptoms or diseases that you have suspected to result from wind turbine infrasound?
3 How often during the last year (12 months) have you had wind turbine infrasound related symptoms
4 How severe have the symptoms been at their worst?
5 Has infrasound from wind turbines affected harmfully on the following aspects of life?

Table C.3: Descriptives for variables in multivariate models among all questionnaire respondents (n=1159) and respondents with wind turbine infrasound related symptoms (n=58).

	All respondents		Symptomatic respondents	
	%	n	%	n
Occupational status[1]				
Employed, entrepreneur/self-employed	43	495	52	30
Pensioner	46	536	29	17
Unemployed	5	60	10	6
At-home mother/father, on family leave, student	6	68	9	5
Distance to the closest wind turbine from home (zones)[2]				
≤ 2.5 km	17	197	45	26
> 2.5–5 km	24	278	17	10
> 5–10 km	32	373	24	14
> 10–20 km	27	311	14	8
Chronic diseases[3]				
No	52	598	44	26
1	29	338	28	16
≥ 2	19	223	28	16
Impaired hearing[4]	42	485	59	34
Functional disorders[5]				
No	85	980	66	38
≥ 1	15	179	34	20
Annoyance caused by audible sound from wind turbines[6]				
No	89	1023	38	22
Low or moderate	9	110	33	19
High or extreme	2	26	29	17
Annoyance caused by wind turbine lights[7]				
Not in the neighbourhood	31	352	14	8
No	57	663	26	15
Yes, at least low	12	144	60	35
Annoyance caused by shadow flicker from wind turbines[8]				
Not at all	92	1067	50	29
Yes, at least occasionally	8	92	50	29
Received enough information about wind power projects[9]				
No	39	454	90	52
Yes or not needed	61	705	10	6
Opinion about personal health risk due to wind turbine infrasound[10]				
No risk	54	629	3	2
Low or moderate risk	36	419	21	12
High or extreme risk	10	111	76	44
Opinion about the effect of wind turbine infrasound on different diseases[11]				
Small effects (score 0–6)	58	677	3	2
Moderate effects (score 7–12)	26	301	26	15
Major effects (score 13–24)	16	181	71	41
	Mean	SD[15]	Mean	SD
Noise sensitivity (score 0–24)[12]	11	5.2	14	5.0
Sensitivity to other exposure in living environment (score 0–28)[13]	9.8	5.5	13	6.5
Opinion about the health effects of wind power production (score 0–16)[14]	6.9	3.6	12	2.7

1 What is your current main activity?
2 Distance calculated based on dwelling coordinates and the locations of wind turbines in the study areas
3 Have you had any of the following diseases diagnosed or treated by a doctor within the last year (12 months)?: high blood pressure, heart insufficiency, ischaemic heart disease, diabetes, depression, rheumatoid arthritis, asthma, pulmonary emphysema/chronic bronchitis/cancer
4 Has a doctor detected that your hearing is impaired? or Do you think that your hearing is impaired?
5 Have you had any of the following diseases diagnosed or treated by a doctor within the last year (12 months)?: panic disorder/other anxiety disorder, chronic fatigue syndrome, irritable bowel syndrome, chronic pain syndrome (for example fibromyalgia)
6 Are you usually annoyed or is your concentration disturbed etc. by audible sound from wind turbines inside when the windows are closed?
7 Are you annoyed by wind turbine lights at home during a dark time of the day?
8 Are you annoyed by shadow flicker caused by wind turbines at home?
9 Have you received enough information regarding realised wind power projects in the neighbourhood before the construction has started?
10 What is the level of personal health risk you associate with infrasound from wind turbines in your own living environment?
11 How much do you think exposure to infrasound from wind turbines can affect the following things and diseases in general?: mood, sleep quality, blood pressure, diabetes, heart diseases, cancer
12 What do you think about the following statements describing yourself? a) I wake easily because of noise. b) I get irritated if my neighbours cause noise. c) I get used to most of noise without particular difficulties. d) I find it difficult to relax in a noisy place. e) I'm good at concentrating no matter what happens around me. f) I'm sensitive to noise.
13 How often do the following things make you feel uncomfortable or ill when you are exposed to them?: exhaust fumes from traffic, paints or paint thinners, perfumes, air fresheners or other odorants, new surface materials (for example carpets, floor covering), smell of mold from moisture damaged buildings, cigarette smoke, electromagnetic field (radiation)
14 To what extent you agree or disagree with the following? a) I'm worried about potential health risks associated with wind power production. b) The potential health risks associated with wind turbines are being diminished in Finland. c) It is difficult to assess whether symptoms are caused by wind turbines or other things. d) Mere worry about the potential health risks associated with wind turbines can result to symptoms.
15 Standard deviation

Table C.4: Results from multiple logistic regression analyses (dependent variable: having symptoms intuitively associated with wind turbine infrasound).

	Building and individual characteristics[1]		Annoyance and opinions[2]		Combined model[3]	
Independent variables	**OR[4]**	**95% CI[5]**	**OR**	**95% CI**	**OR**	**95% CI**
Occupational status						
Employed, entrepreneur/self-employed	*ref*[6]	*ref*	-	-	*ref*	*ref*
Pensioner	0.4	0.2–0.7	-	-	0.3	0.1–0.9
Unemployed	0.9	0.3–2.4	-	-	1.2	0.3–4.8
At-home mother/father, on family leave, student	1.4	0.5–3.8	-	-	1.2	0.3–4.9
Distance to the closest wind turbine from home (zones)						
≤ 2.5 km	8.1	3,5–18	-	-	3.7	1.3–11
> 2.5–5 km	1.7	0.7–4.3	-	-	2.1	0.6–6.8
> 5–10 km	1.4	0.5–3.4	-	-	1.9	0.6–5.8
> 10–20 km	*ref*	*ref*	-	-	*ref*	*ref*
Chronic diseases						
No	*ref*	*ref*	-	-	*ref*	*ref*
1	1.1	0.6–2.1	-	-	1.6	0.6–4.0
≥ 2	2.2	1.1–4.6	-	-	3.5	1.2–11
Impaired hearing	2.4	1.4–4.2	-	-	-	-
Noise sensitivity (score 0–24)	1.1	1.0–1.2	-	-	-	-
Sensitivity to other exposure in living environment (score 0–28)	-	-	1.0	1.0–1.1	-	-
Functional disorders						
No	-	-	*ref*	*ref*	*ref*	*ref*
≥ 1	-	-	2.8	1.2–6.3	1.9	0.7–5.0
Annoyance caused by audible sound from wind turbines						
No	-	-	*ref*	*ref*	-	-
Low or moderate	-	-	0.8	0.3–2.1	-	-
High or extreme	-	-	3.9	1.0–14	-	-
Annoyance caused by wind turbine lights						
Not in the neighbourhood	-	-	*ref*	*ref*	-	-
No	-	-	2.1	0.8–5.9	-	-
Yes, at least low	-	-	2.9	1.0–8.3	-	-
Annoyance caused by shadow flicker from wind turbines						
No	-	-	-	-	*ref*	*ref*
Yes, at least occasionally	-	-	-	-	1.9	0.8–4.3
Received enough information about wind power projects						
No	-	-	-	-	2.6	0.9–7.6
Yes or no information needed	-	-	-	-	*ref*	*ref*
Opinion about the health effects of wind power production (score 0–16)	-	-	1.3	1.1–1.5	1.3	1.1–1.5
Opinion about personal health risk due to wind turbine infrasound						
No risk	-	-	*ref*	*ref*	*ref*	*ref*
Low or moderate risk	-	-	3.0	0.6–14	2.3	0.5–11
High or extreme risk	-	-	21	4.0–105	14	2.9–71
Opinion about the effect of wind turbine infrasound on different diseases						
Small effects (score 0–6)	-	-	*ref*	*ref*	*ref*	*ref*
Moderate effects (score 7–12)	-	-	5.7	1.2–28	5.2	1.0–26
Major effects (score 13–24)	-	-	5.9	1.2–30	7.6	1.5–38

1 N=1230, 64 cases
2 N=1186, 60 cases
3 N=1175, 62 cases
4 Odds ratio estimate
5 95% confidence interval
6 Reference group

Table C.5: The prevalence of exposure, annoyance and sleep disturbance caused by audible sound from wind turbines at home among all questionnaire respondents (n=1296–1320) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Audible sound from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	55	127	67	210	84	355	83	294	**75**	**986**
Low or moderate	24	56	26	81	12	49	11	37	**17**	**223**
High or extreme	21	50	4	12	1	6	1	4	**5**	**72**
Unable to answer	0	1	3	8	3	11	5	19	**3**	**39**
Annoyance outdoors[2]										
No	64	146	76	238	90	370	92	317	**83**	**1071**
Low or moderate	21	48	21	64	8	34	7	25	**13**	**171**
High or extreme	15	34	3	8	2	7	1	4	**4**	**53**
Annoyance indoors[3]										
No	73	167	84	263	93	382	93	326	**88**	**1138**
Low or moderate	20	45	14	43	6	26	6	20	**10**	**134**
High or extreme	7	17	2	5	1	6	1	2	**2**	**30**
Sleep disturbance[4]										
No	79	179	89	274	93	382	93	322	**89**	**1157**
Low or moderate	11	26	10	32	6	26	6	22	**8**	**106**
High or extreme	10	22	1	4	1	5	1	2	**3**	**33**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.6: The prevalence of exposure, annoyance and sleep disturbance caused by audible sound from road traffic at home among all questionnaire respondents (n=1308–1322) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Audible sound from road traffic	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	38	88	34	107	40	169	37	131	**37**	**495**
Low or moderate	53	122	56	174	55	230	57	206	**55**	**732**
High or extreme	9	20	9	27	5	23	5	17	**7**	**87**
Unable to answer	0	0	1	3	0	2	1	3	**1**	**8**
Annoyance outdoors[2]										
No	49	113	48	150	54	226	49	172	**51**	**661**
Low or moderate	45	102	47	147	43	179	47	165	**45**	**593**
High or extreme	6	13	5	14	3	14	4	15	**4**	**56**
Annoyance indoors[3]										
No	68	155	68	212	71	298	72	253	**70**	**918**
Low or moderate	30	70	30	93	28	115	27	97	**28**	**375**
High or extreme	2	5	2	6	1	5	1	4	**2**	**20**
Sleep disturbance[4]										
No	76	173	73	225	70	293	73	258	**72**	**949**
Low or moderate	22	51	25	79	29	121	25	87	**26**	**338**
High or extreme	2	5	2	5	1	4	2	7	**2**	**21**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.7: The prevalence of exposure, annoyance and sleep disturbance caused by infrasound from wind turbines at home among all questionnaire respondents (n=1294–1312) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	53	122	65	200	79	332	79	281	**71**	**935**
Low or moderate	19	44	24	74	13	56	12	41	**16**	**215**
High or extreme	23	52	5	17	3	11	2	7	**7**	**87**
Unable to answer	5	11	6	19	5	21	7	24	**6**	**75**
Annoyance outdoors[2]										
No	70	159	79	246	90	369	91	311	**84**	**1085**
Low or moderate	17	39	17	53	8	33	8	28	**12**	**153**
High or extreme	13	30	4	11	2	10	1	5	**4**	**56**
Annoyance indoors[3]										
No	74	170	86	266	92	377	92	318	**87**	**1131**
Low or moderate	16	36	11	34	6	25	7	25	**9**	**120**
High or extreme	10	23	3	10	2	10	1	3	**4**	**46**
Sleep disturbance[4]										
No	78	178	86	269	93	380	92	317	**88**	**1144**
Low or moderate	11	25	11	33	5	22	7	23	**8**	**103**
High or extreme	11	25	3	8	2	10	1	4	**4**	**47**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.8: The prevalence of exposure, annoyance and sleep disturbance caused by infrasound from road traffic at home among all questionnaire respondents (n=1303–1313) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from road traffic	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	52	117	52	164	57	241	52	185	**54**	**707**
Low or moderate	41	94	37	114	36	153	40	140	**38**	**501**
High or extreme	3	7	5	15	3	12	3	10	**3**	**44**
Unable to answer	4	10	6	18	4	15	5	18	**5**	**61**
Annoyance outdoors[2]										
No	72	164	74	229	78	322	74	257	**75**	**972**
Low or moderate	26	58	23	73	21	89	24	85	**23**	**305**
High or extreme	2	4	3	9	1	5	2	8	**2**	**26**
Annoyance indoors[3]										
No	83	188	85	264	87	366	86	302	**86**	**1120**
Low or moderate	16	37	13	41	12	49	13	46	**13**	**173**
High or extreme	1	2	2	5	1	3	1	3	**1**	**13**
Sleep disturbance[4]										
No	88	198	87	270	88	369	86	302	**87**	**1139**
Low or moderate	12	28	12	36	11	46	13	44	**12**	**154**
High or extreme	0	1	1	3	1	3	1	3	**1**	**10**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.9: The prevalence of exposure, annoyance and sleep disturbance caused by vibration from wind turbines at home among all questionnaire respondents (n=1294–1318) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Vibration from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	71	165	81	251	87	365	86	303	**83**	**1084**
Low or moderate	19	43	13	41	8	34	8	28	**11**	**146**
High or extreme	7	16	2	6	1	5	1	5	**2**	**32**
Unable to answer	3	7	4	13	4	18	5	18	**4**	**56**
Annoyance outdoors[2]										
No	80	180	87	271	92	379	94	326	**89**	**1156**
Low or moderate	16	37	12	36	6	26	5	17	**9**	**116**
High or extreme	4	9	1	3	2	7	1	3	**2**	**22**
Annoyance indoors[3]										
No	84	190	91	283	93	385	94	329	**92**	**1187**
Low or moderate	14	33	8	24	5	22	5	17	**7**	**96**
High or extreme	2	5	1	3	2	7	1	2	**1**	**17**
Sleep disturbance[4]										
No	84	191	92	285	93	384	94	325	**92**	**1185**
Low or moderate	12	28	7	23	6	23	5	18	**7**	**92**
High or extreme	4	8	1	2	1	6	1	3	**1**	**19**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.10: The prevalence of exposure, annoyance and sleep disturbance caused by vibration from road traffic at home among all questionnaire respondents (n=1301–1318) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Vibration from road traffic	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	60	139	55	171	59	250	58	206	**58**	**766**
Low or moderate	35	80	39	122	38	160	38	137	**38**	**499**
High or extreme	5	11	5	14	3	11	3	10	**3**	**46**
Unable to answer	0	0	1	3	0	2	1	2	**1**	**7**
Annoyance outdoors[2]										
No	70	161	64	199	72	298	73	257	**70**	**915**
Low or moderate	26	59	33	101	26	107	25	86	**27**	**353**
High or extreme	4	8	3	9	2	8	2	8	**3**	**33**
Annoyance indoors[3]										
No	75	172	75	230	79	333	78	274	**78**	**1009**
Low or moderate	23	53	23	72	20	82	21	74	**21**	**281**
High or extreme	2	4	2	7	1	3	1	4	**1**	**18**
Sleep disturbance[4]										
No	83	190	80	249	81	338	83	289	**82**	**1066**
Low or moderate	16	36	19	57	18	76	15	53	**17**	**222**
High or extreme	1	2	1	2	1	4	2	8	**1**	**16**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.11: Cross-tabulation between the prevalence of annoyance indoors at home caused by audible sound from wind turbines and the prevalence of annoyance indoors at home caused by infrasound from wind turbines among all questionnaire respondents (n=1304).

Annoyance inside[1]	Audible sound from wind turbines: No annoyance		Low or moderate annoyance		High or extreme annoyance		Total	
	%	n	%	n	%	n	%	n
Infrasound from wind turbines								
No annoyance	98	1106	2	25	0	0	**100**	**1131**
Low or moderate annoyance	19	23	78	94	3	3	**100**	**120**
High or extreme annoyance	9	4	30	13	61	27	**100**	**44**

1 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors at home when the windows are closed?

Table C.12: The prevalence of exposure, annoyance and sleep disturbance caused by audible sound from wind turbines at home among respondents with wind turbine infrasound related symptoms (n=67–69) at different distance zones.

	Distance between the respondent's home and the closest wind turbine: ≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Audible sound from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	3	1	21	3	23	3	37	3	**14**	**10**
Low or moderate	26	9	43	6	54	7	50	4	**38**	**26**
High or extreme	71	24	29	4	23	3	13	1	**47**	**32**
Unable to answer	0	0	7	1	0	0	0	0	**1**	**1**
Annoyance outdoors[2]										
No	3	1	36	5	38	5	62	5	**23**	**16**
Low or moderate	26	9	43	6	38	5	25	2	**32**	**22**
High or extreme	71	24	21	3	23	3	13	1	**45**	**31**
Annoyance indoors[3]										
No	9	3	57	8	36	5	87	7	**34**	**23**
Low or moderate	47	15	29	4	36	5	13	1	**37**	**25**
High or extreme	44	14	14	2	28	4	0	0	**29**	**20**
Sleep disturbance[4]										
No	13	4	57	8	31	4	62	5	**32**	**21**
Low or moderate	31	10	29	4	46	6	38	3	**34**	**23**
High or extreme	56	18	14	2	23	3	0	0	**34**	**23**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.13: The prevalence of exposure, annoyance and sleep disturbance caused by infrasound from wind turbines at home among respondents with wind turbine infrasound related symptoms (n=68–70) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	0	0	0	0	7	1	13	1	**3**	**2**
Low or moderate	15	5	36	5	29	4	37	3	**24**	**17**
High or extreme	82	28	57	8	57	8	37	3	**67**	**47**
Unable to answer	3	1	7	1	7	1	13	1	**6**	**4**
Annoyance outdoors[2]										
No	0	0	21	3	14	2	29	2	**10**	**7**
Low or moderate	32	11	36	5	50	7	57	4	**39**	**27**
High or extreme	68	23	43	6	36	5	14	1	**51**	**35**
Annoyance indoors[3]										
No	9	3	21	3	14	2	29	2	**14**	**10**
Low or moderate	32	11	29	4	36	5	71	5	**36**	**25**
High or extreme	59	20	50	7	50	7	0	0	**50**	**34**
Sleep disturbance[4]										
No	9	3	14	2	8	1	14	1	**10**	**7**
Low or moderate	26	9	43	6	38	5	72	5	**37**	**25**
High or extreme	65	22	43	6	54	7	14	1	**53**	**36**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.14: The prevalence of exposure, annoyance and sleep disturbance caused by vibration from wind turbines at home among respondents with wind turbine infrasound related symptoms (n=67–70) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Vibration from wind turbines	%	n	%	n	%	n	%	n	%	n
Exposure[1]										
No	21	7	43	6	21	3	37	3	**27**	**19**
Low or moderate	35	12	43	6	43	6	50	4	**40**	**28**
High or extreme	32	11	7	1	21	3	13	1	**23**	**16**
Unable to answer	12	4	7	1	14	2	0	0	**10**	**7**
Annoyance outdoors[2]										
No	29	9	57	8	36	5	87	7	**44**	**29**
Low or moderate	48	15	36	5	36	5	0	0	**37**	**25**
High or extreme	23	7	7	1	28	4	13	1	**19**	**13**
Annoyance indoors[3]										
No	43	14	72	10	42	6	87	7	**54**	**37**
Low or moderate	41	13	21	3	29	4	13	1	**31**	**21**
High or extreme	16	5	7	1	29	4	0	0	**15**	**10**
Sleep disturbance[4]										
No	34	11	57	8	29	4	75	6	**43**	**29**
Low or moderate	41	13	36	5	42	6	25	2	**38**	**26**
High or extreme	25	8	7	1	29	4	0	0	**19**	**13**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outdoors in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.15: Cross-tabulation between the prevalence of annoyance indoors at home caused by audible sound from wind turbines and the prevalence of annoyance indoors at home caused by infrasound from wind turbines among respondents with wind turbine infrasound related symptoms (n=67–70).

Annoyance inside[1]	Audible sound from wind turbines: No annoyance		Low or moderate annoyance		High or extreme annoyance		**Total**	
	%	n	%	n	%	n	%	**n**
Infrasound from wind turbines								
No annoyance	80	8	20	2	0	0	**100**	**10**
Low or moderate annoyance	40	10	56	14	4	1	**100**	**25**
High or extreme annoyance	13	4	28	9	59	19	**100**	**32**

1 Are you usually annoyed or is your concentration disturbed etc. by the following factors indoors when the windows are closed?

Table C.16: Opinion about health risk from wind turbine infrasound among all questionnaire respondents (n=1285–1303) at different distance zones.

	Distance between the respondent's home and the closest wind turbine: ≤ 2.5 km		**> 2.5–5 km**		**> 5–10 km**		**> 10–20 km**		**Total**	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	%	**n**
Personal health risk[1]										
No	41	95	51	157	58	243	57	199	**53**	**694**
Low or moderate	39	89	39	122	35	143	35	122	**37**	**476**
High or extreme	20	46	10	30	7	28	8	29	**10**	**133**
Health risk in general[2]										
No	16	37	22	68	20	84	19	66	**20**	**255**
Low or moderate	59	134	63	194	63	263	63	219	**62**	**810**
High or extreme	25	55	15	46	17	69	18	62	**18**	**232**
Effect on mood[3]										
No	27	61	28	87	22	93	25	87	**25**	**328**
Low or moderate	49	109	54	166	58	237	51	179	**54**	**691**
High or extreme	24	55	18	56	20	84	24	82	**21**	**277**
Effect on sleep quality										
No	26	58	27	83	23	97	24	82	**25**	**320**
Low or moderate	43	98	50	155	54	220	52	182	**50**	**655**
High or extreme	31	69	23	71	23	97	24	84	**25**	**321**
Effect on blood pressure										
No	36	80	39	119	37	152	32	113	**36**	**464**
Low or moderate	40	88	47	145	48	201	50	174	**47**	**608**
High or extreme	24	53	14	43	15	62	18	61	**17**	**219**
Effect on diabetes										
No	62	137	66	201	61	250	58	200	**61**	**788**
Low or moderate	33	72	30	92	33	136	36	126	**33**	**426**
High or extreme	5	12	4	11	6	26	6	22	**6**	**71**
Effect on heart diseases										
No	43	94	48	148	44	183	43	147	**44**	**572**
Low or moderate	38	85	42	128	45	187	43	150	**43**	**550**
High or extreme	19	43	10	32	11	47	14	49	**13**	**171**
Effect on cancer										
No	61	137	66	204	62	257	57	198	**61**	**796**
Low or moderate	31	69	29	89	31	129	35	120	**32**	**407**
High or extreme	8	17	5	15	7	28	8	29	**7**	**89**

1 What is the level of personal health risk you associate with infrasound from wind turbines in your own living environment?
2 What is the level of general health risk you associate with infrasound from wind turbines?
3 How much do you think exposure to infrasound from wind turbines can affect the following things and diseases in general?

Table C.17: Opinion about health risk from wind turbine infrasound among respondents with wind turbine infrasound related symptoms (n=66–69) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	**%**	**n**
Personal health risk[1]										
No	0	0	0	0	14	2	0	0	**3**	**2**
Low or moderate	13	4	43	6	14	2	38	3	**22**	**15**
High or extreme	87	28	57	8	72	10	62	5	**75**	**51**
Health risk in general[2]										
No	0	0	0	0	7	1	0	0	**1**	**1**
Low or moderate	12	4	36	5	21	3	38	3	**22**	**15**
High or extreme	88	29	64	9	72	10	62	5	**77**	**53**
Effect on mood[3]										
No	0	0	0	0	0	0	0	0	**0**	**0**
Low or moderate	30	10	36	5	43	6	25	2	**33**	**23**
High or extreme	70	23	64	9	57	8	75	6	**67**	**46**
Effect on sleep quality										
No	0	0	0	0	0	0	0	0	**0**	**0**
Low or moderate	6	2	7	1	43	6	25	2	**16**	**11**
High or extreme	94	31	93	13	57	8	75	6	**84**	**58**
Effect on blood pressure										
No	3	1	7	1	0	0	0	0	**3**	**2**
Low or moderate	13	4	36	5	50	7	38	3	**28**	**19**
High or extreme	84	26	57	8	50	7	62	5	**69**	**46**
Effect on diabetes										
No	23	7	46	6	7	1	13	1	**23**	**15**
Low or moderate	58	18	46	6	50	7	74	6	**56**	**37**
High or extreme	19	6	8	1	43	6	13	1	**21**	**14**
Effect on heart diseases										
No	6	2	14	2	0	0	0	0	**6**	**4**
Low or moderate	19	6	29	4	29	4	62	5	**28**	**19**
High or extreme	75	24	57	8	71	10	38	3	**66**	**45**
Effect on cancer										
No	29	9	36	5	14	2	25	2	**27**	**18**
Low or moderate	52	16	50	7	50	7	62	5	**52**	**35**
High or extreme	19	6	14	2	36	5	13	1	**21**	**14**

1 What is the level of personal health risk you associate with infrasound from wind turbines in your own living environment?
2 What is the level of general health risk you associate with infrasound from wind turbines?
3 How much do you think exposure to infrasound from wind turbines can affect the following things and diseases in general?

Table C.18: The prevalence of wind turbine infrasound related symptoms among telephone interview respondents, their spouses and their children (n=318) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	**%**	**n**
Respondent has symptoms[1]										
No	85	41	92	70	96	95	97	92	**93**	**298**
Yes	13	6	7	5	3	3	1	1	**5**	**15**
Unable to answer	2	1	1	1	1	1	2	2	**2**	**5**
Spouse has symptoms[2]										
No	59	28	66	50	69	68	73	69	**68**	**215**
Yes	6	3	1	1	2	2	1	1	**2**	**7**
No spouse	29	14	33	25	27	27	25	24	**28**	**90**
Unable to answer	6	3	0	0	2	2	1	1	**2**	**6**
Child has symptoms[3]										
No	38	18	58	44	63	62	67	64	**59**	**188**
Yes	6	3	0	0	3	3	0	0	**2**	**6**
No children	54	26	41	31	33	33	31	29	**37**	**119**
Unable to answer	2	1	1	1	1	1	2	2	**2**	**5**

1 In your own opinion, have you ever had any symptoms that you have associated with wind turbine infrasound in your current home?
2 Has your spouse had any symptoms associated with wind turbine infrasound?
3 Has your any of your children had any symptoms associated with wind turbine infrasound?

Table C.19: The prevalence of exposure, annoyance and sleep disturbance caused by audible sound from wind turbines at home among telephone interview respondents (n=318) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Audible sound from wind turbines	%	n	%	n	%	n	%	n	**%**	**n**
Exposure[1]										
No	63	30	89	67	85	84	73	69	**78**	**250**
Low or moderate	31	15	9	7	5	5	4	4	**10**	**31**
High or extreme	6	3	1	1	1	1	4	4	**3**	**9**
Unable to answer	0	0	1	1	2	2	1	1	**1**	**4**
Not in the neighbourhood	0	0	0	0	7	7	18	17	**8**	**24**
Annoyance outside[2]										
No	58	28	87	66	88	87	87	82	**83**	**263**
Low or moderate	31	15	9	7	10	10	4	4	**11**	**36**
High or extreme	11	5	4	3	0	0	4	4	**4**	**12**
Unable to answer	0	0	0	0	2	2	5	5	**2**	**7**
Annoyance inside[3]										
No	90	43	95	72	96	95	90	85	**92**	**295**
Low or moderate	10	5	4	3	0	0	0	0	**3**	**8**
High or extreme	0	0	1	1	1	1	4	4	**2**	**6**
Unable to answer	0	0	0	0	3	3	6	6	**3**	**9**
Sleep disturbance[4]										
No	86	41	92	70	98	97	92	87	**92**	**295**
Low or moderate	10	5	3	2	1	1	0	0	**3**	**8**
High or extreme	4	2	5	4	1	1	2	2	**3**	**9**
Unable to answer	0	0	0	0	0	0	6	6	**2**	**6**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outside in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors inside when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

Table C.20: The prevalence of exposure, annoyance and sleep disturbance caused by infrasound from wind turbines at home among telephone interview respondents (n=318) at different distance zones.

	Distance between the respondent's home and the closest wind turbine									
	≤ 2.5 km		> 2.5–5 km		> 5–10 km		> 10–20 km		Total	
Infrasound from wind turbines	%	n	%	n	%	n	%	n	**%**	**n**
Exposure[1]										
No	79	38	84	64	85	84	76	72	**81**	**258**
Low or moderate	15	7	11	8	5	5	3	3	**7**	**23**
High or extreme	4	2	1	1	1	1	2	2	**2**	**6**
Unable to answer	2	1	4	3	2	2	1	1	**2**	**7**
Not in the neighbourhood	0	0	0	0	7	7	18	17	**8**	**24**
Annoyance outside[2]										
No	79	38	90	68	88	87	91	86	**88**	**279**
Low or moderate	17	8	5	4	9	9	2	2	**7**	**23**
High or extreme	2	1	4	3	0	0	2	2	**2**	**6**
Unable to answer	2	1	1	1	3	3	5	5	**3**	**10**
Annoyance inside[3]										
No	92	44	93	70	94	93	92	87	**92**	**294**
Low or moderate	4	2	5	4	1	1	0	0	**2**	**7**
High or extreme	2	1	1	1	1	1	2	2	**2**	**5**
Unable to answer	2	1	1	1	4	4	6	6	**4**	**12**
Sleep disturbance[4]										
No	86	41	94	72	96	95	93	88	**93**	**296**
Low or moderate	10	5	3	2	2	2	0	0	**3**	**9**
High or extreme	2	1	3	2	2	2	1	1	**2**	**6**
Unable to answer	2	1	0	0	0	0	6	6	**2**	**7**

1 Please assess to what extent you are usually exposed to following factors at home?
2 Are you usually annoyed or is your concentration disturbed etc. by the following factors outside in the garden or balcony?
3 Are you usually annoyed or is your concentration disturbed etc. by the following factors inside when the windows are closed?
4 Do the following factors usually disturb your sleep (prevent from falling asleep, wake up too early etc.)?

D Questionnaire study form

TERVEYDEN JA HYVINVOINNIN LAITOS
Institutet för hälsa och välfärd

A-Posti Oy Posti Green

Malli Mallikas
Mallitie 1
99997 MALLILA

Päivämäärä

Tuulivoima asuinympäristössä -kysely

Arvoisa vastaanottaja

Terveyden ja hyvinvoinnin laitos (THL) selvittää tämän Tuulivoima asuinympäristössä -kyselyn avulla tuulivoima-alueiden ympäristössä (alle 20 km) asuvien mielipiteitä ja riskikäsityksiä tuulivoimaan liittyen, asuinympäristön ääni- ja muita olosuhteita sekä oireilua, terveydentilaa ja elämäntapoja. Kyselytutkimus kuuluu valtioneuvoston kanslian rahoittamaan laajempaan tutkimushankkeeseen *Tuulivoimaloiden ääni, sen fysiologiset vaikutukset ja yhteys sairauksiin*, jonka tavoitteena on pyrkiä selvittämään, onko tuulivoimaloiden tuottamalla äänellä haitallisia vaikutuksia ihmisten terveyteen. Laajempaan tutkimushankkeeseen kuuluu myös erillinen Työterveyslaitoksella suoritettava havaitsemiskoe, johon haetaan tutkittavia tämän kyselyn mukana olevalla kirjeellä.

Tuulivoimarakentaminen on herättänyt vilkasta keskustelua julkisuudessa. Osa jo toiminnassa olevien tuulivoima-alueiden läheisyydessä asuvista henkilöistä on raportoinut kärsivänsä monenlaisista oireista, jotka he itse ovat yhdistäneet tuulivoimaloiden tuottamaan infraääneen. Infraääni tarkoittaa matalaa ääntä, jonka taajuusalue (värähtelyjen määrä sekunnissa) on 0–20 Hz. Infraääni on elinympäristössä yleensä kuuloalueen alapuolella, mutta sen voi havaita, jos äänenpainetaso on riittävän suuri. Infraääntä esiintyy kaikkialla luonnossa ja rakennetussa ympäristössä yhdessä kuuluvan äänen kanssa.

Tämän kyselytutkimuksen avulla voidaan muodostaa kuva siitä, kuinka monet kokevat infraäänen aiheuttavan oireita, ja mitkä tekijät ovat yhteydessä oireiluun. Lisäksi saadaan arvio yleisemmällä tasolla siitä, kuinka usein tuulivoimaloiden äänen koetaan aiheuttavan haittoja.

Kyselytutkimukseen on valittu satunnaisesti noin 5000 vähintään 18-vuotiasta henkilöä neljän tuulivoima-alueen ympäristöstä. Te olette yksi näistä otokseen osuneista henkilöistä. Osoitetietonne on saatu Väestörekisterikeskuksesta*.

Kattavan tiedon keräämiseksi jokaisen kyselylomakkeen saaneen vastaus on tärkeä. Kyselytutkimuksen tilastollinen luotettavuus edellyttää, että kysymyksiin vastaa henkilö, jolle kirje on osoitettu. Kyselyllä kerättävien henkilö- ja muiden tietojen käsittelyn perusteena on yleisen edun mukainen tieteellinen tutkimus.

Kaikkia kerättyjä tietoja käsitellään ehdottoman luottamuksellisina. Aineisto analysoidaan tilastollisin menetelmin, eikä yksittäisen henkilön vastauksia voi erottaa tuloksista. Analyyseissä käytettävä aineisto ei sisällä nimi- eikä osoitetietoja.

*Osoitelähde: Väestötietojärjestelmä, Väestörekisterikeskus, PL 123, 00581 HELSINKI

Irrottakaa kansilehti katkoviivan kohdalta itsellenne, jotta henkilötietonne pysyvät kyselystä erillään

Kyselyn palauttaminen

Pyydämme Teitä täyttämään oheisen kyselylomakkeen ja palauttamaan sen mukana olevassa valmiiksi maksetussa kuoressa. Pyydämme lisäksi irrottamaan tämän kansilehden itsellenne, jotta henkilötietonne pysyvät erillään kyselystä. Vaihtoehtoisesti voitte vastata kyselyyn sähköisesti osoitteessa: **www.webropolsurveys.com**

Käyttäjätunnus: **@fYPNpUe4p7**

Salasana: **123456**

Kyselyyn vastanneiden kesken arvotaan kaksi Samsung Galaxy Tab A -taulutietokonetta. Voitte halutessanne kieltäytyä arvonnasta kyselylomakkeen lopussa. Annamme mielellämme lisätietoja tutkimuksesta.

Yhteistyöstä etukäteen kiittäen,

Anu Turunen, erikoistutkija

puhelin 029 524 6473, sähköposti anu.turunen@thl.fi

Ohjeet vastaajalle

- [X] Lukekaa kysymys huolellisesti ennen vastaamista. Eräiden kysymysten kohdalla on myös täydentäviä vastausohjeita.
- [X] Rastittakaa kuulakärkikynällä sopiva vaihtoehto tai kirjoittakaa kysytty tieto sille varattuun tilaan.
- [X] Valitkaa kunkin kysymyksen kohdalla vain yksi, Teille parhaiten sopiva vaihtoehto.
- ■ Mikäli teette merkinnän väärään ruutuun, niin pyydämme Teitä mustaamaan väärän ruudun kokonaan ja rastittamaan oikean ruudun.
- [X] Toivomme, että vastaatte kaikkiin kysymyksiin – merkitkää myös kieltävä vastaus näkyviin joko rastittamalla "Ei" tai merkitsemällä "0" vastaukselle varatulle viivalle.

ESIMERKKI 1.

Millainen terveydentilanne on?

1 [ ] Erittäin hyvä
2 [X] Melko hyvä
3 [ ] Keskitasoinen
4 [ ] Melko huono
5 [ ] Erittäin huono

ESIMERKKI 2.

Kuinka pitkä olette?

168 cm

123456789

TUULIVOIMA ASUINYMPÄRISTÖSSÄ

TAUSTATIEDOT

1. Minkä ikäinen olette? ______ vuotta

2. Mikä on sukupuolenne?

1 ☐ Nainen
2 ☐ Mies
3 ☐ En halua määritellä

3. Mikä on siviilisäätynne?

1 ☐ Avioliitossa tai rekisteröidyssä parisuhteessa
2 ☐ Avoliitossa
3 ☐ Naimaton
4 ☐ Eronnut tai asumuserossa
5 ☐ Leski

4. Kuinka moni taloutenne jäsenistä kuuluu seuraaviin ikäryhmiin <u>mukaan lukien itsenne</u>?
Merkitkää 0, jos ei yksikään.

Alle 3 vuotta ______

3–17 vuotta ______

18 vuotta tai enemmän ______

5. Mikä on koulutuksenne?
Merkitkää ylin suorittamanne koulutus.

1 ☐ Kansakoulu tai peruskoulu
2 ☐ Keskikoulu
3 ☐ Ammattikoulu tai vastaava
4 ☐ Lukio
5 ☐ Opistotutkinto
6 ☐ Ammattikorkeakoulututkinto
7 ☐ Akateeminen tutkinto

123456789

6. Mitä teette tällä hetkellä pääasiallisesti?
Valitkaa vain yksi vaihtoehto.

1 ☐ Palkkatyössä tai yrittäjänä/ammatinharjoittajana
2 ☐ Työtön
3 ☐ Opiskelija
4 ☐ Eläkkeellä
5 ☐ Kotiäiti tai -isä, perhevapaalla
6 ☐ Jokin muu

7. Kuinka suuret olivat taloutenne kokonaistulot viime vuonna veroja vähentämättä (bruttotulot)?

1 ☐ Alle 15 000 €
2 ☐ 15 000–30 000 €
3 ☐ 30 001–50 000 €
4 ☐ 50 001–70 000 €
5 ☐ 70 001–90 000 €
6 ☐ Yli 90 000 €

8. Hyödyttekö taloudellisesti lähiseudun toteutuneista tuulivoimahankkeista (esim. olette saanut myynti- tai vuokratuloja tontista tai olette osakkaana hankkeessa)?

1 ☐ En
2 ☐ Kyllä

9. Kuinka tyytyväinen olette seuraaviin asioihin elämässänne?

	Erittäin tyytyväinen 1	Melko tyytyväinen 2	En tyytyväinen enkä tyytymätön 3	Melko tyytymätön 4	Erittäin tyytymätön 5
a) Terveys	☐	☐	☐	☐	☐
b) Rahatilanne	☐	☐	☐	☐	☐
c) Selviytyminen päivittäisistä toimista	☐	☐	☐	☐	☐
d) Oma itse	☐	☐	☐	☐	☐
e) Ihmissuhteet	☐	☐	☐	☐	☐

10. Kuinka hyväksi arvioitte elämänlaatunne eli elämäntilanteenne kokonaisuudessaan?
Ajatelkaa viimeksi kulunutta kuukautta.

1 ☐ Erittäin hyvä
2 ☐ Melko hyvä
3 ☐ Ei hyvä eikä huono
4 ☐ Melko huono
5 ☐ Erittäin huono

123456789

ASUINYMPÄRISTÖ

11. Kuinka tyytyväinen olette seuraaviin asuinympäristönne olosuhteisiin?

	Erittäin tyytyväinen 1	Melko tyytyväinen 2	En tyytyväinen enkä tyytymätön 3	Melko tyytymätön 4	Erittäin tyytymätön 5
a) Julkiset liikenneyhteydet	☐	☐	☐	☐	☐
b) Palvelut	☐	☐	☐	☐	☐
c) Turvallisuus	☐	☐	☐	☐	☐
d) Naapurit	☐	☐	☐	☐	☐
e) Ulkoilumahdollisuudet	☐	☐	☐	☐	☐
f) Maisema	☐	☐	☐	☐	☐

12. Kuinka terveellisenä pidätte omaa elinympäristöänne?

1 ☐ Erittäin terveellisenä
2 ☐ Melko terveellisenä
3 ☐ Ei terveellisenä eikä epäterveellisenä
4 ☐ Melko epäterveellisenä
5 ☐ Erittäin epäterveellisenä

13. Arvioikaa, missä määrin seuraavat tekijät vaikuttavat maisemaan kotinne ympärillä.

	Parantavat paljon 1	Parantavat jonkin verran 2	Eivät paranna eivätkä huononna 3	Huononta-vat jonkin verran 4	Huononta-vat paljon 5	Ei ole lähistöllä 9
a) Tiet	☐	☐	☐	☐	☐	☐
b) Rautatie	☐	☐	☐	☐	☐	☐
c) Sillat	☐	☐	☐	☐	☐	☐
d) Satama	☐	☐	☐	☐	☐	☐
e) Teollisuuslaitokset	☐	☐	☐	☐	☐	☐
f) Tuulivoimalat	☐	☐	☐	☐	☐	☐
g) Radio-, TV- tai puhelinmastot	☐	☐	☐	☐	☐	☐

14. Häiritsevätkö seuraavien toimintojen valot pimeänä aikana kotonanne?

	Ei häiritse lainkaan 1	Häiritsee vähän 2	Häiritsee jonkin verran 3	Häiritsee paljon 4	Häiritsee erittäin paljon 5	Ei ole lähistöllä 9
a) Katuvalot	☐	☐	☐	☐	☐	☐
b) Autojen valot	☐	☐	☐	☐	☐	☐
c) Vesiliikenteen tai sataman valot	☐	☐	☐	☐	☐	☐
d) Teollisuuslaitosten valot	☐	☐	☐	☐	☐	☐
e) Tuulivoimaloiden valot	☐	☐	☐	☐	☐	☐
f) Radio-, TV- tai puhelinmastojen valot	☐	☐	☐	☐	☐	☐

123456789

15. Koetteko tuulivoimaloiden tuottaman vilkkuvan varjostuksen (lapojen aiheuttama välke, kun aurinko paistaa lapojen takaa ja tuulivoimala pyörii) häiritseväksi kotonanne?

1 ☐ En
2 ☐ Kyllä, satunnaisesti
3 ☐ Kyllä, usein

16. Millaisessa asunnossa asutte tällä hetkellä?

1 ☐ Omistusasunnossa (omassa tai jonkun perheenjäsenen omistamassa)
2 ☐ Osaomistusasunnossa tai asumisoikeusasunnossa
3 ☐ Vuokra-asunnossa
4 ☐ Palvelutalossa, kuntoutuskodissa tai vanhainkodissa
5 ☐ Jossain muualla

17. Mikä on asuinrakennuksenne tyyppi?

1 ☐ Omakoti- tai paritalo
2 ☐ Rivi- tai luhtitalo
3 ☐ Kerrostalo
4 ☐ Muu, mikä ________________________________

18. Millainen on asuinrakennuksenne alapohjan rakenne?

1 ☐ Maanvarainen
2 ☐ Tuulettuva
3 ☐ Muu, mikä ________________________________
4 ☐ En tiedä

19. Mikä on asuinrakennuksenne runkorakenteen pääasiallinen materiaali?

1 ☐ Puu
2 ☐ Hirsi
3 ☐ Betoni
4 ☐ Kevytbetoni
5 ☐ Tiili
6 ☐ Muu, mikä ________________________________
7 ☐ En tiedä

20. Mikä on asuinrakennuksenne vesikattomateriaali?

1 ☐ Bitumihuopa
2 ☐ Pelti
3 ☐ Tiili
4 ☐ Muu, mikä ________________________________

21. Millainen on asuinrakennuksenne pääasiallinen ikkunoiden rakenne?

1 ☐ Yksilasinen
2 ☐ Kaksilasinen
3 ☐ Kolme- tai nelilasinen

123456789

22. Kuinka pitkään olette asunut nykyisessä asunnossanne?

1 ☐ Alle vuoden
2 ☐ 1–3 vuotta
3 ☐ 4–9 vuotta
4 ☐ 10–19 vuotta
5 ☐ 20 vuotta tai kauemmin

23. Kuinka paljon vietätte yleensä aikaa vapaa-ajan asunnolla vuoden aikana?

1 ☐ En yhtään / Käytössäni ei ole vapaa-ajan asuntoa
2 ☐ Alle 1 kk
3 ☐ 1–3 kk
4 ☐ Yli 3 kk

TERVEYS JA ELÄMÄNTAVAT

24. Millainen terveydentilanne on omasta mielestänne?

1 ☐ Erittäin hyvä
2 ☐ Melko hyvä
3 ☐ Keskitasoinen
4 ☐ Melko huono
5 ☐ Erittäin huono

25. Kuinka pitkä olette? __________ cm

26. Kuinka paljon painatte? _________ kg

27. Onko Teillä viimeksi kuluneen kuukauden (30 pv) aikana ollut seuraavia oireita tai vaivoja?

	Ei 1	Kyllä 2
a) Päänsärky, migreeni	☐	☐
b) Selkäkipu	☐	☐
c) Lihas- tai nivelkipu	☐	☐
d) Toistuvat vatsavaivat	☐	☐
e) Pahoinvointi (ei vatsatauti)	☐	☐
f) Huimaus	☐	☐
g) Korvien soiminen (tinnitus)	☐	☐
h) Korvien lukkiutuminen, paineen tunne korvissa	☐	☐
i) Sydämen rytmihäiriöt	☐	☐
j) Ihottuma, ihon kutina	☐	☐

123456789

28. Onko Teillä viimeksi kuluneen vuoden (12 kk) aikana ollut seuraavia lääkärin toteamia tai hoitamia sairauksia?

	Ei (1)	Kyllä (2)
a) Kohonnut verenpaine (verenpainetauti)	☐	☐
b) Sydämen vajaatoiminta	☐	☐
c) Sepelvaltimotauti	☐	☐
d) Diabetes (sokeritauti)	☐	☐
e) Masennus	☐	☐
f) Paniikkihäiriö, muu ahdistuneisuushäiriö	☐	☐
g) Krooninen väsymysoireyhtymä	☐	☐
h) Ärtyvän suolen oireyhtymä	☐	☐
i) Krooninen kipuoireyhtymä, esim. fibromyalgia	☐	☐
j) Nivelreuma	☐	☐
k) Keuhkoastma	☐	☐
l) Keuhkolaajentuma, krooninen keuhkoputkentulehdus	☐	☐
m) Syöpä	☐	☐
n) Muu pitkäaikainen sairaus	☐	☐

29. Ajatelkaa viimeksi kulunutta kuukautta (30 pv). Kuinka usein kysytty asia on ollut mielessänne tai oire vaivannut Teitä?

	Ei koskaan (1)	Harvoin (2)	Silloin tällöin (3)	Usein (4)	Jatkuvasti (5)
a) Uupumus ja ylirasittuneisuus	☐	☐	☐	☐	☐
b) Painajaisunet	☐	☐	☐	☐	☐
c) Nukahtamisvaikeudet	☐	☐	☐	☐	☐
d) Liian aikainen herääminen	☐	☐	☐	☐	☐
e) Ahdistuneisuus	☐	☐	☐	☐	☐
f) Stressi	☐	☐	☐	☐	☐
g) Yksinäisyys	☐	☐	☐	☐	☐

30. Onko lääkäri todennut kuulonne heikentyneen?

1 ☐ Ei
2 ☐ Kyllä

31. Onko kuulonne omasta mielestänne heikentynyt?

1 ☐ Ei
2 ☐ Kyllä

32. Kuinka monta savuketta (tai sikaria, piipullista) poltatte keskimäärin päivässä?

1 ☐ En yhtään, en tupakoi
2 ☐ Alle 1, en tupakoi päivittäin
3 ☐ 1–2 päivässä
4 ☐ 3–10 päivässä
5 ☐ Yli 10 päivässä

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33. Kuinka usein juotte olutta, viiniä tai muita alkoholijuomia?

1 ☐ En koskaan *(siirtykää kysymykseen 35)*
2 ☐ Kerran kuukaudessa tai harvemmin
3 ☐ 2–3 kertaa kuukaudessa
4 ☐ 1–2 kertaa viikossa
5 ☐ 3–4 kertaa viikossa
6 ☐ 5 kertaa viikossa tai useammin

34. Kuinka monta annosta alkoholia olette yleensä ottanut niinä päivinä, jolloin olette juonut alkoholia?
Katsokaa viereisen kuvan mallia annoksista.

1 ☐ 1–2 annosta
2 ☐ 3–4 annosta
3 ☐ 5–6 annosta
4 ☐ 7 annosta tai enemmän

35. Kuinka paljon liikutte työssänne?

1 ☐ Vähän, työni on pääsääntöisesti istuma- tai seisomatyötä
2 ☐ Jonkin verran
3 ☐ Paljon, työni on fyysisesti rasittavaa

36. Kuinka usein liikutte <u>muualla kuin töissä</u> vähintään 20 minuuttia kerrallaan niin, että ainakin lievästi hengästytte ja hikoilette?

1 ☐ En koskaan
2 ☐ Harvemmin kuin kerran viikossa
3 ☐ Kerran viikossa
4 ☐ 2 kertaa viikossa
5 ☐ 3 kertaa viikossa
6 ☐ 4 kertaa viikossa tai useammin

37. Mitä mieltä olette seuraavista itseänne kuvaavista väittämistä?
Valitkaa jokaisesta kohdasta mielipidettänne parhaiten kuvaava vaihtoehto.

	Täysin samaa mieltä 1	Melko samaa mieltä 2	En samaa enkä eri mieltä 3	Melko eri mieltä 4	Täysin eri mieltä 5
a) Herään helposti meluun	☐	☐	☐	☐	☐
b) Närkästyn, kun naapurini aiheuttavat melua	☐	☐	☐	☐	☐
c) Totun suurimpaan osaan melua ilman erityisiä vaikeuksia	☐	☐	☐	☐	☐
d) Minun on vaikea rentoutua meluisassa paikassa	☐	☐	☐	☐	☐
e) Olen hyvä keskittymään, tapahtuipa ympärilläni mitä tahansa	☐	☐	☐	☐	☐
f) Olen meluherkkä	☐	☐	☐	☐	☐

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38. Kuinka usein seuraavat tekijät aiheuttavat Teille epämiellyttävää oloa tai sairauden tunnetta, kun olette tekemisissä niiden kanssa?

	Ei koskaan 1	Hyvin harvoin 2	Joskus 3	Usein 4	Lähes aina 5
a) Liikenteen pakokaasut	☐	☐	☐	☐	☐
b) Maalit tai maalien ohennusaineet	☐	☐	☐	☐	☐
c) Hajuvedet, ilmanraikastajat tai muut hajusteet	☐	☐	☐	☐	☐
d) Uudet sisustusmateriaalit (esim. matto, lattiapäällyste)	☐	☐	☐	☐	☐
e) Kosteusvaurioituneiden rakennusten homeen haju	☐	☐	☐	☐	☐
f) Tuulivoimalat	☐	☐	☐	☐	☐
g) Tupakansavu	☐	☐	☐	☐	☐
h) Sähkömagneettinen kenttä (säteily)	☐	☐	☐	☐	☐

MIELIPITEET JA RISKIKÄSITYKSET

39. Missä määrin olette samaa tai eri mieltä seuraavista tuulivoimaan liittyvistä väittämistä?

	Täysin samaa mieltä 1	Melko samaa mieltä 2	En samaa enkä eri mieltä 3	Melko eri mieltä 4	Täysin eri mieltä 5
a) Tuulivoiman käyttöä energiantuotantoon tulisi lisätä Suomessa	☐	☐	☐	☐	☐
b) Energian tuottaminen tuulivoimalla on liian kallista	☐	☐	☐	☐	☐
c) Tuulivoimalat ovat parantaneet oman kuntani taloutta	☐	☐	☐	☐	☐
d) Minua huolestuttavat mahdolliset tuulivoiman tuottamiseen liittyvät terveyshaitat	☐	☐	☐	☐	☐
e) Tuulivoimaloiden haittoja linnustolle ei huomioida riittävästi	☐	☐	☐	☐	☐
f) Tuulivoimaloista mahdollisesti aiheutuvia terveyshaittoja vähätellään Suomessa	☐	☐	☐	☐	☐
g) Tuulivoimatuotannon avulla voidaan ehkäistä ilmastonmuutosta	☐	☐	☐	☐	☐
h) Minulla on riittävästi tietoa tuulivoimaloiden mahdollisista vaikutuksista terveyteen	☐	☐	☐	☐	☐
i) Lähipiirissäni on keskusteltu paljon tuulivoimaloiden mahdollisista terveysvaikutuksista	☐	☐	☐	☐	☐
j) On vaikea arvioida, johtuvatko henkilön oireet tuulivoimaloista vai jostain muusta	☐	☐	☐	☐	☐
k) Pelkkä huolestuminen tuulivoimaloiden mahdollisista terveyshaitoista voi tuottaa oireita	☐	☐	☐	☐	☐

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40. Missä määrin olette samaa tai eri mieltä seuraavista kotikuntanne päätöksentekoon liittyvistä väittämistä?

	Täysin samaa mieltä 1	Melko samaa mieltä 2	En samaa enkä eri mieltä 3	Melko eri mieltä 4	Täysin eri mieltä 5
a) Kunnan virkamiehet ja luottamushenkilöt pyrkivät toimimaan koko kunnan parhaaksi	☐	☐	☐	☐	☐
b) Päätöksenteko kunnassa ei ole avointa	☐	☐	☐	☐	☐
c) Kunnan viranomaiset ovat liian läheisessä yhteydessä tuulivoiman tuottajiin	☐	☐	☐	☐	☐
d) Kunta tiedottaa riittävästi tuulivoimarakentamiseen liittyvistä asioista	☐	☐	☐	☐	☐

41. Uskotteko, että lähiseudun tuulivoimalat laskevat asuntonne arvoa?
Jos ette asu omistusasunnossa, siirtykää seuraavaan kysymykseen.

1 ☐ En
2 ☐ Kyllä, vähän
3 ☐ Kyllä, paljon

42. Oletteko saanut mielestänne riittävästi tietoa lähiseudun toteutuneista tuulivoimahankkeista ennen tuotantoalueiden rakentamisen aloittamista?

1 ☐ En
2 ☐ Kyllä
3 ☐ En ole kaivannut tietoa

43. Missä määrin olette samaa tai eri mieltä seuraavista tieteeseen ja tutkimukseen liittyvistä väittämistä?

	Täysin samaa mieltä 1	Melko samaa mieltä 2	En samaa enkä eri mieltä 3	Melko eri mieltä 4	Täysin eri mieltä 5
a) Ihmistoiminta ei vaikuta merkittävässä määrin ilmastoon	☐	☐	☐	☐	☐
b) Tieteeseen ei voi luottaa, koska saman alan asiantuntijat voivat olla jostakin asiasta täysin eri mieltä	☐	☐	☐	☐	☐
c) Tieteen vähättely ja tiedevastaisuus on lisääntynyt maassamme viime aikoina	☐	☐	☐	☐	☐
d) On hyvä, että sosiaalisessa mediassa haastetaan tutkimustietoa ja esitetään vaihtoehtoisia näkemyksiä ja esitystapoja	☐	☐	☐	☐	☐
e) Sosiaalisessa mediassa ja yleensäkin julkisuudessa esitetään nykyään paljon perättömiä, tieteen tulokset kiistämään pyrkiviä väitteitä	☐	☐	☐	☐	☐
f) Erilaisia terveysriskejä on kaikkialla, joten niiden pohtiminen on turhaa	☐	☐	☐	☐	☐

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44. Kuinka paljon luotatte seuraaviin tahoihin tuulivoimatuotannon mahdollisiin terveysvaikutuksiin liittyvissä asioissa? *Valitkaa mielipidettänne parhaiten kuvaava vaihtoehto asteikolla "luotan täysin – en luota lainkaan".*

	Luotan täysin 1	2	3	4	En luota lainkaan 5
a) Julkiset terveyspalvelut	☐	☐	☐	☐	☐
b) Oikeuslaitos	☐	☐	☐	☐	☐
c) Tutkimuslaitokset	☐	☐	☐	☐	☐
d) Yliopistot ja ammattikorkeakoulut	☐	☐	☐	☐	☐
e) Hallitus ja ministeriöt	☐	☐	☐	☐	☐
f) Alueelliset viranomaiset	☐	☐	☐	☐	☐
g) Tuulivoimayritykset	☐	☐	☐	☐	☐
h) Media (televisio, radio, lehdet)	☐	☐	☐	☐	☐
i) Sosiaalinen media ja keskustelufoorumit	☐	☐	☐	☐	☐
j) Lääkärit	☐	☐	☐	☐	☐
k) Potilasjärjestöt	☐	☐	☐	☐	☐
l) Kansalaisjärjestöt	☐	☐	☐	☐	☐

45. Kuinka suurena riskinä omalle terveydellenne pidätte seuraavia tekijöitä omassa elinympäristössänne?

	Ei lainkaan riskiä 1	Pieni riski 2	Kohtalainen riski 3	Suuri riski 4	Erittäin suuri riski 5
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐
g) Asuinrakennusten kosteusvauriot	☐	☐	☐	☐	☐
h) Sähkölaitteiden sähkömagneettinen kenttä (säteily)	☐	☐	☐	☐	☐

46. Entä kuinka suurena riskinä ihmisten terveydelle yleisesti ottaen pidätte näitä tekijöitä Suomessa?

	Ei lainkaan riskiä 1	Pieni riski 2	Kohtalainen riski 3	Suuri riski 4	Erittäin suuri riski 5
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐
g) Asuinrakennusten kosteusvauriot	☐	☐	☐	☐	☐
h) Sähkölaitteiden sähkömagneettinen kenttä (säteily)	☐	☐	☐	☐	☐

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47. Kuinka paljon arvelette tuulivoimaloista aiheutuvalle kuuluvalle äänelle altistumisen voivan vaikuttaa seuraaviin tekijöihin tai sairauksiin yleisesti ottaen?

	Ei vaikuta lainkaan 1	Vaikuttaa vähän 2	Vaikuttaa jonkin verran 3	Vaikuttaa paljon 4	Vaikuttaa erittäin paljon 5
a) Mieliala	☐	☐	☐	☐	☐
b) Unen laatu	☐	☐	☐	☐	☐
c) Verenpaine	☐	☐	☐	☐	☐
d) Diabetes	☐	☐	☐	☐	☐
e) Sydänsairaudet	☐	☐	☐	☐	☐
f) Syöpä	☐	☐	☐	☐	☐

48. Kuinka paljon arvelette tuulivoimaloista aiheutuvalle infraäänelle altistumisen voivan vaikuttaa seuraaviin tekijöihin tai sairauksiin yleisesti ottaen?

	Ei vaikuta lainkaan 1	Vaikuttaa vähän 2	Vaikuttaa jonkin verran 3	Vaikuttaa paljon 4	Vaikuttaa erittäin paljon 5
a) Mieliala	☐	☐	☐	☐	☐
b) Unen laatu	☐	☐	☐	☐	☐
c) Verenpaine	☐	☐	☐	☐	☐
d) Diabetes	☐	☐	☐	☐	☐
e) Sydänsairaudet	☐	☐	☐	☐	☐
f) Syöpä	☐	☐	☐	☐	☐

ASUINYMPÄRISTÖN ÄÄNIOLOSUHTEET

Ajatelkaa vastatessanne nykyistä asuntoanne ja asuinympäristöänne.

49. Arvioikaa, missä määrin altistutte seuraaville tekijöille kotonanne keskimäärin.

	En altistu lainkaan 1	Altistun vähän 2	Altistun jonkin verran 3	Altistun paljon 4	Altistun erittäin paljon 5	En osaa sanoa 9
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐	☐

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50. Häiritsevätkö seuraavat tekijät Teitä (ärsyttävät, häiritsevät keskittymistä yms.) tavallisesti kotonanne sisätiloissa ikkunoiden ollessa kiinni?

	Ei häiritse lainkaan 1	Häiritsee vähän 2	Häiritsee jonkin verran 3	Häiritsee paljon 4	Häiritsee erittäin paljon 5
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐

51. Häiritsevätkö seuraavat tekijät Teitä (ärsyttävät, häiritsevät keskittymistä yms.) tavallisesti kotonanne ulkona pihalla tai parvekkeella?

	Ei häiritse lainkaan 1	Häiritsee vähän 2	Häiritsee jonkin verran 3	Häiritsee paljon 4	Häiritsee erittäin paljon 5
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐

52. Häiritsevätkö seuraavat tekijät tavallisesti nukkumistanne kotona (esim. estävät nukahtamasta, herättävät)?

	Ei häiritse lainkaan 1	Häiritsee vähän 2	Häiritsee jonkin verran 3	Häiritsee paljon 4	Häiritsee erittäin paljon 5
a) Autoliikenteestä aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
b) Autoliikenteestä aiheutuva infraääni	☐	☐	☐	☐	☐
c) Autoliikenteestä aiheutuva tärinä	☐	☐	☐	☐	☐
d) Tuulivoimaloista aiheutuva kuuluva ääni	☐	☐	☐	☐	☐
e) Tuulivoimaloista aiheutuva infraääni	☐	☐	☐	☐	☐
f) Tuulivoimaloista aiheutuva tärinä	☐	☐	☐	☐	☐

53. Kuinka usein tuulivoimaloista aiheutuva ääni kuuluu kotonanne sisätiloissa ikkunoiden ollessa kiinni?

1 ☐ Ei koskaan
2 ☐ Kerran kuukaudessa tai harvemmin
3 ☐ Useamman kerran kuukaudessa
4 ☐ Noin kerran viikossa
5 ☐ Useamman kerran viikossa
6 ☐ Lähes joka päivä
7 ☐ Joka päivä

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54. Onko tuulivoimaloista aiheutuva <u>kuuluva ääni</u> vaikuttanut siihen, kuinka usein pidätte ikkunoita auki kotonanne?

1 ☐ Ei
2 ☐ Kyllä, on vaikuttanut jonkin verran
3 ☐ Kyllä, on vaikuttanut paljon

55. Kuinka usein tuulivoimaloista aiheutuva kuuluva ääni kuuluu kotonanne <u>pihalla tai parvekkeella</u>?

1 ☐ Ei koskaan
2 ☐ Kerran kuukaudessa tai harvemmin
3 ☐ Useamman kerran kuukaudessa
4 ☐ Noin kerran viikossa
5 ☐ Useamman kerran viikossa
6 ☐ Lähes joka päivä
7 ☐ Joka päivä

56. Onko tuulivoimaloista aiheutuva kuuluva ääni vaikuttanut siihen, kuinka paljon vietätte aikaa kotonanne <u>pihalla tai parvekkeella</u>?

1 ☐ Ei
2 ☐ Kyllä, on vaikuttanut jonkin verran
3 ☐ Kyllä, on vaikuttanut paljon

57. Onko tuulivoimaloista aiheutuva kuuluva ääni vaikuttanut haitallisesti seuraaviin asioihin?

	Ei lainkaan 1	Vähän 2	Jonkin verran 3	Paljon 4	Erittäin paljon 5
a) Ihmissuhteet	☐	☐	☐	☐	☐
b) Taloudellinen tilanne	☐	☐	☐	☐	☐
c) Psyykkinen jaksaminen	☐	☐	☐	☐	☐
d) Asumisjärjestelyt	☐	☐	☐	☐	☐
e) Terveys	☐	☐	☐	☐	☐
f) Työkyky	☐	☐	☐	☐	☐

58. Oletteko mielestänne joskus saanut oireita tuulivoimaloista aiheutuvasta <u>infraäänestä</u> nykyisessä asunnossanne?

1 ☐ En *(siirtykää kysymykseen 66)*
2 ☐ Kyllä

59. Jos olette saanut oireita tuulivoimaloista aiheutuvasta infraäänestä, arvioikaa milloin oireilu alkoi?

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60. Kuvailkaa millaisia oireita olette saanut tuulivoimaloista aiheutuvasta infraäänestä.

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61. Kuinka usein viimeksi kuluneen vuoden (12 kk) aikana olette saanut oireita tuulivoimaloista aiheutuvasta infraäänestä?

1 ☐ Kerran kuukaudessa tai harvemmin
2 ☐ Useamman kerran kuukaudessa
3 ☐ Noin kerran viikossa
4 ☐ Useamman kerran viikossa
5 ☐ Lähes joka päivä
6 ☐ Joka päivä

62. Miten vaikeita saamanne oireet ovat pahimmillaan olleet?

1 ☐ Lieviä
2 ☐ Kohtalaisia
3 ☐ Vaikeita
4 ☐ Erittäin vaikeita

63. Oletteko ollut lääkärin vastaanotolla oireilun tai sairastelun takia, jonka olette epäillyt johtuvan tuulivoimaloista aiheutuvasta infraäänestä?

1 ☐ En
2 ☐ Kyllä

64. Oletteko ollut sairauslomalla oireilun tai sairastelun takia, jonka olette epäillyt johtuvan tuulivoimaloista aiheutuvasta infraäänestä?

1 ☐ En
2 ☐ Kyllä

65. Onko tuulivoimaloista aiheutuva infraääni vaikuttanut haitallisesti seuraaviin asioihin?

	Ei lainkaan 1	Vähän 2	Jonkin verran 3	Paljon 4	Erittäin paljon 5
a) Ihmissuhteet	☐	☐	☐	☐	☐
b) Taloudellinen tilanne	☐	☐	☐	☐	☐
c) Psyykkinen jaksaminen	☐	☐	☐	☐	☐
d) Asumisjärjestelyt	☐	☐	☐	☐	☐
e) Terveys	☐	☐	☐	☐	☐
f) Työkyky	☐	☐	☐	☐	☐

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66. Tuulivoimaloista aiheutuvaan infraääneen liittyvä oireilu tai sairastelu puolisolla.
Jos teillä ei ole puolisoa, siirtykää seuraavaan kysymykseen.

	Ei 1	Kyllä 2
a) Onko puolisonne saanut oireita tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐
b) Onko puolisonne ollut lääkärin tutkimuksessa tai hoidossa oireilun tai sairastelun takia, jonka on epäilty johtuvan tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐
c) Onko puolisonne ollut sairauslomalla oireilun tai sairastelun takia, jonka on epäilty johtuvan tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐

67. Tuulivoimaloista aiheutuvaan infraääneen liittyvä oireilu tai sairastelu lapsilla.
Jos teillä ei ole lapsia, siirtykää seuraavaan kysymykseen.

	Ei 1	Kyllä 2
a) Onko joku lapsistanne saanut oireita tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐
b) Onko joku lapsistanne ollut lääkärin tutkimuksessa tai hoidossa oireilun tai sairastelun takia, jonka on epäilty johtuvan tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐
c) Onko joku lapsistanne ollut poissa päivähoidosta tai koulusta oireilun tai sairastelun takia, jonka on epäilty johtuvan tuulivoimaloista aiheutuvasta infraäänestä?	☐	☐

68. Kuinka usein tuulivoimaloista aiheutuva tärinä on aistittavissa kotonanne sisätiloissa?

1 ☐ Ei koskaan
2 ☐ Kerran kuukaudessa tai harvemmin
3 ☐ Useamman kerran kuukaudessa
4 ☐ Noin kerran viikossa
5 ☐ Useamman kerran viikossa
6 ☐ Lähes joka päivä
7 ☐ Joka päivä

69. Oletteko mielestänne joskus saanut oireita tuulivoimaloista aiheutuvasta tärinästä nykyisessä asunnossanne?

1 ☐ En
2 ☐ Kyllä, millaisia: ____________________

____

____

____

123456789

70. Oletteko huolestunut tuulivoimaloiden aiheuttaman sähkömagneettisen kentän mahdollisista terveyshaitoista?

1 ☐ En
2 ☐ Kyllä

71. Oletteko mielestänne joskus saanut oireita tuulivoimaloista aiheutuvasta sähkömagneettisesta kentästä nykyisessä asunnossanne?

1 ☐ En
2 ☐ Kyllä, millaisia: ____________________

____

____

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72. Asutteko vakituisesti jossain muussa osoitteessa kuin siinä, johon tämä kysely on lähetetty?

1 ☐ En
2 ☐ Kyllä

Jos kyllä, voitte halutessanne kirjoittaa tähän nykyisen osoitteenne:

____

73. Vastauspäivämäärä (pp.kk.vvvv): ____ . ____ . ________

En halua osallistua palkintojen arvontaan ☐

Jos haluatte, voitte vielä kirjoittaa alle kommentteja kyselyn aihepiiriin liittyen.

Kiitos vastauksistanne!

Irrottakaa kyselyn kansilehti itsellenne, jotta henkilötiedot pysyvät kyselystä erillään, ja palauttakaa täyttämänne kysely oheisessa valmiiksi maksetussa kirjekuoressa.

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List of Abbreviations and Acronyms

AD	Analog-to-digital
AM	Amplitude modulation
ANOVA	Analysis of variance
ANS	Autonomic nervous systems
CI	Confidence interval
CPT	cold pressure test
DC	Direct-coupled
d.f.	Degrees of freedom
DSM	Directional starter method
DW	Durbin–Watson statistical test quantity
EDA	Electrodermal Activity
ECG	electrocardiography
EMG	electromyography
EOG	electro-oculography
EXP	Exponential, an elimination method in regression analysis
FIR	Finite Impulse Response
FMI	Finnish Meteorological Institute
FWMP	Forward missing pairwise, an elimination method in regression analysis
GB	Gigabyte, 10^9 bytes
GRO	Growth, an elimination method in regression analysis
GWh	Gigawatt hours
HP	High-pass (filtering)
HR	Heart rate
HRV	Heart rate variability
IIR	Infinite Impulse Response
IQR	Interquartile range
IS	Infrasound
LGS	Logistic, an elimination method in regression analysis
LIN	Linear, an elimination method in regression analysis
LOG	Logarithmic, an elimination method in regression analysis
Max	Maximum
Min	Minimum
MW	Megawatt
n	number of individuals/respondents
N	validated measurements in Ch. 2

NA	Not Available
NAS	Network-attached storage
nSCR	Number of significant (=above-threshold) SCRs within response window
OR	Odds ratio
RH	Relative humidity
RMSSD	Root mean square of successive inter-beat-intervals
Rsq	A statistical measure of the strength of association, R^2
SCL	Skin conductance level
SCR	Skin conductance response
SD	Standard deviation
Sigf	Statistical significance level, *p* value
SNR	Signal-to-noise ratio
SPL	Sound pressure level
SWTI	Symptoms attributed to wind turbine infrasound
UTC	Coordinated Universal Time
WAV	Waveform Audio File Format
WPP	Wind power plant
WP	Work package
WTRS	Wind Turbine Related Symptoms
WTIS	Wind Turbine Infrasound
WTS	Wind Turbine Sound

List of symbols

The definitions are based on ISO/TR 25417[96] and are consistent in essence with ISO 80000-8[97]. Frequency weightings are specified in IEC 61672-1[98]. Reference values for acoustic levels follow ISO 1683[99].

Roman and Greek Symbols

E	Emission.
I	Immission.
L	Distance.
L_{A}	A-weighted (equivalent) sound pressure level.
L_{eq}	Equivalent sound pressure level.
L_{G}	G-weighted (equivalent) sound pressure level.
L_p	Sound pressure level.
$L_{p,\mathrm{A}}$	A-weighted sound pressure level.
$L_{p,\mathrm{A,eq}}$	A-weighted equivalent sound pressure level.
L_{Z}	Unweighted equivalent sound pressure level.
$L_{\mathrm{Z,max}}$	Maximum unweighted equivalent sound pressure level.
N	A reference to the number of events, samples or subjects.
R^2	Statistical measurand of the strength of association.
S_{d}	Projected area of the driver diaphragm, a loudspeaker Thiele/Small driver parameter.
U_{RMS}	Root mean squared voltage.
X_{max}	Linear excursion (one way), a loudspeaker driver Thiele/Small parameter.
X_{mech}	Maximum physical excursion of the driver, a loudspeaker driver Thiele/Small parameter.
c	The speed of sound, m/s.
g	Acceleration of free fall, ≈ 9.81 m/s.
i	Imaginary unit.
k	Wave number, ω/c
ρ_0	Static density of air.
σ_{r}	Flow resistivity.

Alphabetical Index

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