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Research Paper

The Assessment of Infrasound and Low Frequency Noise Impact on the Results of Learning in Primary School – Case Study

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The aim of the research was to determine the occurrence of possible, significant levels of infrasound and low frequency noise both in classrooms and around the primary school. Two sources of noise during research were significant: traffic on the national road and a wind farm, located near the school building. So far, few studies have been published regarding the impact of low-frequency, environmental noise from communication routes. The identification of hazards in a form of estimated noise levels resulted in preliminary information whether the location of the school near the road with significant traffic and the nearby wind farm can cause nuisance to children. There have been determined the criteria for assessing infrasound and low frequency noise. There have been made third octave band analyses of noise spectrum and the essential noise indicators were calculated. The results of learning in that school were thoroughly analysed for a long period of time and they were compared to the results obtained in other schools within a radius of 200 km situated near similar noise sources. Chosen assessment criteria show small exposure to low frequency noise. Measured infrasound noise levels are below hearing threshold.

Keywords: impact on environment; ease of learning factor; traffic noise; wind turbine; noise measurements.

1. Introduction

The aim of the research was to determine whether the level of low-frequency noise coming from the environment, including infrasound noise, in the primary school, can be felt by children and may affect the results of learning. Levels of infrasound noise in the close surrounding of the school were also studied. During conducted research, the anthropogenic sources of noise were car traffic on the national road (MR – main road) on the north side of the school building and a wind farm situated on the east and south sides of the school building (Fig. 1). The analysed school is a communal school and it is located far away from the urban agglomeration.

Within our environment, there are different sources of noise, but they generally depend on our activity, location, and the time of day. Transportation noise represents a large majority of external noise affecting people in cities and their surroundings. Traffic and wind turbine noise can lead to sleep disturbance and to psychological and physiological sustained stress reactions, which could impact health. The health issues associated with excessive exposure to environmental noise pollution (particularly from transportation sources) are now fairly well-established and extensively documented (Muzet, 2007; Murphy *et al.*, 2009; Pirrera *et al.*, 2010). Authors of many publications (Seetha *et al.*, 2008; Shield, Dockrell, 2008; Xie *et al.*, 2011; Bakar *et al.*, 2013) describe the influence of external noise coming from school environment on the results of learning at school. There were studied correlations between the impact of external, environmental noise around schools and noise in school classrooms on learning results. The source of external noise was mainly traffic noise coming from a large urban agglomeration. Some authors point out the possibility of health problems related to the exposure to traffic noise. For example, it is suggested that it may increase the risk of developing type 2 diabetes (Thiesse *et al.*, 2018) or asthma (Eze *et al.*, 2018). Authors also indicate that there may be small connection between the

Fig. 1. School location and sources of noise.

exposure to road noise in childhood and the later risk of overweight (Schultz Christensen *et al.*, 2016). Traffic noise is also indicated as a factor discouraging children from physical activity (Roswall *et al.*, 2017). The range of above studies included also acoustic noise. Such research conducted in primary schools, concerning infrasound and low frequency noise which occurs in classroom is rarely described in literature. Our objective was to check the possible threats. The small number of studies of impact of low frequency noise on human health carried out so far does not allow us to draw unambiguous conclusions (Kaczmarska, Łuczak, 2008; Baliatsas *et al.*, 2016). In the further part of the article, low-frequency noise is described by the abbreviation LFN.

The dominant effect of exposure to infrasound is the annoying feeling, which occurs at small exceeding of hearing thresholds, manifested by subjective states of extreme tiredness, discomfort, drowsiness and psychomotor and physiological disorders (Lundquist, 2003). LFN in the range of 125 to 250 Hz can lead to worse student-teacher communication. Children generally have less precise speech, more limited vocabulary, and less familiarity with language rules than adults. Masking effects of noise may therefore be particularly critical both for the perception of children's speech and for the children's perception of speech (Lundquist *et al.*, 2000; Lundquist, 2003; Wu *et al.*, 2014).

Many adults report environmental sensitivity to infrasound and LFN from wind farms. This is characterized by recurrent, unspecified symptoms resulting in a bad mood of the residents. The causal nexus between the exposure and its symptoms cannot be indicated by empirical evidence. Studies indicate that the symptoms can be explained by nocebo reaction, in which health problems and nuisances reported as a result of social discourse and media reports (McCunney *et al.*, 2014; Crichton, Petrie, 2015). Generally, children are unbiased when they perceive reality and they often do not identify their own environmental and health problems as a result of environmental conditions. Therefore, checking the potential impact of infrasound noise and LFN noise on primary school students is an important aspect of environmental research.

Many researchers describe in their publications the occurrence of infrasound noise near wind turbines (Boczar *et al.*, 2012; Ingielewicz, Zagubień, 2014; Herrmann *et al.*, 2016) and roads (Herrmann *et al.*, 2016). The sound pressure levels within the infrasound range presented here do not generally exceed the hearing thresholds. Presented noise spectra show that the level of LFN above the central frequency of third octave band of 25 Hz is above the hearing threshold. There are some cases of masking the audible noise of wind turbines by roads of significant traffic (Pedersen *et al.*, 2010). To get a full picture of acoustic situation it is necessary to get information on infrasound and LFN levels in a total state, i.e. for sounds coming simultaneously from the wind farm and high traffic noise.

2. Methodology

2.1. Noise measurements

The analyses were carried out in the primary school classrooms to determine the level of infrasound and LFN coming from the environment. The walls of the school building are made of brick, both sides plastered (wall thickness – about 40 cm), over 60% of the surface of external walls is covered by windows. Window frames are made of PVC and are double-pane ones. The anthropogenic sources of noise during the measurements were: car traffic on the national road (MR – main road) located 150 m to the north facade of the school building and a wind farm. The nearest turbine of the wind farm is located 500 m from the eastern facade of the school building (Fig. 1). Average traffic intensity on the national road is 15 000 vehicles per day. The wind farm devices are located to the east and south side of the analysed school building and the farm consists of 25 turbines. The capacity of wind turbines of horizontal rotation axis is 2 MW each, the rotor's diameter is 80 m and there are three blades. The turbines' towers of 100 m are tubular ones.

Due to eastern and north-eastern location of classrooms (Fig. 2), the measurements were carried out when the wind direction was eastern or north-eastern (Fig. 1). Measurement points were located in six measurement sections (Fig. 2), A1 and A2 in the east, B1 and B2, and BG1 and BG2 in the north. The measurements, at external sections A1 and B1, were carried out at 3 different heights −4, 8 and 12 m above the ground level, at the distance of 2 m from the building's façade. Internal measurements – A2 and B2 – were carried out at three floors of the school building (ground floor, 1st floor, 2nd floor). The measurement was made in the middle of the classroom, 1.5 m from windows at a height of 1.5 m above the floor. The microphone was minimum 0.5 m above the desk and any other reflecting surface. The measurement was made in 3 points situated 1 m from each other. The points were located parallel to windows, due to students' frequent activity in this part of the classroom. The average size of analysed classroom was 5×8 m. Taking into consideration the furniture, the desk and teacher's area and other school equipment, there is 3×5 m left for children. The measurements were carried out when all windows in external walls were closed. In the BG measurement sections, there was measured only the acoustic background noise level at a height of 4 m above the ground level, at a distance of 2 m from the building facade (BG1) and at a height of 1.5 m above the ground floor level inside the school building (BG2) – minimum 0.5 m above any reflecting surface. Due to the fact that there was no possibility to stop turbines during acoustic background measurement, measurement points BG1 and BG2 were located in the acoustic shadow created by the east wing of the school building and a building of 6 m, which is a link building between the east and west wing of the school (Fig. 2). Chosen location of acoustic background measurement points, allowed to minimise the impact of wind turbines on the measurement results and at the same time, this did not eliminate the influence of blowing wind on these results. Measurements of acoustic background were made when there was no traffic on the national road (MR). In order to eliminate disturbances caused by the presence of teachers and students in classrooms, the research was conducted between 1:00 pm and 9:00 pm, after classes. Dates of the measurements were selected so as the meteorological conditions remained constant during measurements. Much attention has been paid to wind speed and its direction – it was important that it did change much. There were selected three measurement days in spring and summer. Thanks to favourable meteorological conditions, there were two series of measurements conducted each day.

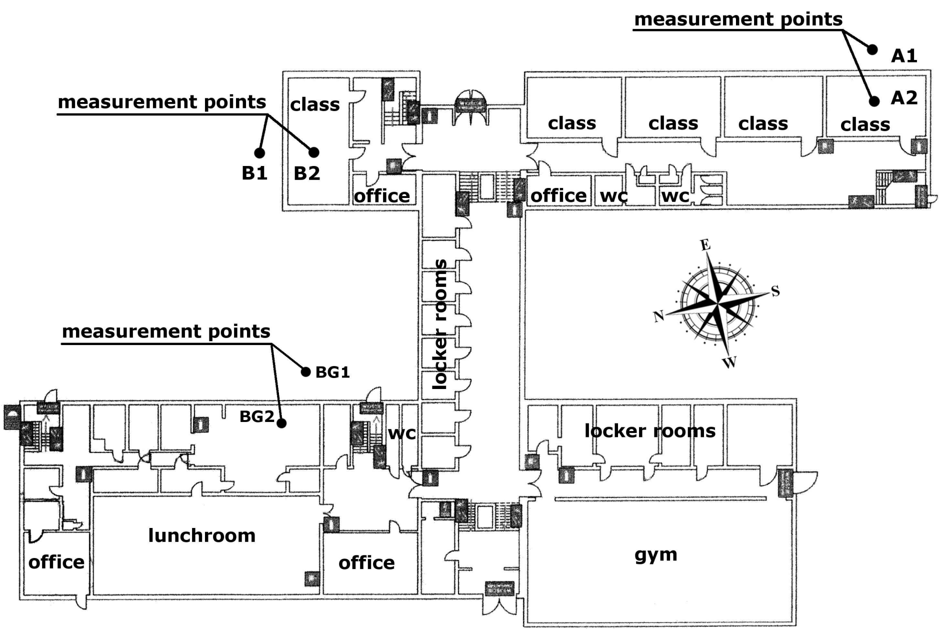

Fig. 2. Location of measurement points.

During both measurement series, there were taken three samples at each point, the duration of one trial was 5 minutes. Each sample contained third octave band analysis of sound conducted without correction, at the frequency range from 0.4 to 16 000 Hz. Next, the appropriate corrections A-weighted, C-weighted and G-weighted were digitally applied (ISO 7196, 1995; ISO 226, 2003) by the use of dedicated meter software.

The measurements were carried out under the following meteorological conditions: the temperature 15–21°C, humidity 61–79%, pressure 1005–1020 hPa and wind speed at the height of the measurement point 3.0–6.0 m/s. The average wind speed during the measurement did not exceed 5 m/s, the direction of wind – east and north-east. The measurement of selected meteorological parameters was made by the meteo-station set on the eastern side of the school, at a height of 4 m. Conducting measurements at wind speeds of 3.0–6.0 m/s, on one hand, allows to take into account wind turbines' noise emission working with maximum acoustic power and on the other hand, it allows to lower relatively the impact of acoustic background on noise measurement results (Bullmore *et al.*, 2009; Wszołek, Kłaczyński, 2014; Zagubień, Ingielewicz, 2017). The measurements were made by digital sound analyzer class 1 SVAN 912AE with wind protector, which enabled simultaneous measurement of most parameters characterizing noise. Before and after measurements, the measurement trajectory and sound analyzer were checked by class 1 calibrator. The whole equipment had valid calibration certificates. There was used the SV02/C4 microphone with constant measurement characteristics of frequency range from 0.4 to 16 000 Hz (Zagubień, 2016).

In the literature, a number of methods have been used for the detection of low frequency noise problems (Leventhall, 2003). One of those focuses, on the difference between C- and A-weighted noise levels due to the difference being an indicator of the amount of low frequency energy in the noise as well as a useful predictor of annoyance (Holmberg *et al.*, 1997; Kjellberg *et al.*, 1997). Kjellberg *et al.* (1997) suggest that if the difference between the noise values for the two weightings – dB(C) and dB(A) – is bigger than 15 dB, there may occur a low frequency noise problem. While this indicator does not provide definitive proof of a low frequency noise problem, it points to the need for further investigation within narrower frequency bands.

The LFN evaluation criteria were estimated regarding differences between the measured equivalent sound level L_{Aeq} and L_{Ceq}. For example, in Germany, in accordance with the DIN 45680 norm, the confirmation of LFN is the difference between (equivalent or maximum) sound levels C and A, which is more or equal 20 dB. Considering different suggestions of authors (Lundquist *et al.*, 2000; Pawlaczyk-Łuszczyńska *et al.*, 2006; 2007; Pawlas *et al.*, 2013) and the criteria used in the world (Pawlas *et al.*, 2013; DIN 45680, 2013; Hygiene norm HN 30, 2016; Shehap *et al.*, 2016), there was adopted an own LFN potential threat rating scale:

- $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} < 10$ – no threat,
- $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} = 10$–15 – low LFN threat,
- $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} = 15$–20 – medium LFN threat,
- $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} > 20$ – high threat of LFN.

In a further part of the study A-weighted and C-weighted equivalent sound pressure levels were calculated for a limited frequency range, i.e. 20–16 000 Hz.

The criteria for assessing infrasound noise were estimated both for the school surroundings and in the classrooms. According to Danish recommendations (Jacobsen, 2001), the permissible level of infrasound noise inside a school building was estimated at 85 dB(G). Considering the levels of natural infrasound in the environment during windy weather (Ingielewicz, Zagubień, 2014), the permissible level of infrasound noise outside a school building was estimated at 95 dB(G).

2.2. Learning results

The results of learning were checked on the basis of pass rates of final tests done by primary school students. The results concern children learning in the 6-grade primary school system, in other words, children graduating from school at the age of 13.

The assessment was made on the basis of two indicators, the average-percentage of the school results in this region within last two years and a long-term analysis of the ease of learning factor. Ease of learning factor used in didactic measurements tells us whether the graduate's achievements are his strength or weakness. The ease of learning factor is calculated by dividing the points obtained by the graduate by the maximum number of points possible to get for the task.

3. Results and discussions

The results of the conducted research are presented in a graphics form and in the form of tabular presentation. Long-term analysis of ease of learning factor, non-corrected third octave band analysis with hearing thresholds of acoustic noise (ISO 226, 2003) and low-frequency noise (Moller, Pedersen, 2004; Leventhall, 2007) are presented in a graphic way.

3.1. Third octave band analyses

Figure 3 shows the results of the conducted third octave band analyses outside school at measurement points located 2 m from the facade of the building.

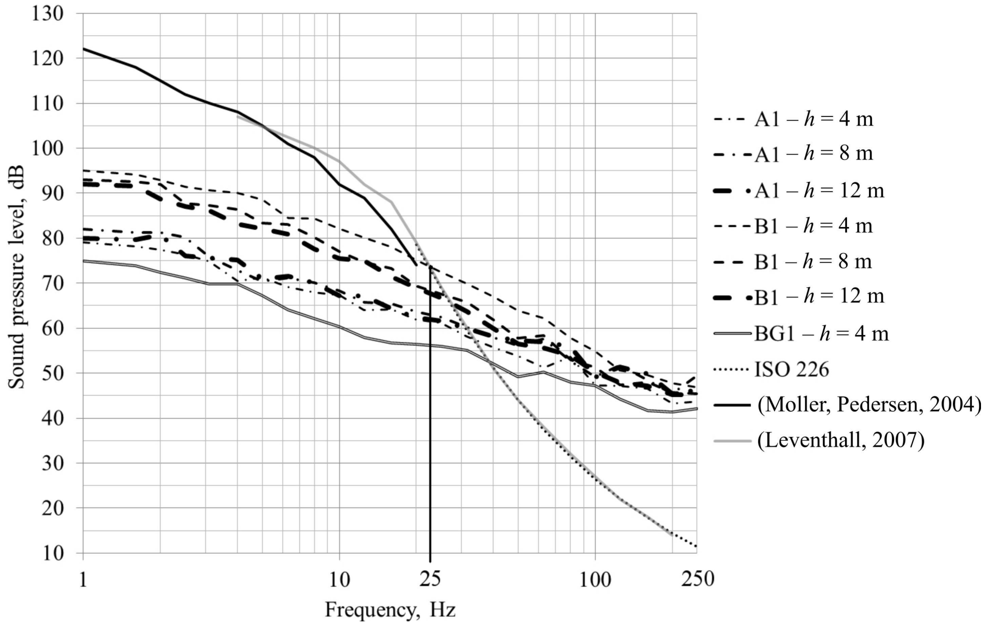

Fig. 3. Frequency spectrum of low frequency noise (LFN) occurring outside the building (ranges of measured sound pressure levels in 1/3-octave bands from 1 to 250 Hz).

The central frequency of 25 Hz of third octave band was highlighted; exceeding this frequency resulted in measurement results above hearing thresholds.

While identifying the potential threat of LFN to health of children, who stay outside school, the results of measurements at the height of 4 m are important. It should be noted that in the A1 measurement section (on wind turbines sides) the highest sound pressure levels are recorded at heights of 8 and 12 m, and in the measurement section B1 (from the road side) at a height of 4 m. At frequencies above 25 Hz, the results of measurements at the height of 4 m in the measurement section A1 are close to the background noise measured in BG1 section.

Figure 4 shows the results of third octave band analyses conducted in classrooms in A2, B2 and BG2 sections. Because of the large number of measurements, only the results of the highest values are presented. The frequency of the 63 Hz of third octave band was highlighted; exceeding this frequency resulted in measurement results above hearing thresholds.

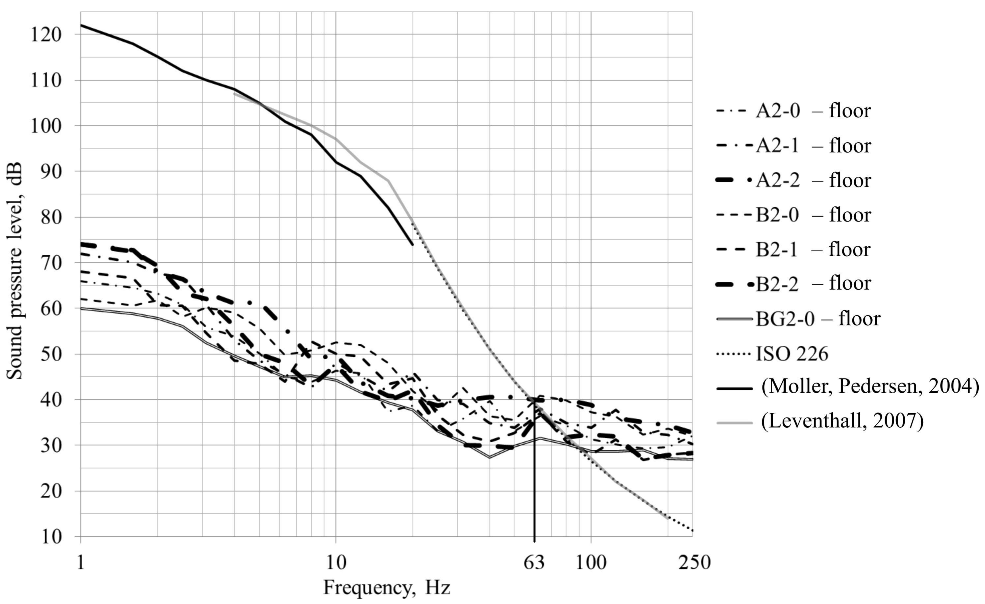

Fig. 4. Frequency spectrum of low frequency noise (LFN) occurring in classrooms (ranges of measured sound pressure levels in 1/3-octave bands from 1 to 250 Hz).

3.2. Infrasound noise

Table 1 summarizes the results of the selected measurement day from two series of measurements of the G-weighted equivalent sound pressure level. The mean equivalent sound level G was calculated for each test series at all measuring points. The measured values contain the background contribution. The values of the G-weighted equivalent sound pressure level of the background have been mixed up in separate columns.

The results of all collected infrasound noise measurements inside classrooms do not exceed 67 dB, and the ones collected outside the school do not exceed 92 dB. Calculated average values of equivalent sound level corrected by G weighted equivalent sound pressure level do not exceed 65 dB inside classrooms and 89 dB outside the school. Comparing the obtained results to values obtained during measurements carried out under similar meteorological conditions for natural sources of infrasound noise (Ingielewicz, Zagubień, 2014) and during everyday household activities (Zagubień, Wolniewicz, 2016), it can be stated that they are at similar levels.

3.3. LFN noise

The analysis of the diagrams shown in Figs 3 and 4 indicates that within the spectrum of the analysed noise there are the LFN members above the hearing threshold. It should be considered whether the measured noise levels can have a bothersome or harmful impact on students. Table 2 summarizes the average results of measurements of the equivalent sound level A and C in A and B measurement sections and the calculated difference $L_{\text{Ceq}} - L_{\text{Aeq}}$, which is the estimated criterion of assessment. Table 3 shows maximum sound levels registered in measurement points all types of frequency weightings A, C and G.

The following dependence of the $L_{\text{Ceq}} - L_{\text{Aeq}}$ assessment criterion was observed:

- in measurement sections A (from wind turbines side) larger differences (>10) were registered at heights of 8 and 12 m (A1) which corresponds to classrooms on the first and second floor of the school building (A2), it is probably caused by the direct (no reflections and loss) sound wave propagation on these points, from classroom win-

Table 1. Results of infrasound noise measurements.

Measurement height/floor [m]/–	Number of sample [–]	G-weighted equivalent sound pressure level, L_{Geq} [dB]									
		Measurement series 1				Measurement series 2				Background	
		Measurement section									
		A1	A2	B1	B2	A1	A2	B1	B2	BG1	BG2
4/0	1_0	80.8	52.5	84.7	60.6	77.9	52.8	85.4	60.6	76.4	53.1
	2_0	78.5	53.2	87.2	60.2	78.4	54.5	91.4	61.0	74.8	52.3
	3_0	77.5	55.0	83.9	59.9	76.9	55.7	86.5	59.4	75.1	52.7
	$L_{\text{Geq,avg}}$	79.2	53.7	85.5	60.2	77.8	54.5	88.6	60.4	75.5	52.7
8/I	1_I	87.8	60.9	78.6	58.2	86.2	60.6	80.8	57.5	–	
	2_I	88.4	66.6	77.5	58.9	87.8	66.0	80.0	59.8		
	3_I	85.6	62.8	74.8	59.1	83.4	63.4	75.0	59.1		
	$L_{Geq,avg}$	87.5	64.1	77.3	58.8	86.2	63.9	79.2	58.9		
12/II	1_{II}	89.6	62.6	81.7	56.9	89.4	62.7	82.2	55.7		
	2_{II}	84.6	60.3	82.6	58.8	83.0	57.9	82.5	55.7		
	3_{II}	85.5	61.1	82.3	60.6	85.2	61.1	82.3	62.7		
	$L_{\text{Geq,avg}}$	87.1	61.4	82.2	59.0	86.7	61.0	82.3	59.4		

Table 2. Results of the L_{Ceq} and L_{Aeq} measurements.

Measurement height/floor [m]/–	C-weighted equivalent sound pressure level, L_{Ceq} [dB]				A-weighted equivalent sound pressure level, L_{Aeq} [dB]				$L_{\text{Ceq}} - L_{\text{Aeq}}$ [dB]			
	Section A		Section B		Section A		Section B		Section A		Section B	
	A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2
4/0	68.1	46.3	75.2	50.8	59.7	40.4	60.2	37.5	8.4	5.9	15.0	13.3
8/I	74.9	51.1	69.3	49.1	63.6	38.5	63.5	40.3	11.3	12.6	5.8	8.8
12/II	74.4	54.0	71.2	48,9	59.5	40.8	62.8	38,1	14.9	13.2	8.4	10.8

Table 3. Results of the L_{Cmax}, L_{Amax} and L_{Gmax} measurements.

Measurement height/floor [m]/–	C-weighted sound pressure level, L_{Cmax} [dB]				A-weighted sound pressure level, L_{Amax} [dB]				G-weighted sound pressure level, L_{Gmax} [dB]			
	Section A		Section B		Section A		Section B		Section A		Section B	
	A1	A2	B1	B2	A1	A2	B1	B2	A1	A2	B1	B2
4/0	72.7	54.2	83.4	57.9	64.5	49.1	66.1	45.7	91.1	65.1	99.5	71.6
8/I	78.9	58.0	76.0	55.4	68.1	46.4	69.9	48.5	95.9	75.3	94.4	70.8
12/II	78.8	61.8	78.5	55.9	63.6	48.2	68.2	47.0	97.8	74.2	94.7	72.1

dows on the 1st and 2nd floor it is possible to see wind turbines while on the ground floor they are partly obscured by trees and bushes,

- in measurement sections B (from the national road side) larger differences (>10) were registered at a height of 4 m (B1) which corresponds to classrooms on the ground floor of the school building (B2), which may be caused by shorter sound wave propagation from vehicles on this part of the road,
- the results of measurements were never higher than 15 – which is the adopted numerical evaluation criterion (low LFN threat).

Beside chosen criteria, differences between levels $L_{\text{Cmax}} - L_{\text{Amax}}$ in Table 3 have also been checked. They did not exceed 20 dB in any measurement point. Only in one point the difference level was exceeded – $L_{\text{Cmax}} - L_{\text{Amax}} = 15$ dB, it was 17.3 dB registered from the MR road side, at the height of 4 m.

3.4. Learning results

Figures 5 to 7 show a long-term analysis of the ease of learning factor for three selected tasks: reading, writing and reasoning. The trend line of the results is presented. The results are shown in comparison with the results of the comparative school. The comparative school is of similar size as the analysed one and it is located in the same municipality. The comparative school is located at the distance of 250 m from the

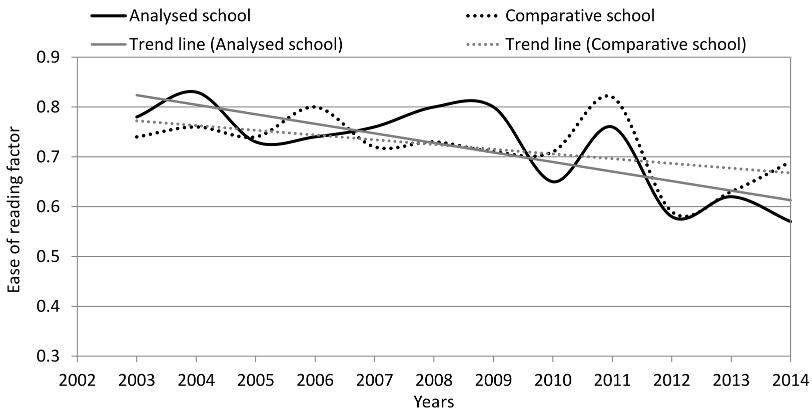

Fig. 5. Long-term analysis of ease of reading factor.

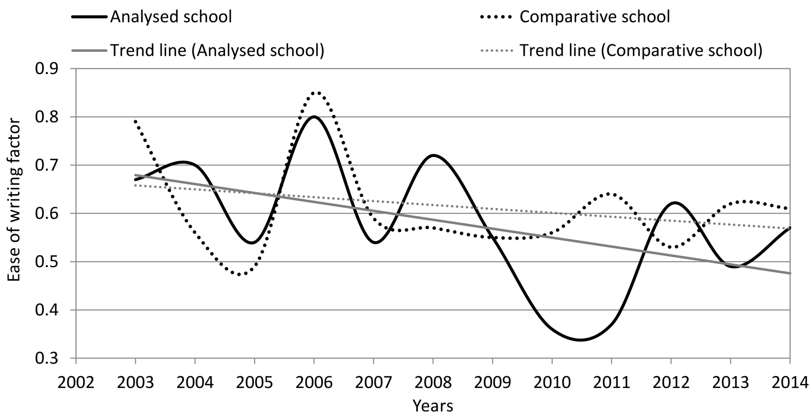

Fig. 6. Long-term analysis of ease of writing factor.

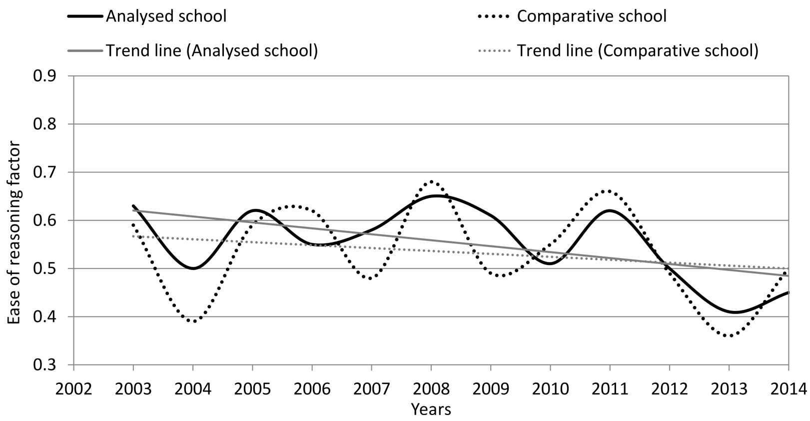

Fig. 7. Long-term analysis of the ease of reasoning factor.

Table 4. Average learning results compared to schools in the region.

Number of graduates	Year	Average school result [%]			
		School	Municipality	County	Voivodship
Analysed school: 24	2014	53.75	57.68	59.13	62.28
Comparative school: 19		58.55			
Analysed school: 17	2015	50.59	63.96	62.60	64.95
Comparative school: 32		69.28			
Analysed school: 20	2016	56.30	60.19	58.79	59.59
Comparative school: 21		62.24			

national road (MR) and partly shielded from traffic noise by buildings. The windows of the comparative school classrooms do not look out to the national road. The distance between the nearest wind turbine and the comparative school is 15 km.

The charts show that both schools have a declining trend line for all analysed factors. However, in the case of the analysed school, the line drops at an alarmingly large angle. Table 4 summarizes the average-percentage of learning results at the analysed school and the comparative school compared to schools in this region for last three years. The analysis of the presented data leads to the conclusion that the analysed school's educational results are below the average results in schools in this region.

4. Conclusions

The main conclusions of conducted research are:

1) The measured equivalent sound level A which is the acoustic background in analysed classrooms does not exceed 41 dB and most registered results are below 40 dB.
2) Adopted LFN assessment criterion describes the exposure of students to low-frequency noise as meaningless.
3) No threat of infrasound noise. Measured levels are below the threshold of human perception of infrasound.
4) Recreational facilities outside the school are located 100 m from the national road, which may discourage children from playing in the environment of increased noise levels. The measured values of the equivalent sound level A at the height of 4 m above the ground level, from the national road side, are higher than 60 dB (measurement sections B1). Lack of physical activity during breaks between lessons may cause tiredness and may lead to children's lower concentration.

Due to the fact that the express road, 500 m southeast from the school building, is still under construction, the research will be repeated within two years. There will be a survey conducted among students to know their subjective opinions on noise at school and its surroundings. On the basis of the measurement results collected so far, it is difficult to state clearly that worse learning results at this school are influenced by the acoustic climate in the school environment.

References

1. Bakar A.H.A., Alias A., Rahmat N. (2013), Teaching and Learning: The impact of noise pollution from Light Rail Transit (LRT) near the school compound, *Proceedings of International Academic Conference* (IAC 2013), Malaysia.

2. Baliatsas C., van Kamp I., van Poll R., Yzermans J. (2016), Health effects from low-frequency

noise and infrasound in the general population: Is it time to listen? A systematic review of observational studies, *Science of The Total Environment*, **557–558**: 163–169, doi: 10.1016/j.scitotenv.2016.03.065.

3. Boczar T., Malec T., Wotzka D. (2012), Studies on infrasound noise emitted by wind turbines of large power, *Acta Physica Polonica A*, **122**(5): 850–853, doi: 10.12693/APhysPolA.122.850.

4. Bullmore A., Adcock J., Jiggins M., Cand M. (2009), Wind farm noise predictions and comparison with measurements, *Proceedings of Third International Meeting on Wind Turbine Noise*, Aalborg, Denmark.

5. Crichton F., Petrie K.J. (2015), Health complaints and wind turbines: The efficacy of explaining the nocebo response to reduce symptom reporting, *Environmental Research*, **140**: 449–455, doi: 10.1016/j.envres.2015.04.016.

6. DIN 45680: 2013, *Measurement and assessment of low-frequency noise immissions in the neighbourhood*, Berlin, Deutches Institut für Normung.

7. Eze I.C. *et al.* (2018), Transportation noise exposure, noise annoyance and respiratory health in adults: A repeated-measures study, *Environment International*, **121**: 741–750, doi: 10.1016/j.envint.2018.10.006.

8. Herrmann L. *et al.* (2016), Low-frequency noise incl. infrasound from wind turbines and other sources, *Proceedings of Inter-Noise 2016*, pp. 5786–5795, Hamburg, Germany.

9. Holmberg K., Landstrom U., Kjellberg A. (1997), Low frequency noise level variations and annoyance in working environments, *Journal of Low Frequency Noise, Vibration and Active Control*, **16**(2): 81–88, doi: 10.1177/026309239701600202.

10. Hygiene norm HN 30:2016, *Infrasound and low frequency sounds: Limit values for residential and public buildings*, Minister of Health of the Republic of Lithuania.

11. Ingielewicz R., Zagubień A. (2014), Infrasound noise of natural sources in environment and infrasound noise of wind turbines, *Polish Journal of Environmental Studies*, **23**(4): 1323–1327.

12. ISO 226:2003 (2003), *Acoustics – Normal equal-loudness level contours*, International Organization for Standardization, Geneva.

13. ISO 7196:1995 (1995), *Acoustics – Frequency weighting characteristic for infrasound measurements*, International Organization for Standardization, Geneva.

14. Jacobsen J. (2001), Danish guidelines on environmental low frequency noise, infrasound and vibration, *Journal of Low Frequency Noise, Vibration and Active Control*, **20**(3): 141–148, doi: 10.1260/0263092011493091.

15. Kaczmarska A., Łuczak A. (2008), Analysis of annoyance caused by infrasound and low-frequency noise during mental work, *Archives of Acoustics*, **33**(3): 331–340.

16. Kjellberg A., Tesarz M., Holmberg K., Landström U. (1997), Evaluation of frequency-weighted sound level measurements for prediction of low-frequency noise annoyance, *Environment International*, **23**: 519–527, doi: 10.1016/S0160-4120(97)00054-8.

17. Leventhall G. (2003), *A review of published research on low frequency noise and its effects*, DEFRA, London.

18. Leventhall G. (2007), What is infrasound?, *Progress in Biophysics & Molecular Biology*, **93**(1–3): 130–137, doi: 10.1016/j.pbiomolbio.2006.07.006.

19. Lundquist P. (2003), *Classroom noise – Exposure and subjective response among pupils*, Umeå University, Sweden.

20. Lundquist P., Holmberg K., Landström U. (2000), Low frequency noise and annoyance in classroom, *Journal of Low Frequency Noise, Vibration and Active Control*, **19**(4): 175–182, doi: 10.1260/0263092001493010.

21. McCunney R.J., Mundt K.A., Colby W.D., Dobie R., Kaliski K., Blais M. (2014), Wind turbines and health: A critical review of the scientific literature, *Journal of Occupational and Environmental Medicine*, **56**(11): e108–e130, doi: 10.1097/JOM.0000000000000313.

22. Moller H., Pedersen C.S. (2004), Hearing at low and infrasonic frequencies, *Noise and Health*, **6**(23): 37–57.

23. Murphy E., King E.A., Rice H.J. (2009), Estimating human exposure to transport noise in central Dublin, Ireland, *Environment International*, **35**(2): 298–302, doi: 10.1016/j.envint.2008.07.026.

24. Muzet A. (2007), Environmental noise, sleep and health, *Sleep Medicine Reviews*, **11**: 135–42, doi: 10.1016/j.smrv.2006.09.001.

25. Pawlaczyk-Łuszczyńska M., Dudarewicz A., Śliwińska-Kowalska M. (2007), Proposals of exposure criteria for the assessment of low frequency noise at workplaces in industrial control rooms and office-like areas, *Archives of Acoustics*, **32**(2): 303–312.

26. Pawlaczyk-Łuszczyńska M., Szymczak W., Dudarewicz A., Śliwińska-Kowalska M. (2006), Proposed criteria for assessing low frequency noise annoyance in occupational settings, *International Journal of Occupational Medicine and Environmental Health*, **19**(3): 185–197.

27. Pawlas K., Pawlas N., Boroń M., Szłapa P., Zachara J. (2013), Infrasound and low frequency noise assessment at workplaces and environment – review of criteria, *Environmental Medicine*, **16**(1): 82–89.

28. Pedersen E., van den Berg F., Bakker R., Bouma J. (2010), Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound, *Energy Policy*, **38**(5): 2520–2527, doi: 10.1016/j.enpol.2010.01.001.

29. Pirrera S., de Valck E., Cluydts R. (2010), Nocturnal road traffic noise: a review on its assessment and consequences on sleep and health, *Environment International*, **36**(5): 492–498, doi: 10.1016/j.envint.2010.03.007.

30. Roswall N. *et al.* (2017), Residential exposure to traffic noise and leisure-time sports – A population-based study, *International Journal of Hygiene and Environmental Health*, **220**(6): 1006–1013, doi: 10.1016/j.ijheh.2017.05.010.

31. Schultz Christensen J., Hjortebjerg D., Raaschou-Nielsen O., Ketzel M., Sørensen T.I.A., Sørensen M. (2016), Pregnancy and childhood exposure to residential traffic noise and overweight at 7 years of age, *Environment International*, **94**: 170–176, doi: 10.1016/j.envint.2016.05.016.

32. Seetha P., Karuppiah K., Ismail M.Y., Sapuan S., Ismail N., Moli T. (2008), Effects to teaching environment of noise level in school classrooms, *Journal of Scientific and Industrial Research*, **67**(9): 659–664.

33. Shehap A.M., Shawky H.A., El-Basheer T.M. (2016), Study and assessment of low frequency noise in occupational settings, *Archives of Acoustics*, **41**(1): 151–160, doi: 10.1515/aoa-2016-0015.

34. Shield B., Dockrell J. (2008), The effects of environmental and classroom noise on the academic attainments of primary school children, *Journal of the Acoustical Society of America*, **123**: 133–144, doi: 10.1121/1.2812596.

35. Thiesse L. *et al.* (2018), Adverse impact of nocturnal transportation noise on glucose regulation in healthy young adults: Effect of different noise scenarios, *Environment International*, **121**: 1011–1023, doi: 10.1016/j.envint.2018.05.036.

36. Wszołek T., Kłaczyński M. (2014), Problems in measurements of noise indicators for wind turbines in Poland, *Proceedings of Forum Acusticum*, Cracow, Poland.

37. Wu S., Peng J., Bi Z. (2014), Chinese speech intelligibility in low frequency reverberation and noise in a simulated classroom, *Acta Acustica united with Acustica*, **100**: 1067–1072, doi: 10.3813/AAA.918786.

38. Xie H., Kang J., Tompsett R. (2011), The impacts of environmental noise on the academic achievements of secondary school students in Greater London, *Applied Acoustics*, **72**: 551–555, doi: 10.1016/j.apacoust.2010.10.013.

39. Zagubień A. (2016), Non-occupational exposure to low frequency noise – the analysis on the basis of chosen mean of transport [in Polish: Pozazawodowe narażenie na hałas niskoczęstotliwościowy – analiza na podstawie wybranego środka transportu], *Rocznik Ochrona Srodowiska*, **18**: 626–641.

40. Zagubień A., Ingielewicz R. (2017), The analysis of similarity of calculation results and local measurements of wind farm noise, *Measurement*, **106**: 211–220, doi: 10.1016/j.measurement.2017.03.041.

41. Zagubień A., Wolniewicz K. (2016), Everyday exposure to occupational/non-occupational infrasound noise in our life, *Archives of Acoustics*, **41**(4): 659–668, doi: 10.1515/aoa-2016-0063.