VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2023.1.01
Vibrations in Physical Systems, 2023, 34(1), 2023101

Psychoacoustic metrics in the psychological diagnosis of noise annoyance

Jan RADOSZ

Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy, Czerniakowska 16, 00-701 Warszawa

Corresponding author: Jan RADOSZ, email: jarad@ciop.pl

Abstract Aim of the study was to asses noise annoyance in relation to psychoacoustic metrics of sound in an office environment. The Vienna Test System was used for this purpose. Virtual office acoustic environments were developed with sources of different psychoacoustic parameters (loudness, sharpness, fluctuation strength, roughness) but with a constant A-weighted sound pressure level of 55 dB – sound environment with conversations, sound environment with office equipment (computers, printers, telephones) and sound environment with all office noise sources together. The reference environment was a quiet office room with no additional noise sources. Recorded real noise sources were transferred to a virtual 3D sound environment and converted into binaural sound, which was then played back on headphones. During the exposure to each of the acoustic environments, the subjects performed the ALS test (work performance series) and COG test (measurement of attention and concentration) and then assessed the given environment using a questionnaire. The paper presents the results of the statistical analysis – despite different psychoacoustic metrics of office noise sources in the examined acoustic environments, no statistically significant differences were observed in the results of psychological tests.

Keywords: noise, annoyance, workplace, sound, office, psychoacoustics.

1. Introduction

Noise is any unwanted sound that may be disruptive or harmful to health or increase the risk of an accident at work. Noise, apart from the impact on the hearing organ, as a stressor, may contribute to the development of various types of diseases, cause distraction, hinder work, and reduce its efficiency [1]. According to the definition of ISO/TS 15666 [2], annoyance is one person's adverse reaction to noise. The reaction may be referred to in various ways including dissatisfaction, annoyance and disturbance due to noise. The World Health Organization links noise annoyance with the experience of many different reactions, such as anger, disappointment, dissatisfaction, anxiety, distraction, exhaustion [3]. The most significant characteristic of noise related to annoyance is loudness. Many parameters are commonly used to assess loudness, e.g. A-weighted sound pressure level (LA), loudness level according to ISO 532 [4]/ANSI 3.4-2007 [5], and the perceived noise level, PNL [6]. Nevertheless, numerous studies show that only a small part of the perception of annoyance can be predicted by loudness. There is a study [7] suggesting that only about 30% of the annoyance is related to loudness due to other acoustic characteristics (e.g. tonality, impulsiveness) and non-acoustic factors (e.g. sensitivity to noise). A large part of the research on annoyance concerns environmental noise or noise in the place of residence [8]. Nevertheless, noise annoyance is equally important at workplaces in administrative rooms, design offices, for theoretical work, data processing, and other similar.

Noise is one of the main annoyance factors in open space workplaces where there are many sources of noise. Numerous laboratory studies have shown that noise in that kind of workplace has a disruptive effect on cognitive functions, such as counting displayed visual information and text comprehension and memory [9-20]. Noise in the workplace also appears to affect physical and mental health [21]. Many studies emphasize the importance of the impact of noise on health, comparing the declared health of people working in open spaces and people working in private spaces. It turned out that the percentage of people complaining about noise was 10 times higher in open spaces than in private spaces. The same study found an association between room type and symptoms such as headache, fatigue, and difficulty concentrating.

There are many research results on the impact of various types of sound signals on the performance of the examined people, including the efficiency of the tasks performed. These tasks usually include remembering numbers, remembering words, crosswords, mathematical operations, puzzles, e.g. Sudoku, etc. There has been no attempt to objectively parameterize noise in the work environment to determine dose-response models, and to develop annoyance criteria.

As regards measurement methods and admissible noise levels at workplaces, the regulations and standards are based only on the equivalent sound pressure level and do not take into account other characteristics of sound: time, amplitude, and frequency.

2. Material and methods

In creating the research sample, the method of non-random selection was used, which consisted of determining in advance certain characteristics to be met by individual units, i.e. age (range 18-50), education (secondary or higher), good health, no hearing loss. The sample structure was formed arbitrarily. 50 people (19 men and 31 women) participated in the research. The range of 0 - 20 dB HL (no hearing loss) was adopted as the qualification threshold for the tests. Before starting the study, each person was asked to complete a noise sensitivity questionnaire. For this purpose, the reduced questionnaire (NoiSeQ) developed by Schutte [23] was used. Histogram of the global noise sensitivity index (Figure 1) shows that test sample was diversified in terms of noise sensitivity.

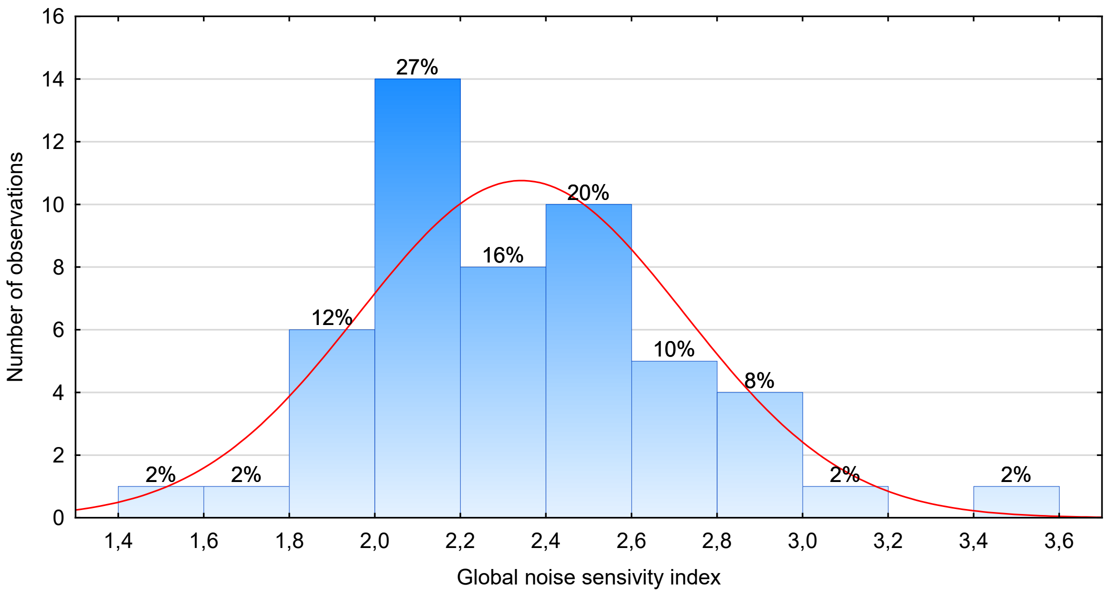

Figure 1. Histogram of the global noise sensitivity index of the test sample (NoiSeQ questionnaire).

Each of the respondents was familiarized with the purpose of the study and received appropriate instructions on how to perform the tasks. The study consisted of four parts divided according to the acoustic environment. In each part, the respondents performed specific tasks on the computer (psychological test) and then assessed the test signals using a questionnaire containing:

- assessment of the annoyance of the acoustic environment (ISO 15666 with verbal rating scale [2]),
- assessment of difficulties and workloads during the task (NASA Task Load Index reduced questionnaire).

In the study, the Vienna Test System and the ALS test were selected to assess the performance of the subjects under exposure to various virtual acoustic environments. The Vienna Test System (VTS) is a commonly used tool for computerized psychological assessments. VTS allows digital psychological tests to be administered while also providing automatic and comprehensive scoring. It includes classical questionnaires and tests that can only be scored by a computer, such as time-sensitive test presentation, multi-media presentation, adaptive tests, psychomotricity, combinations of tests for specific purposes and differentiated scoring of individual responses. The purpose of the ALS test is to measure generally understood efficiency and performance in the field of mental work. In the ALS test, participant add or subtract two digits placed one above the other on the screen and are required to perform as many actions as possible at any given time.

The research scenario included four types of virtual acoustic environments with different sound characteristics in terms of time, amplitude, and frequency (Table 1). These are typical values for office noise sources and can be expected to be similar in other office environments. During the exposure to each of the acoustic environments, the subjects performed the ALS test and then assessed the given environment with a questionnaire. The duration of the full study for one participant was approx. 2 hours.

The test stand consisted of

- Interacoustics AD629 diagnostic audiometer,
- PC with Schuffried software – Vienna Test System,
- VSX headphones – MODELING HEADPHONE SYSTEM,
- GRAS 45CB acoustic dummy,
- B&K PULSE sound analyzer.

Four types of virtual acoustic environments were developed:

- Environment A – quiet office room,
- Environment B – noise from office equipment (printers, computers, telephones, computer keyboards),
- Environment C – office conversations with moderate speech intelligibility,
- Environment D – all sources of office noise (computer, air conditioning, conversations with moderate speech intelligibility, printers, computers, telephones, computer keyboards, movement of workers).

Table 1. Psychoacoustic parameters of individual noise sources used for laboratory tests.

No.	Noise source	Sharpness - Aures, ISO 532-1 2017 (acum)	Fluctuation strength ISO 532-1 2017 (vacil)	Roughness ISO 532-1 2017 (asper)	Acoustic environment
1	Landline phone 1	17.77	3.175	3.249	C, D
2	Mobile phone 1	29.58	1.064	5.226	C, D
3	Landline phone 2	15.54	1.548	3.606	C, D
4	Mobile phone 1	10.31	2.036	2.635	C, D
5	Background conversations 1	6.81	1.386	1.567	B, D
6	Background conversations 2	22.91	1.012	2.04	B, D
7	Talking person 1	12.01	5.195	2.005	B, D
8	Talking person 2	14.72	7.934	2.198	B, D
9	Footstep	9.448	2.362	2.125	D
10	Ink printer	16.94	2.332	3.124	C, D
11	Laser printer	8.414	1.741	2.589	C, D
12	Copier	5.907	2.138	2.218	C, D
13	Computer keyboard 1	15.52	3.056	3.151	C, D
14	Computer keyboard 2	8.041	1.681	3.164	C, D

Table 2. Psychoacoustic parameters of the acoustic environments used in the laboratory study.

Acoustic environments	Loudness ISO 532-2 2017 CPB (sone)	Sharpness - Aures. ISO 532-1 2017 (acum)	Fluctuation strength ISO 532-1 2017 (vacil)	Roughness ISO 532-1 2017 (asper)	A-weighted sound pressure level (dB)
A	-	-	-	-	24.2
B	58.5	1.37	0.65	1.33	55.0
C	55.7	2.69	0.73	1.04	55.0
D	57.5	2.33	0.82	1.55	55.0

After the individual sources of office noise were assembled in the virtual acoustic environments, the psychoacoustic parameters were analyzed again, and are presented in the table (Table 2).

The first assumption of the developed acoustic environments B, C and D were that for each of them the equivalent sound pressure level A would be 55 dB (the noise annoyance criterion at the workplace according to PN-N-01307:1994 [22]). The second assumption was to develop acoustic environments different in terms of the noise sources and the values of psychoacoustic parameters.

Recorded in real environments noise sources were transferred to a virtual 3D sound environment and converted into binaural sound, which was then played on headphones. The dearVR PRO software was used for this purpose.

3. Results

The test results showed a moderate noise annoyance in acoustic environments B, C and D (Figure 2). The mean values of the annoyance rating were 4.24 (B) to 4.92 (D) on a scale from 0 to 10. According to subjective assessments, the most annoying environment was environment D.

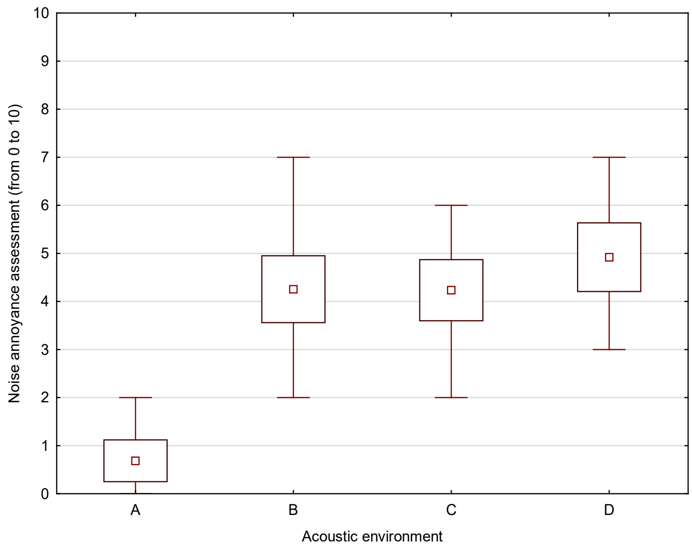

Figure 2. The results of the noise annoyance assessment of the tested acoustic environments (mean, 95% CI, and range of non-outliers).

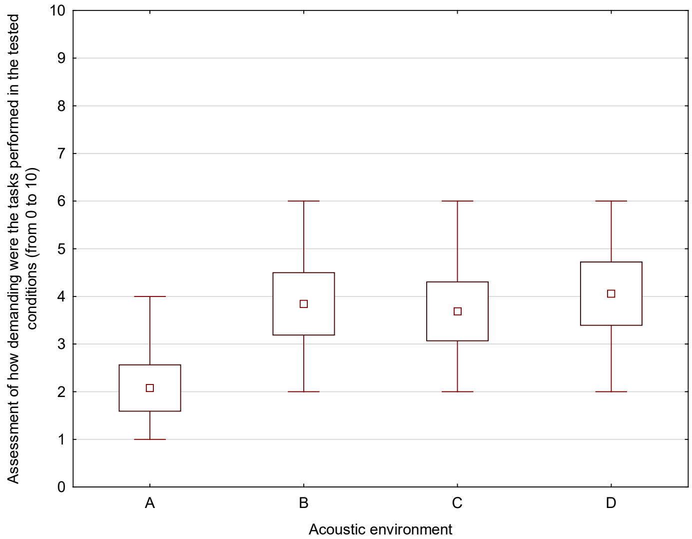

Figure 3. Results of the assessment of how demanding were the tasks performed in the tested conditions (mean, 95% CI, and range of non-outliers).

The subjective assessment of how demanding the tasks was performed ranged from 0 to 9 (on the rating scale from 0 to 10). Despite the large range of individual assessments. the average values were similar for environments B, C and D – the assessment values were between 3.7 and 4.1 (Figure 3). In general, it can be concluded that for the respondents the task was moderately demanding for environments B, C, D, and undemanding for environments A.

The results of the subjective assessment of the difficulty of performing the task showed, as in the case of the loudness of research environments, a large range of individual ratings (from 0 to 9 on the rating scale from 0 to 10). On the other hand, the average rating values indicate a moderate difficulty in performing the task in noise conditions – rating values from 3.9 to 4.4 for environments B, C and D (Figure 4).

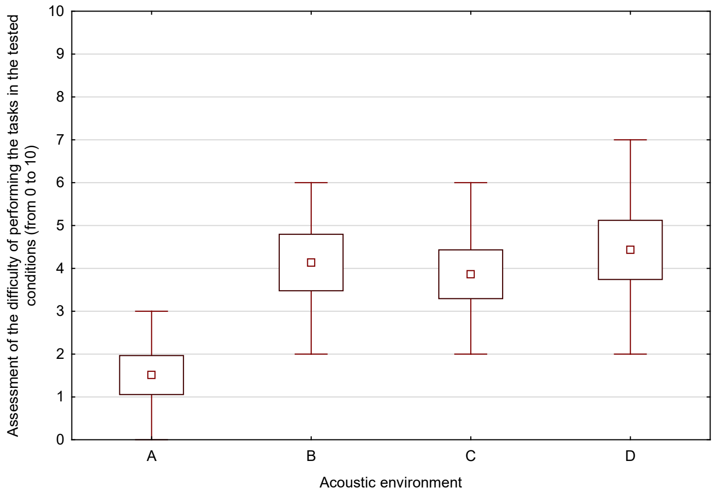

Figure 4. The results of the assessment of the difficulty of performing the tasks in the tested conditions (mean, 95% CI, and range of non-outliers).

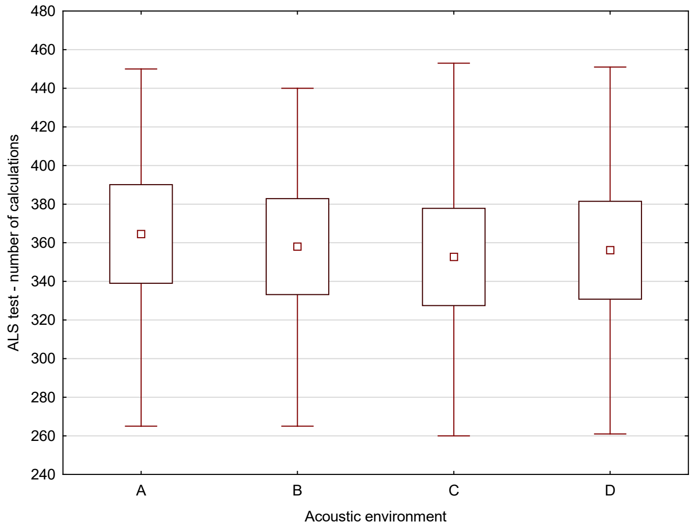

Figure 5. ALS test – number of calculations (mean, 95% CI, and range of non-outliers).

The range of number of calculations performed in the ALS test for all environments ranged from 199 to 637. The mean values ranged from 352 to 364. The differences in the mean values between individual environments did not exceed 4%. The lowest average number of calculations performed was observed for the C environment, and the highest for the A environment (Figure 5).

The percentage of errors made in the test for individual environments reached 8%. The average percentage of errors ranged from 2.0% to 2.2% (Figure 6). The lowest average number of errors was observed for the A environment, and the highest for the C environment.

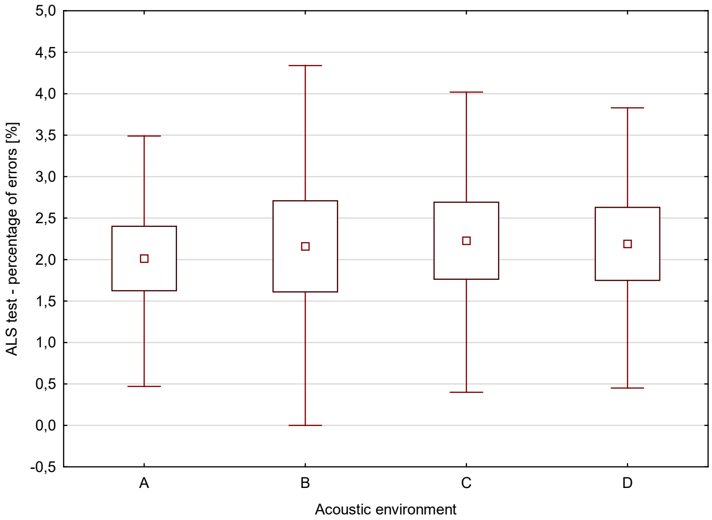

Figure 6. ALS test – the percentage of errors (mean, 95% CI, and range of non-outliers).

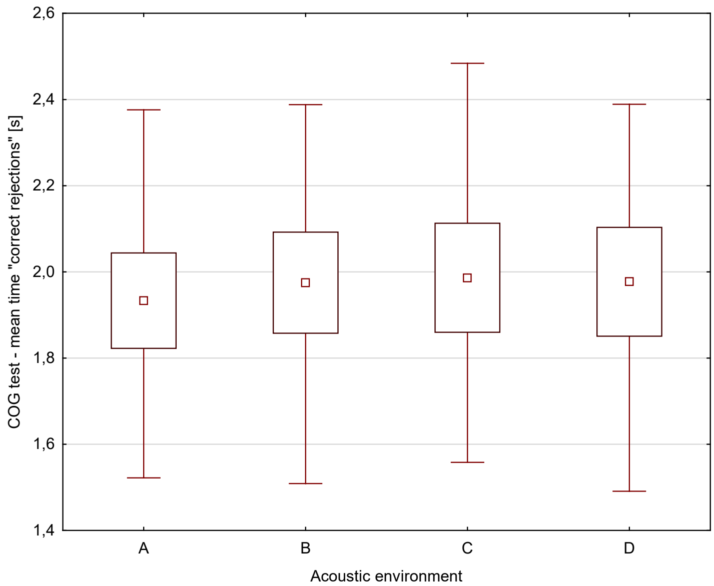

Figure 7. COG test – the mean time of "correct rejections" (mean, 95% CI, and range of non-outliers).

The mean time of correctly rejected figures in the COG test is shown. The range of obtained mean times ranged from 1.18 s to 3.16 s. The mean values ranged from 1.93 s to 1.98 s for individual signals (Figure 7). The shortest averaged time of correctly rejected figures was obtained for environment A and the longest for environment C.

The following statistical tests were used to analyze the test results: Shapiro-Willk test to evaluate the normality of the variable distribution, ANOVA for dependent groups, unifactorial MANOVA and ANOVA Friedman test. Statistica 13 and PQStat 1.6.8 were used in the statistical analysis. A significance level of 0.05 was adopted in the analysis. For the ALS and COG tests no statistically significant differences were observed between individual environments.

4. Conclusions

The Vienna Test System was used for the laboratory study. At the test stand, a set of the necessary measuring and diagnostic equipment was completed and 3 virtual office environments were developed with different psychoacoustic parameters, but with a constant A sound level of 55 dB. Environment A was adopted as the reference – a quiet office room. Acoustic environments used in the study were assessed ranging from not annoying to very annoying. On average, environments B, C, and D – were rated as moderately annoying. Despite the wide range of individual assessments, the average values of the subjective assessment of mental demand were similar for environments B, C, and D. In general, it can be concluded that for the respondents the task was moderately demanding for environments B, C, and D and undemanding in the case of environment A.

The results of the subjective assessment of the effort showed a wide range of individual ratings, while the average rating values indicate a moderate difficulty in performing the task in conditions with noise (environments B, C and D).

The results of psychological tests showed a reduction in the number of calculations performed in the ALS test and an extension of the average time of correctly rejected figures (comparisons) in the COG test for environments with sources of office noise (B, C and D). Despite different psychoacoustic metrics of office noise sources in the examined acoustic environments B, C and D, no significant changes were observed in the results of psychological tests. The subjective feelings of the respondents were not reflected in the results of the psychological tests, however further research is required to determine whether subjectively perceived nuisance can be related to acoustic parameters. The lack of differentiation of research results between particular environments does not provide grounds for the differentiation of sound stimuli in the context of psychoacoustic parameters.

The results did not give a clear answer as to whether the psychoacoustic parameters could be used as indicators of noise annoyance. The lack of differentiation in the results of psychological tests could result from insufficient differentiation of acoustic environments in the context of noise sources. It is also possible that the used sound pressure levels (maximum admissible according to PN-N-01307:1994) also contributed to the lack of differentiation of the results. In subsequent studies, a more detailed analysis of individual noise sources is planned.

Acknowledgments

This paper has been based on the results of a research task carried out within the scope of the fifth stage of the National Programme "Improvement of safety and working conditions" partly supported in 2021–2022 – within the scope of state services – by the Ministry of Economic Development, Labour and Technology. The Central Institute for Labour Protection – National Research Institute is the Programme's main coordinator.

Additional information

The author declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

References

1. G. Belojevic; Noise and Performance: Research in Central, Eastern and South-Eastern Europe and Newly Independent States; Noise Health, 2013, 15(62), 2–5; DOI: 10.4103/1463-1741.107146
2. ISO/TS 15666:2003; Acoustics – Assessment of Noise Annoyance by Means of Social and Socio-Acoustic Surveys 2003; International Organization for Standardization, 2003
3. C. Clark, K. Paunovic; WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Quality of Life, Wellbeing and Mental Health; Int. J. Environ. Res. Public Health, 2018, 15(11), 2400; DOI: 10.3390/ijerph15112400
4. ISO 532:1975; Acoustics – Method for calculating loudness level; International Organization for Standardization, 1975
5. ANSI S3.4-2007; Procedure for the Computation of Loudness of Steady Sounds; American National Standards Institute, 2007
6. K.D. Kryter; The Meaning and Measurement of Perceived Noise Level; Noise Control, 1960, 6, 12–27; DOI: 10.1121/1.2369423
7. L. Brocolini, C. Lavandier, C. Marquis-Favre, M. Quoy, M. Lavandier; Prediction and explanation of sound quality indicators by multiple linear regressions and artificial neural networks; Proceedings of Acoustics 2012; Nantes, 2012, 2121–2126
8. N.A. Çoban, K. Gedik, S. Kayal; A case study on public noise annoyance in relation to research trends on noise pollution; Proceedings of Euronoise 2015, 1621–1626
9. L. Fredianelli, S. Carpita, G.A. Licitra; A procedure for deriving wind turbine noise limits by taking into account annoyance; Sci Total Environ., 2019, 648, 728-736; DOI: 10.1016/j.scitotenv.2018.08.107
10. C. Lechner, D. Schnaiter, S. Bose-O'Reilly; Combined Effects of Aircraft, Rail, and Road Traffic Noise on Total Noise Annoyance-A Cross-Sectional Study in Innsbruck; Int. J. Environ. Res. Public Health, 2019, 16(18), 3504; DOI: 10.3390/ijerph16183504

11. P. Maigrot, É . Parizet, C. Marquis-Favre; Annoyance due to combined railway noise and vibration: Comparison and testing of results from the literature; Applied Acoustics, 2020, 165, 107324; DOI: 10.1016/j.apacoust.2020.107324
12. W. Paszkowski, J. Kotus, T. Poremski, B. Kostek; Evaluation of sound quality features on environmental noise effects – a case study applied to road traffic noise; Metrol. Meas. Syst., 2018, 25, 517–31; DOI: 10.24425/123901
13. W. Paszkowski, M. Sobiech; The Modeling of the Acoustic Condition of Urban Environment Using Noise Annoyance Assessment; Environ. Model Assess., 2019, 24, 319–30; DOI: 10.1007/s10666-018-9643-1
14. J. Ryu, H. Song; Effect of building façade on indoor transportation noise annoyance in terms of frequency spectrum and expectation for sound insulation; Applied Acoustics, 2019, 152, 21–30; DOI: 10.1016/j.apacoust.2019.03.020
15. M. Sheikh, A. Mitchell; Design strategies for perceived acoustic comfort in urban environments – A literature review; Proceedings of Acoustics 2018, 249–258
16. P. Wallner, H.P. Hutter, H. Moshammer; Evaluating an 80 Hz tonal noise from a hydropower plant; Int. J. Occup. Med. Environ. Health, 2019, 32, 401–11; DOI: 10.13075/ijomeh.1896.01361
17. E. Sundstrom, J.P. Town, R.W. Rice, D.P. Osborn, M. Brill; Office Noise, Satisfaction, and Performance; Environ. Behav., 1994, 26, 195–222; DOI: 10.1177/001391659402600204
18. E.M. De Croon, J.K. Sluiter, P.P. Kuijer, M.H. Frings-Dresen; The effect of office concepts on worker health and performance: a systematic review of the literature; Ergonomics, 2005, 48, 119–34; DOI: 10.1080/00140130512331319409
19. A. Kaarlela-Tuomaala, R. Helenius, E. Keskinen, V. Hongisto; Effects of acoustic environment on work in private office rooms and open-plan offices – longitudinal study during relocation; Ergonomics, 2009, 52, 1423–44; DOI: 10.1080/00140130903154579
20. S. Banbury, D.C. Berry; Disruption of office-related tasks by speech and office noise; Br. J. Psychol., 1998, 89, 499–517
21. B. Smagowska, M. Pawlaczyk-Łuszczyńska; Effects of ultrasonic noise on the human body – a bibliographic review; Int. J. Occup. Saf. Ergon. JOSE, 2013, 19, 195–202; DOI: 10.1080/10803548.2013.11076978
22. PN-N-01307:1994; Noise – Permissible values of noise parameters in the work environment – Requirements for performing measurements; Polish Committee for Standardization, 1994
23. M. Schütte, A. Marks, E. Wenning, B. Griefahn; The development of the noise sensitivity questionnaire; Noise Health, 2007, 9, 15–24; DOI: 10.4103/1463-1741.34700