



## THE IMPACT OF INFRASOUNDS GENERATED BY WIND POWER STATIONS ON A HUMAN BEING

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### ABSTRACT

In some opinion-forming environments the problem of noise emitted by wind power stations is very controversial. It is even suggested that they negatively affect the quality and length of human life. Based on the review of domestic and foreign publications an analysis of the impact of the low-frequency noise on a human being was carried out. Wind power stations operating in groups (farms) constituted the source of noise. It was proved that the level of acoustic pressure with G weighting does not exceed the value of 85 dB. The value of the admissible burdensome noise (102 dB) was exceeded in the bus cabins which were driving with the speed exceeding 30 km·h<sup>-1</sup>. The opinion of the Ministry of Health confirms the findings. It proves that the present knowledge does not allow a clear indication of the relation between the wind farms and their negative impact on the human health.

## Introduction

Location of wind farms in the neighbourhood of residential buildings often stirs emotions and discussions with more or less substantial arguments provided by followers and opponents. Majority of previously used opponents' arguments such as: "wind stations kill birds and chase out animals"; "the land under the wind power stations is not suitable for cultivation"; "too high level of noises that can be heard" etc., which are far from reality, are rarely used. Today, the main argument posed by some opponents of wind power stations is infrasound and low-frequency noise. Do wind power stations have indeed a negative impact on the human health as some publications suggest? (Nowa Stepnica, 2011).

Wind power stations generate two types of noise: mechanical and aerodynamic. The first one is caused by the operation of devices located in the nacelle of a wind turbine. The level of the acoustic pressure inside the nacelle usually exceeds the value of 110 dB. It is necessary for the persons staying near the wind turbine, that this level is not perceptible inside the nacelle but in a practicable distance therefrom. In Poland and other countries it was assumed that a safe distance of the wind power station from buildings must be at least 600 m; the further the better. As a result of numerous works carried out by constructors of wind power stations, mechanical noise was separated (through the use of acoustic insulations and muting the operation of devices working in the nacelle) to the decisively lower

level than the standard concerning the noise provisions for (Dz.U. [Journal of Laws] No.178,2004; Dz.U. No.120,2007).

Aerodynamic noise is created at the turbulent air flow and may be of a high and low-frequency nature. The low-frequency noise (mainly infrasound) is more unfavourable for human health. It is generated during the operation of the wind power station after blades of the turbine rotor go through the area of air with lower pressure, which results from the turbine operation and an uneven distribution of the speed of the flowing stream of winds. Noise spectrum contains infrasound components with levels higher than the levels located in the audible band (Dobrucki and Bogusz, 2011).

Infrasounds are nothing extraordinary. What is more, we may say that it is a natural phenomenon in the surrounding world. They are defined as vibrations of solid bodies and liquids. According to the standard ISO 7196/1995 and ISO 9612/1997, noise or sounds with 1 to 20 Hz frequency are called infrasounds. The Polish standard PN-Z-01338:2010 uses a wider definition of 'infrasound noise'. It says that it is noise, in whose spectrum, components of 2-16Hz frequencies (infrasounds) and of audible frequencies to 50 Hz occur. After this standard was amended in 2010, the range of infrasounds was increased to the range of 1-10 Hz.

### **The sources of infrasound noise**

Both infrasounds as well as sounds of lower frequency are generated during earthquakes, volcano eruptions, avalanches, during storm with lightnings, tornadoes, they are generated by the aurora polaris, waterfalls, heavy sea and wind. They are generated during the operation of machines and devices (inter alia, they are found in trucks, buses, airplanes during the operation of fans, compressor, hammers and construction vibrators, fridges, air conditioners and wind power stations (table 1). The infrasound noise is generated also during the working liquids dump in plants, thermal and hydra water stations. Even more often infrasounds are generated in passenger cars with loud music on recorded through stereo recorders (the level above 100 dB). It must be noted that also purposefully, they are generated by animals in order to communicate to a great distance e.g. by elephants, hippos, giraffes, alligators, whales.

The level of the natural background of infrasounds is 35-40 dB and for example during storms it exceeds 140 dB.

The infrasound noise is received by sound receptors but also it is felt as pressure in ears, rumble or hum.

### **Description and properties of infrasounds**

Infrasound waves distribute in matter in the form of circular waves and are weakly absorbed by the centre within which they move. According to table 2 they are characterised by considerable distances, which decrease along with the increase of frequency. Then, they are more absorbed by air. Low-frequency waves – infrasounds can spread in big distances. This ability is used, inter alia, for detection of earthquakes, volcano eruptions or tests with nuclear bombs. At big lengths of waves, their insulation is difficult since acoustic screens are low effective. In the closed objects, they may cause acoustic resonance, which causes

## The impact of infrasounds...

that infrasounds with a proper acoustic level may be a reason for a considerable burden e.g. in submarines, transport fleet or in buildings (Bergluns et al., 1996).

Table 1.  
*Levels of pressure of the selected natural and anthropogenic sources*

Natural sources	Acoustic pressure level (dB) and prevailing frequency range (Hz)	Anthropogenic sources	Acoustic pressure level (dB) and prevailing frequency range (Hz)
Volcano eruption, distance of 1000 km	117 dB at Hz<0,01	Start off of a rocket, distance: - by the launcher - 40 km	188 dB 77-95 dB at (1-20) Hz
Tornado, distance 30-800 km	(67-68) dB at (0.02-10) Hz	Jet engines	(85-120) dB at (4-31.5) Hz
Snow avalanche, distance 100 km	(60-68) dB at (0.05-2) Hz	Propeller planes, helicopters	(80-115) dB at (1-20) Hz
Wind speed 25 km·h <sup>-1</sup> speed 100 km·h <sup>-1</sup>	110 dB 135 dB at Hz<1	Fans, air blowers	(90-108) dB at (2-8) Hz
Waterfalls	(95-100) dB at (2-12) Hz	Wind turbines	(90-115) dB at (2-12) Hz
Lightning strike	(90-100) dB at (1-10) Hz	Bus or truck cabin	(97-100) dB (G) at (1-20) Hz
Ear cleaning	185 dB at (3-5) Hz	Wind power stations	(95-110) dB at (1-5) Hz

Source: based on Pawlas et al., 2009; Cieřlikowski and Pedrycz, 2010

Table 2.  
*Relation of the length of infrasound waves spreading in air to frequency*

Frequency Hz	Length of waves (m)
0.1	3,400
1	340
10	34
100	3.4
1000	0.34
10,000	0.034

Source: ISO 7196: 1995

### Impact of infrasounds on the human body

With regard to infrasounds, the hearing perception determined as "hearing" does not exist but these sounds are perceived by the organism by a specific hearing way (Pawlas, 2009) and through vibration receptors. The border between "hearing" and "sensing" is almost invisible and depends greatly on the level of acoustic pressure as well as on the predisposition of a particular specimen. One may wonder where the border between hearing, sensing

and silence is. The hearing and sensing thresholds are presented in table 3 and were arranged so that over 50% of the tested people does not hear the below values or does not sense infrasounds.

Table 3.  
*Average values of hearing and sensing thresholds for the range of 4-20 Hz*

The investigated thresholds	Acoustic pressure level in (dB G) for frequency					
	4 Hz	8Hz	10 Hz	12.5 Hz	16 Hz	20 Hz
Hearing threshold acc. to DIN 45680:1997	111	103	95	87	79	71
Hearing threshold acc. to (Watanabe 1990)	108	100	97	92	88	79
Perception threshold According to DIN 45680:2011	105	100	92	84	76	68.5

Source: DIN 45680: 1997; DIN 45680:2011; Watanabe and Moller,1990

Simultaneously, the table shows that the lower frequency is, the higher the acoustic pressure level must be – louder sound that a man can hear or perceive. For example at 4 Hz frequency the acoustic pressure level must reach 105 dB and at 20 Hz frequency only ca. 68 dB.

In order to assess the acoustic quality of the surrounding environment and in order to assess the human exposure to noise, corrective curves were introduced, which approximate the human ear sensitivity to the scale of energy carried out by sound. Corrective curves are marked with letters A, C and G. Figure 1 presents the course of sound frequency weighting curves. A scale is commonly applied. It reflects quite well the ear sensitivity for low frequencies.

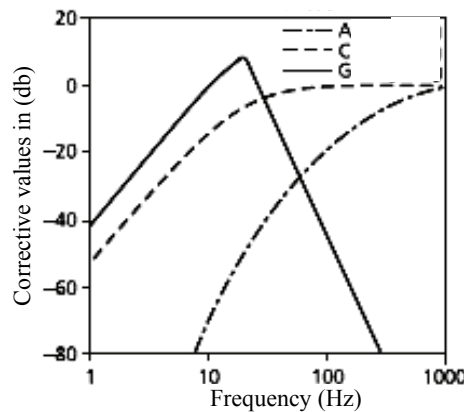


Figure 1. Frequency weighting curves A, G and C (acc. to PN-ISO 7196:2002 and Renewable Energy (World.Com, 2015)

The sound volume in this scale is denoted as dB (A). The A frequency characteristic has a drawback because it does not estimate expositions from the infrasound range and low frequencies because it reduces them (high negative values). On the other hand, frequency characteristic G eliminates the low frequencies range and omits the audible range promoting the same the infrasounds range. Type C characteristic according to figure 1 seems to be a compromise between two mentioned characteristics in case the assessed noise is composed of audible sounds, low-frequency sounds and infrasounds (Pawlas et al., 2013).

One should be aware that except for Denmark, in Europe there are no separate regulations for low frequency sounds and infrasounds in the human living environment and the admissible noise level is determined with the use of A frequency characteristic. Also, despite some reservations, WHO recognizes this manner of defining the noise (Berglund et al., 1999).

Also in Poland, regardless the frequency composition, the admissible level of noise in the human living environment is determined with admissible values of the A sound level; e.g. 40 dB at night (Journal of Laws No. 178, 2004 and Journal of Laws. No. 120, 2007).

On the other hand, for assessment of the infrasound noise at the workplace, one may use a burden criterion (not harmfulness criterion) defined in the Polish standard (PN-Z-01338: 2010) and for all employees this value is 102 dB G and at the conceptual work stands it is 86 dB G.

#### **Noise generated by wind power stations**

Figure 2 presents the noise spectra of the wind power station Vestas V80 located at the edge of the wind farm near Zagorz. The closest wind power station was located 800 m from buildings. Its nominal power is 2 MW (at the moment of measurement it is approx. 0.6 MW). Measuring devices were mounted on the downwind side at the height of 1 m and in the distance of 200 m from the tower. The wind speed was  $8 \text{ m}\cdot\text{s}^{-1}$  (Golec et al., 2006). The presented nomogram shows that the infrasound noise did not exceed the level of 68 dB and the low-frequency noise slightly exceeded the value of 60 dB. It should be mentioned that very similar values for this type of power stations were obtained also by other researchers (Rogers et al., 2006).

The noise spectrum of the wind power stations with the power of 1.5 MW was presented in figure 3. Simultaneously, the level of reference, that is, the acoustic background level was marked with red. It is characteristic that within the range of infrasounds, these levels differed slightly. Other authors (Jakobsen, 2005) examining Enercom E40 wind power station claim that similar values of the noise level occur only within the range of 1-4 Hz and within the range to the value of 30 Hz the noise level generated by a turbine is higher by 10 Hz than the acoustic background. Dobrucki and Bogusz (2011) recorded slightly lower differences of the noise level between the acoustic background and infrasounds generated by Nordex N-80 wind power station with the nominal power of 2.5 MW.

They reported 4-5 Hz differences due to constant recording of the sound level at the infra level during the operation of the wind power station and immediately after it stopped, namely at 1:56. p.m. Another start was recorder at 2:17 p.m. (figure 4).

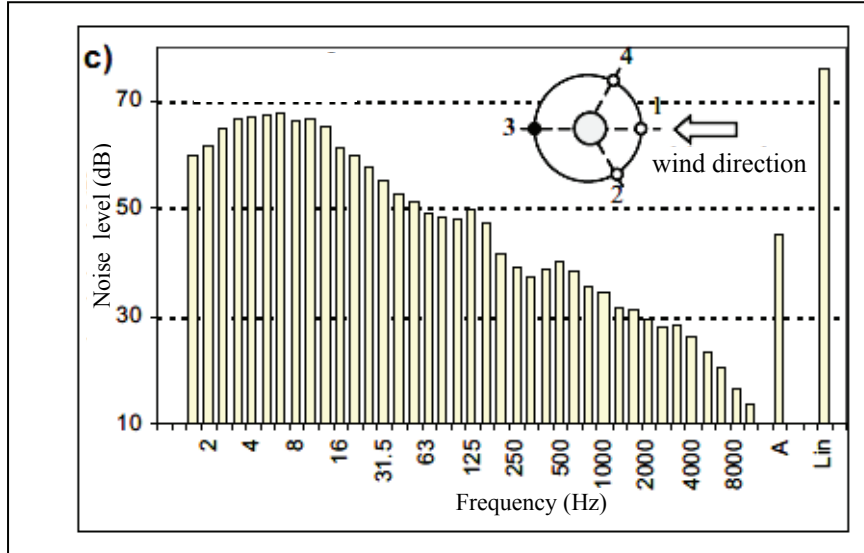


Figure 2. Averaged spectra of noise of V80 wind power station (Golec et al., 2006)

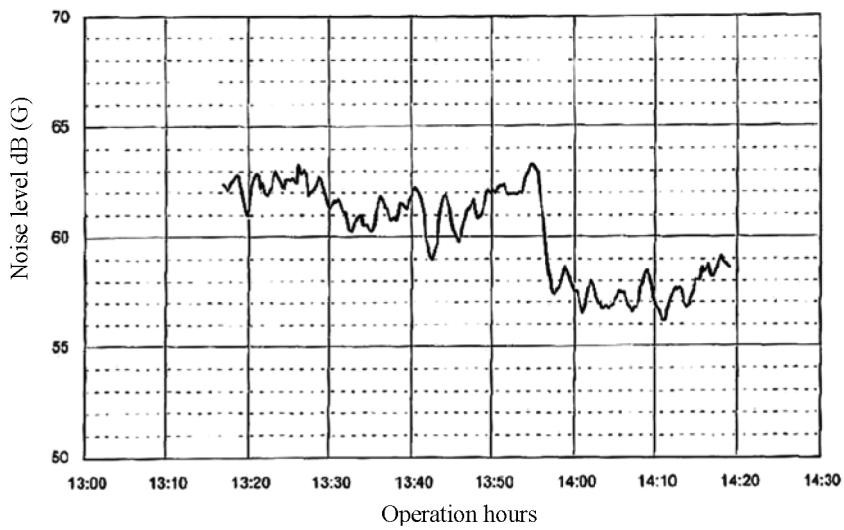


Figure 3. The sound level weighted with the curve of Nordex N-80 wind power station. Distance of the measurement point 200 m from the tower. Stopping the wind power station at 13:56 p.m. (Dobrucki and Bogusz, 2011)

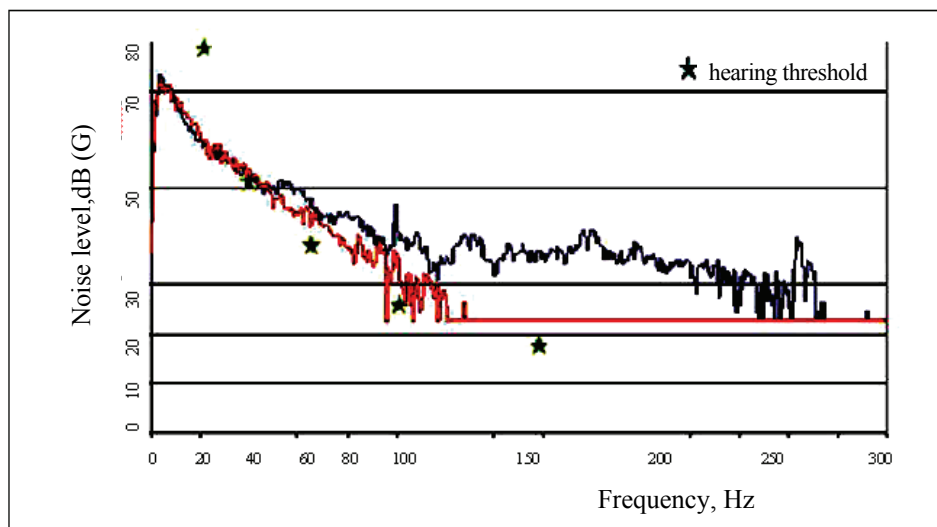


Figure 4. The noise spectrum of the wind power station with the power of 1.5 MW. Natural background was marked with red. Distance of the measurement point from the tower – 65 m (according to Leventhall, 2006)

The enclosed table 4 shows that the average speed of wind at which the wind turbine operated was approx.  $8\text{m}\cdot\text{s}^{-1}$ .

Table 4.

Average levels of G sound of Nordeks N80 wind turbine in the distance of 200 m after removal of the acoustic background impact

Speed ( $\text{m}\cdot\text{s}^{-1}$ )	5	6	7	8	9	10	11	12
Sound level (dB G)	58	59	60	62	62	63	64	65

Source: Dobrucki and Bogusz, 2011

The noise level emitted by numerous wind power stations grouped on one area – on a farm is certainly higher than the noise emitted by a single power station. Differences can be noticed after the analysis of figure 4 and 5. Figure 5 presents the results of 15-hours recording of acoustic pressure levels with the use of the weighting curve G, of the wind farm consisting of 12 wind power stations Nordex N-80 with the nominal power of 2.5 MW each (Hepburn and Edworthy, 2005). The measurement point was in the distance of 200 m from the wind power station tower.

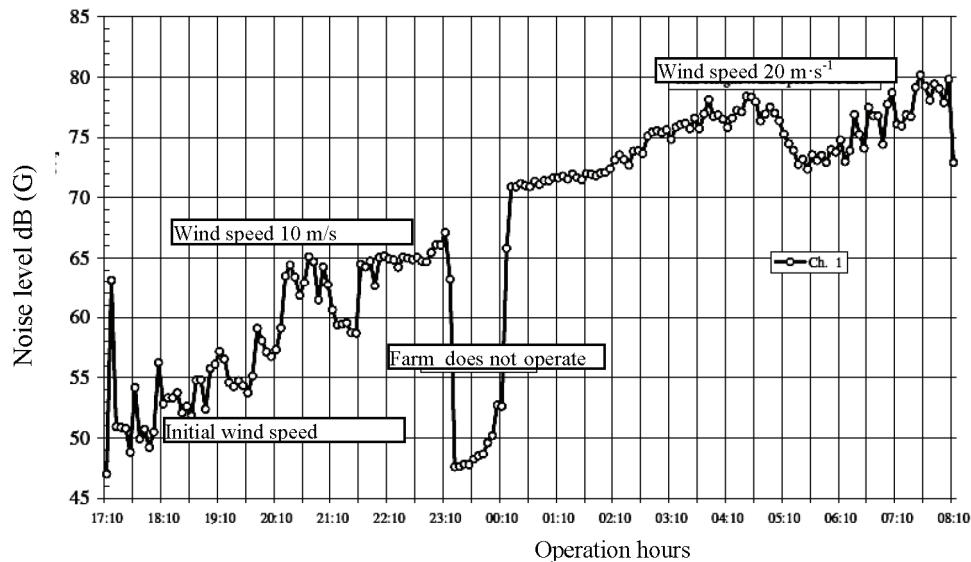


Figure 5. Course of the acoustic pressure variability with G weighting during operation of the wind farm (Hepburn and Edworthy, 2005)

At the speed of  $10 \text{ m}\cdot\text{s}^{-1}$  the level of infrasound noise emitted by the wind farm was approximately  $66 \text{ dB G}$ , and at the wind speed of  $20 \text{ m}\cdot\text{s}^{-1}$  (very rare) approx.  $80 \text{ dB G}$ . At the decrease of the wind speed below the initial speed ( $3 \text{ m}\cdot\text{s}^{-1}$ ), wind power stations did not work and only infrasound noise included in the acoustic background was recorded and it was approx.  $47 \text{ dB G}$ . This value is by  $10 \text{ dB}$  lower than the one presented in figure 10. The reason for differences may result from another surrounding of the investigated objects or from correctness of the measurements, which is less probable. However, in each case, the obtained values are lower than the hearing and perception thresholds for the range of  $4\text{-}20 \text{ Hz}$  (DIN 45680:1997).

The list of the level of infrasound and low-frequency noise of a wind farm as the function of frequency was presented in figure 6. The measurements were carried out according to the standard IEC 61400-11. For absolute correctness of the obtained results, a microphone was secured with an additional anti-wind shell with  $650 \text{ mm}$  diameter (Hepburn and Edworthy, 2005). Curve 1 defines the level of noise near the wind power station when it does not operate (acoustic background), curve 2 is noise at a low wind speed (approx.  $6 \text{ m}\cdot\text{s}^{-1}$ ). Curve 3 – presents the noise level at a very high wind speed ( $20 \text{ m}\cdot\text{s}^{-1}$ ). The level of sound weighted with curve G is reflected by curve 4. Curve 7 (acc. to ISO 226) presents the hearing thresholds within the range of audible frequencies and curve 5 presents them within the range of infrasounds. Low-frequency values for the night time according to recommendations of the Department for Environment, Food and Rural Affairs DEFRA are presented by curve 6.



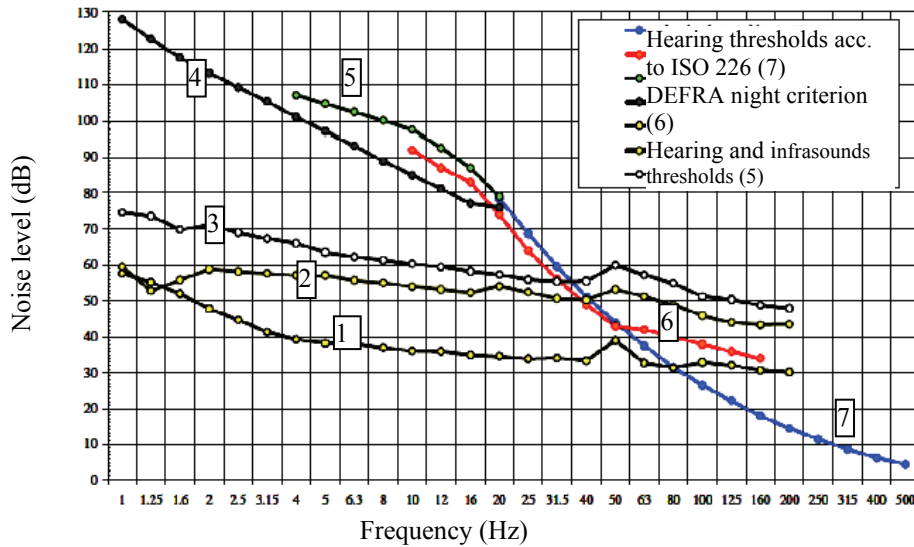


Figure 6. Infrasound and low-frequency noise of a wind farm (Hepburn and Edworthy, 2005)

Analysis of figure 6 shows that in comparison to the acoustic background (wind power stations do not operate) the level of infrasound noise emitted by wind power stations at low wind speed within frequencies of 3-20 Hz increases by 16-19 Hz. For high speed of  $20 \text{ m}\cdot\text{s}^{-1}$  the level of noise increases by approx. 25 dB.

Results of research of modern wind power stations, presented in figures 4-6 do not prove that the level of infrasounds exceeds the threshold values recognized presently as harmful for the human health.

#### Examples of the noise level generated by other sources than wind power stations

Extensive research of the infrasound noise at the bus and truck drivers' workplace was carried out in the Central Institute of Work Protection (Kaczmarek et al., 2007). Vehicles were moving on the asphalt surface of Modlin airport and on Radzymin ringroad. The noise level did not exceed then the value of 45 dB. Exemplary results during testing of the city bus were presented in figure 7. As expected, the noise level was increasing along with the driving speed increase. It was noticed that shortly after the bus exceeded  $30 \text{ km}\cdot\text{h}^{-1}$  the value of the equivalent sound level G exceeded the admissible value (burdensome level) of 102 dB G. The sound level of A type increased at the speed of  $30\text{-}100 \text{ km}\cdot\text{h}^{-1}$  from the value of 58 dB to 73 dB.

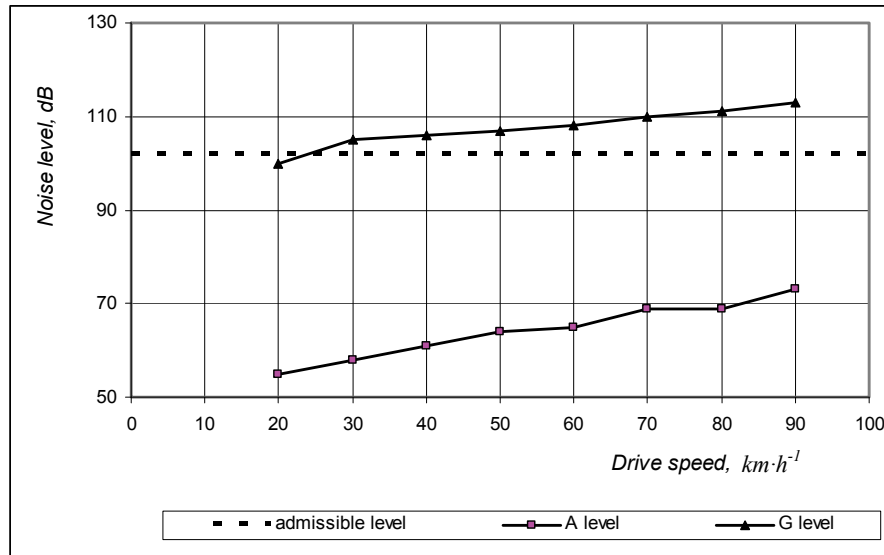


Figure 7. A and G sounds level in the driver's cabin as the function of speed of the bus (Kaczmarek et al., 2007)

Table 6 contains the values of the equivalent level of G sounds in passenger cars and in the office. According to the table, the passenger car ride on the road with an uneven surface generates infrasound noise which is perceivable in the driver's cabin and exceeds the admissible value of 102 dB G; similarly, with the ride on an even surface of the road but with the speed above 100 km·h<sup>-1</sup>. On the background of those two examples, the wind turbine seems to be considerably favourable.

Table 6.

The level of the acoustic pressure in dB G for sources with spectra with the frequency of 4-30 Hz

Source and place of the registered noise	The level of infrasound noise (dB G)
Inside of the passenger car. Drive with the speed of 30 km·h <sup>-1</sup> on the basaltic brick	115.7
Inside of the passenger car. Drive with the speed of 100 km·h <sup>-1</sup>	102.7
Office with the area of 60 m <sup>2</sup> , work of computers and air conditioners	73.6
Wind power station 0.5 MW. Distance of 200 m from the tower	63.9

## Conclusion

The problem of the impact of infrasounds generated by the wind power stations on human is perceived by many environments as extremely different. For instance, analyses and documentations prepared by the Chancellery of the Senate of the Republic of Poland prove

that the "number of research and publications is sufficient enough to not question the harmful and burdensome impact of infrasound generated by wind turbines (The Chancellery of the Senate, 2011). This and numerous other publications emphasise that the acoustic pressure level exceeding the value of 140-150 dB then infrasounds may cause harmful changes in the organism".

In fact, even within so small distance from the wind power station as 200 m (to remind in Poland this distance is assumed to be not lower than 600 m) the noise level is at least half less. Department of the Public Health of the Ministry of Health also notices the above and states "all research show that the noise emitted by wind power stations does not exceed the acoustic pressure level of 85 dB and the present knowledge does not allow to unanimously indicate the relation between the wind farms and their negative impact on human health (Ministry of Health, 2011 and Ministry of Health, 2013). Researchers from the Institute of Work and Environmental Health concluded similarly but explicitly showed that the low-frequency noise does not cause the vibro-acoustic disease (Pawlas et al., 2014).

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## WPLYW INFRADŹWIĘKÓW GENEROWANYCH PRZEZ ELEKTROWNIE WIATROWE NA CZŁOWIEKA

**Streszczenie.** W niektórych środowiskach opiniotwórczych wiele kontrowersji wzbudza problem hałasu jaki emitują elektrownie wiatrowe. Sugeruje się nawet, że mają one bardzo negatywny wpływ na jakość i długość życia człowieka. Na podstawie przeglądu publikacji krajowych i zagranicznych wykonano analizę wpływu hałasu niskoczęstotliwościowego na człowieka. Źródłem hałasu były elektrownie wiatrowe pracujące w skupiskach (farmy). Wykazano, że poziom ciśnienia akustycznego z ważeniem G nie przekraczał wartości 85 dB. Wartość dopuszczalnego poziomu uciążliwego (102 dB) przekraczana była natomiast w kabinach autobusów poruszających się z prędkością przekraczającą 30 km·h<sup>-1</sup>. Potwierdzeniem poczynionych ustaleń jest opinia Ministerstwa Zdrowia z której wynika, że obecna wiedza nie pozwala na jednoznaczne wskazanie związku pomiędzy farmami wiatrowymi i ich negatywnym wpływem na zdrowie człowieka.

**Słowa kluczowe:** elektrownie wiatrowe, hałas, infradźwięki