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OCCUPATIONAL EXPOSURE TO INFRASONIC AND LOW FREQUENCY NOISE: ACTUAL PROBLEMS OF HYGIENIC STANDARDIZATION

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Introduction. Infrasonic and low frequency noise (LFN) are environmental and occupational hazards, whose proportion continually increases. Commonly accepted hygienic standards and requirements to their measurements are absent and vary from country to country.

The purposes of the article are to conduct a literature review concerning current legislation of occupational exposure to LFN and infrasound; compare levels of LFN using frequency analysis in 1/3-octave bands in the ranges from 2 to 250 Hz at the workplaces and living settlements; analyze subjective complaints of people working/living in the areas of conducted measurements; propose an approach to the hygienic evaluation of LFN and infrasound.

Materials and methods of research. Analytical review of scientific publications was carried out using scientometric databases, periodicals and regulations. Sanitary and hygienic measurements of infrasound and LFN were conducted by the Octave 110A sound level meter in octave and 1/3 octave bands with geometric mean frequencies in the range of 2–250 Hz at office premises, Academic Vernadskyi Antarctic Station,on the territory and premises of the residential area «Nova Darnytsia», on maritime transport of the DAT «Chernomorneftgaz» in accordance with current Ukrainian sanitary norms. A survey concerning subjective complaints about the parameters of physical factors (microclimate, artificial lighting, noise) was carried among 30 office workers of State Institution «Kundiiev IOH NAMS of Ukraine».

Results. Most of the published articles, dedicated to the impact of LFN and infrasound, consider results of measurements using A-weighting characteristics, which essentially reduces information about LFN. Our results show that LFN in the range 2–250Hz is widespread in the industrial environment, in transport, residential areas, living premises. Despite the fact that noise levels measured using correction «A» do not exceed sanitary norms, up to (44.0 ± 3.7) % of respondents complain about noise at the workplaces. The spread of noise increases with a prevalence of low frequency bands in its spectrum. So, an absorption of acoustic oscillations by building structures is 8 dB at frequency of 31.5 Hz and 14–16 dB at frequency of 250 Hz. Acoustic oscillations in the range of 2–8 Hz at marine vessels are spread approximately by 1,000 times better than the sound perceived by the human ear.

Conclusions. Existing approaches to the problem of the assessment of occupational and habitual exposure to the infrasonic and LFN don't enable to substantiate generally accepted hygienic standards for these physical factors. National standards vary from country to country and differ from each other by established limits and measuring methods. Most of the published articles consider results of measurements using A-, C- and G-weighting characteristics, which do not provide objective information about spectral characteristics of the exposure hazard level. The authors suggest that the further identification of the problem should start from a common approach. The authors proposed the methodology of data acquisition measuring in the 1–500 Hz range using 1/3 octave bands, linear scale and linear RMS, Min and Max detector for the purpose of profound identification of low frequency sources and for objective analysis of human organism reactions to its exposure.

Key words: low-frequency noise, infrasound, occupational exposure, hygienic standardization

Introduction

Low-frequency noise (LFN) is a background noise whose proportion continually increases in modern urban environments. The World Health Organization (WHO) recognized LFN as an environmental problem [1]. LFN and infrasound are also occupational hazards. Being generated by pumps, compressors, diesel engines, gas turbines, ventilation, heating

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and air conditioning systems and so on, they become the characteristics of various workplaces at airports, petrochemical plants, mines, transport, manufacturing enterprises, industrial control rooms, office-like areas etc.

Unlike the well-studied audible noise which can cause damage of hearing and various non-audible effects, LFN and infrasound remain underexplored. First attempts in their understanding were made 25–30 years ago. Usually, infrasound is defined as a noise in the range of 1–20 Hz. Unfortunately, the upper and lower limits of LFN are still under discussion. Some European countries do not have national sanitary norms establishing admissible levels of infrasound and LFN. On the other hand, numerous studies confirm the negative impact of this noise on human beings [2–4]. Besides, available national standards and suggested methods of LFN and infrasound measurement are to some extent controversial.

The present article is aimed to:

– conduct a literature review concerning current legislation of occupational exposure to LFN and infrasound;
– compare levels of LFN using frequency analysis in 1/3-octave bands in the ranges from 2 to 250 Hz at the workplaces (office premises, marine transport, Academic Vernadskyi Antarctic Station) and living settlements (based on our own results);
– analyze subjective complaints of people working/living in the areas of conducted measurements;
– propose an approach to the hygienic evaluation of LFN and infrasound.

An overview of current sanitary legislation in some European countries for infrasound and LFN

According to Leventhall G., LFN is considered the noise with dominating sound energy in the frequency range from about 10 to 200 Hz [2], which is a common conception. So far, these boundaries are not fixed. In scientific literature, LFN can also be defined in different limits: 10 to 250 Hz [3], from 20 to 250 Hz [4] and even from 20 to 500 Hz [5]. German standard DIN 45680:1997 [6] establishes lower and upper levels of LFN from 10 to 100 Hz, Lithuanian – from 16 to 200 Hz [7]. Several examples of various limits suggested by different authors and national standards are shown in the Table 1.

There is a very indistinct boundary between infrasound and LFN which often causes confusion. ISO 7996:1995 [10] defines infrasound as noise with frequency within 1–20 Hz, although earlier it was different. For instance, Polish norms PN 86/N-01338 – out of order [11] had specified infrasound in the range from 2 to 50 Hz. It is generally accepted that infrasound is nonaudible. However, this common assumption is incorrect because sound at the frequencies below 16 Hz is clearly audible if the level is high [12]. Sometimes, LFN and infrasound are noteven separated from each other, which also leads to misunderstanding for they cause a bit

Table 1

Suggested upper and lower limits of LFN in scientific literature and national standards

Suggested range, Hz	Source
10–200	Leventhall G. et al., 2003 [2]
10–250	Pawlaczyk-Łuszczyńska M. et al., 2010 [3]
20–250	Berglund B. et al., 1996 [4]
20–500	Alves-Pereira M. et al., 2007 [5]
10-100	DIN 45680:1997, 1997 [6]
16–200	HN 30:2016 [7]
10–160	Danish Environmental Protection Agency N 9/1997 [8]
31.5–200	SOSFS 1996:7/E [9]

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different physiological effects in the human body, have dissimilar absorption and, correspondingly, the ability to spread through various mediums.

The variety of hygienic standards for limits of occupational exposure to infrasound in the range 2–20 Hz accepted in different countries are shown in the Table 2.

The above mentioned International standard ISO 7996:1995 specifies G-weighting characteristics for the determination of infrasound. This characteristics, which was specially intended for infrasound, looks as a triangle with maximums at 20 Hz and minimums at 0.2 and 300 Hz correspondingly and differs from another weighting characteristics (Figure 1). Leventhall G. [2] underlines that «too much reliance on the G-weighting, ...may divert attention from problems at higher frequencies ...in the 30 Hz to 80 Hz range».

As it can be seen from the Table 2, the national standards vary from country to country. In some cases, admissible levels exceed hearing threshold (56.3 dB at the frequency 31.5 Hz), established by ISO 226. Such huge difference can be explained by the application of different measuring methods. It is necessary to underline that hygienic assessment of LFN differs from high frequency noise analysis. However, there is still no established guideline for LFN assessment at the workplaces. Some European countries use specific regulations on LFN control in apartments [17, 18]. Most of them are based on the frequency analysis in 1/3-octave bands in the frequency ranges from 8 to 250 Hz using nominal A-weighting correction [19]. This approach is being highly criticized in scientific literature [20]. Alves-Pereira et al. compared the overall (L_{eq}) values measured with A-weighting filter (dB/A) and without it (dB/Lin) in a cockpit of the Airbus-340 [21] and commuter train in motion [22]. The levels of noise in a train and in a cockpit measured in dB/A were the same (72.1 dB/A) but levels without A-weighting were 95.6 dB/Lin and 83.2 dB/Lin correspondingly. In other words, people can hear the same level of noise in a train and a cockpit, but they are exposed to different amounts of acoustical energy. The point is, A-weighting filter is based on equal-loudness threshold and quite well simulates human's auditory thresholds. That's why it is primarily used for evaluating the risk of noise-induced hearing loss. Currently, we know that LFN has unique characteristics, quite different from the noise of higher pitch. It is reduced less by various shields, crosses

Table 2

Admissible levels of infrasound in normative documents of different countries

Country/document	Frequency, [Hz]				
	2	4	8	16	31.5
Poland/PN-86/N-01338 – out of order [11] – Performing basic functions in observations cabins and remote control, or premises for precise work	–	90	90	90	85
– Performing basic functions on premises for administration, design offices, research work, data handling	–	85	85	85	80
Poland/PN-Z-01338:2010 [13]	102				
Ukraine/ДСН 3.3.6.037-99 [14]	105	105	105	105	86–107*
Sweden/AFS2005:16 [15]	130	118	106	94	61
Germany DIN 45680 [6]	–	–	103	79	55.5
Denmark (at night) [2]	–	–	–	76.7	59.4

*Note. *Depending on a type of work.*

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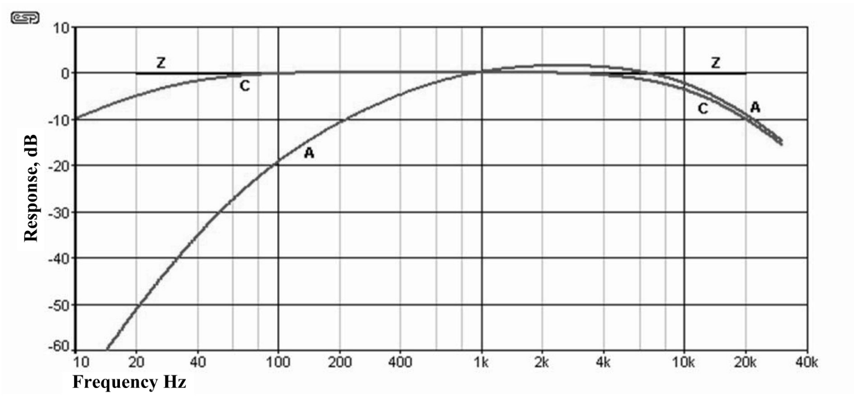

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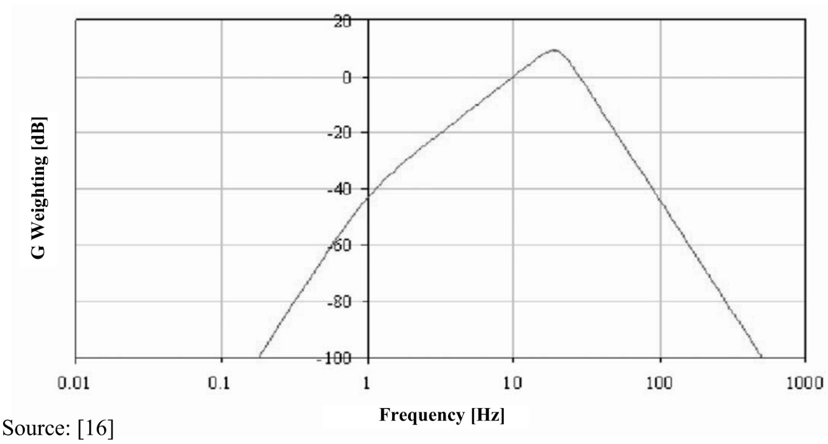

Source: [16]

Figure 1. Frequency weighting curves A, C, G and Z

greater distances, produces resonance in the human body (abdomen, chest, throat) etc. Moreover, ear protection devices are much less effective against it. So, application of A-weighted scale neglects sources below 50 Hz and does not consider physical peculiarities of LFN. According to the Canadian researchers studying aviation noise, it can lead to leaving out occupational health risks in the working population exposed to this occupational hazard [23]. The authors suggested using C-weighted sound exposure level metric as indicator for LFN annoyance. This suggestion is based in the fact that C-weighting level includes nearly all of the low frequency energy in a signal and, correspondingly, is more appropriate for LFN assessment.

Based on a literature review, Broner N. [24] recommends using dB/C – dB/A difference of at least 20 dB to indicate the presence of LFN problem (as an indication of an unbalanced spectrum towards low frequencies). This method is inadequate for the identification of LFN at the workplaces with low noise levels (45dB/A or less) considering the presence of self-generated noise of sound analyzers [16]. Therefore, there are no commonly established hygienic norms and standardized methods of measurement of LFN and infrasound, so their criteria vary from country to country [25]. WHO [26] admits that using of A-weighted scale is unfitted to measurements of noise levels with prevalence of low frequencies, but it does not suggest any alternative. Additionally,

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some industrial and natural sources may generate impulse-like low frequency noise. It means that commonly used SLOW time constant is not enough for the comprehensive analysis.

Materials and methods of research

Sanitary and hygienic measurements of infrasound and LFN were conducted by the Octave 110A sound level meter in octave and 1/3 octave bands with geometric mean frequencies in the range of 2–250 Hz at office premises (State Institution «Kundiiev IOH NAMS of Ukraine» (Kyiv, 2020), Academic Vernadskyi Antarctic Station (Antarctic Peninsula, 2004)), on the territory and premises of the residential area «Nova Darnytsia» (Kyiv), on maritime transport of the DAT «Chernomorneftgaz» (2012–2013). Hygienic assessment of sound pressure levels was conducted in accordance with current Ukrainian sanitary norms: SSN 3.3.6.037-99 «Sanitary Norms of Industrial Noise, Ultrasound and Infrasound» and Order of the Ministry of Health of Ukraine dated 22.02.2019 No. 463» State Sanitary Norms of permissible noise levels in residential and public buildings and in residential areas». A survey concerning subjective complaints on the parameters of physical factors (microclimate, artificiallighting, noise) was carried among 30 office workers of State Institution «Kundiiev IOH NAMS of Ukraine».

Research results and their discussion

According to the data of instrumental measurements, the levels of sound and sound pressure level sat office premises with and without air conditioning systems (Figure 2) meet the requirements of sanitary norms. Nevertheless, results of the survey, conducted among workers show that (44.0 ± 3.7) % respondents complain about the noise level at the workplaces. Considering the fact, that parameters of acoustic load at the workplaces did not exceed admissible level in 65 dB/A, this fact needs further research in the terms of its irritating and interfering action on the human organism and the ability to concentrate at work.

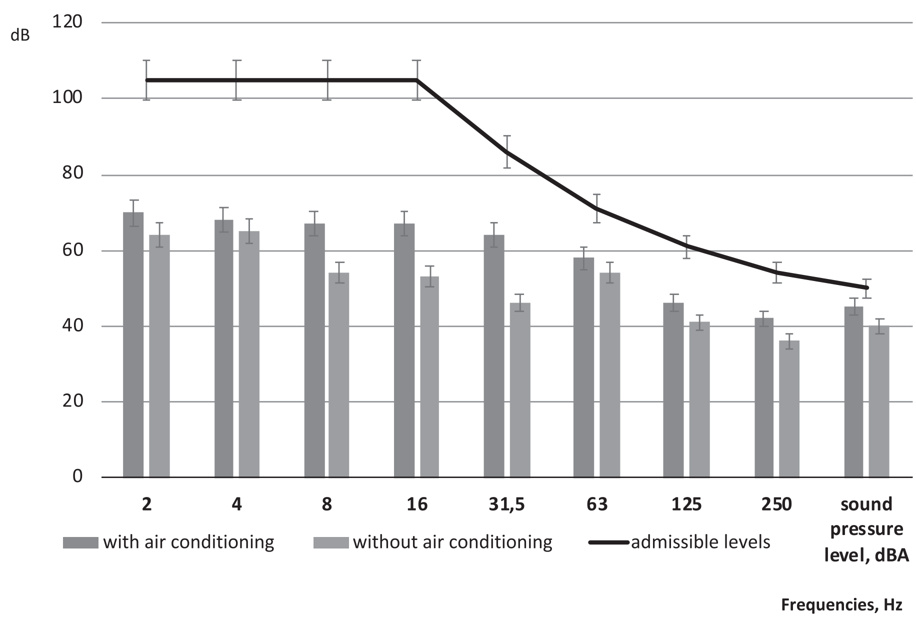

Figure 2. Comparison of admissible sound pressure level and measured at the offices of State Institution «Kundiiev IOH NAMS of Ukraine»

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During scientific expedition to the Antarctic Peninsula, the levels of LFN were measured at the diesel room and living premises of Academic Vernadskyi Antarctic Station. A main building with scientific laboratory and living rooms was located 15 m from the diesel room, generating LFN by three diesel Volvo engines. Our results show, that the absorption of the noise by the walls of the premises and double-glazed windows at the frequency 25 Hz was only 9 dB and at the frequency 80 Hz – 25 dB (Table 3).

Sound pressure levels at these frequencies do not meet sanitary standards for living premises at night time. At the higher frequencies (above 160 Hz) absorption by building structures was much better, making up 47–61 dB.

Various kinds of diesel engines produce infrasonic and LFN in the range of 2–63 Hz in marine transport and affect crew of the ship during performing their duties and at the rest, evidenced by the study of working conditions at the vessels of the DAT «Chernomorneftgaz» (Table 4). It was found that the main sources of noise (31.5–8000 Hz) and infrasound (2–16 Hz) at the ships of I–III categories are diesel generators with power from 50 to 2500 kW. This equipment works constantly, not only when the ship is going to sea, but also when it is at a standstill, in a mode of lower power. At the same time, the maximum noise levels can reach 109 dB/Ain the mode of putting the diesel into operation, and 112–115 dB/Lin (infrasound range). The equivalent noise level (L_{eq}) in the engine room (mechanics, electricians and electromechanical technicians of all types) is 90–98 dB/A. For sailors and boatswains working on the deck and in the service rooms, noise load with levels 84–92dB/Ais formed mainly due to the usage of pneumatic and electric vibrating tools during repair actions. It should be noted that most specialists perform activities inside the premises with different levels of fluctuating or intermittent noise. At the workplaces of the management and auxiliary personnel, the noise load was only 62–67 dB/A and exceeded the permissible level only at 25–40 % of total workplaces. However, in all these rooms there was a significant infrasound level (88–97 dB/Lin) with the maximum acoustic energy at the frequencies of 2–4 Hz.

Measurements of infrasound levels in the main areas of the ship showed that in the cabins it exceeds the threshold of adverse effects (interfering, irritating action) for living premises by 9–15 dB/Lin according to the literature data (Izmerov N. F. et al., 1997). This fact indicates that the crew does not have adequate conditions to rest and recover. Infrasound in the range 2–8 Hz is absorbed by the

Table 3

LFN measurements in the premises of the diesel and living premises of the Academic Vernadskyi Antarctic Station

Place of measurement	Sound pressure levels (dB) in 1/3-octave bands with geometric mean frequencies, [Hz]										
	25	31,5	40	50	63	80	100	125	160	200	250
Diesel room	79	66	73	74	77	93	78	86	89*	98*	94*
Admissible level*	107			95			87			82	
Living premises	68*	53	48	41	48	68*	41	40	42	33	32
Admissible level** day/night	68/63			57/50			48/40			41/33	

*Note. *State Sanitary Norms 3.3.6.037-99, **State Sanitary NormsNr 463-2019.*

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Table 4

Comparison of infrasound level in the main areas of ship to hygienic requirements

Place of measurement	Sound pressure level (dB) in 1/3 octave bands at geometric mean frequencies, M ± δ, [dB]				General level of infrasound/sound, [dB]	
	2	4	8	16	dB Lin	dBA
Engine rooms	97 ± 2.8	87 ± 2.5	84 ± 3.1	93 ± 4.2	103 ± 3.4	97 ± 4.2
Admissible levels*	105	105	105	105	110	80
Central control panel, office	87 ± 4.0	79 ± 3.5	75 ± 3.6	79 ± 3.1	92 ± 4.1	68 ± 4.6
Admissible levels**	95	90	85	80	95	-
Cabin	84 ± 3.2	77 ± 3.0	72 ± 2.8	75 ± 3.3	87 ± 3.6	57 ± 3.4
Admissible levels***	75	70	65	60	75	-

*Note. *State Sanitary Norms 3.3.6.037-99, **Izmerov N. F. (for the work, requiring emotional and intellectual strain), ***Izmerov N. F. (for the living premises).*

vessel constructions only by 10–12 dB. At the same time, noise levels are reduced by 36–44 dBA. This shows that infrasound in the range of 2–8 Hz penetrates through the premises of sea vessels in about 1000 times better than the audible sound, perceived by human ears.

People are exposed to infrasonic and LFN not only at work, but also in residential areas. The main sources of these physical factors in settlements are various installations inside the buildings (ventilation and climatization systems) andsounds from the outside of the buildings (primarily transport). Measurements conducted in residential area «Nova Darnytsia» (Kyiv) showed exceeding of admissible levels of noise in the range of 31.5–250 Hz during the day and night (Figure 3).

As it can be seen, exceeding of the sound pressure levels is up to 16 dB comparing to existing sanitary norms, especially at night. Acoustic oscillations are absorbed by building structuresby 8 dB at the frequency of 31.5 Hz during the day (8 AM–10 PM) and night (10 PM–8 AM) and by 14–16 dB at the frequency of 250 Hz. Unfortunately, absence of standards regulating admissible level of sound pressure in the range 2–31.5 Hz make hygienic assessment impossible. On the other hand, presence of numerous subjective complaints on the noise level and its irritative effect at the workplaces and residential areas rises a significant hygienic problem concerning establishing safe levels of exposure to infrasound and LFN. Solution of this task should include collection of comprehensive bases of measurements of infrasound and LFN at different workplaces, studying of dose-effect relationship which is based not only on subjective complaints, but analysis of objective physiological changes caused by such exposure (hearing thresholds, heart rate variability), investigation of individual sensitivity to noise etc. Such an approach will allow to substantiate hygienic standards and develop effective collective and individual preventive measures.

Conclusions

1. Existing approaches to the problem of assessment of occupational and habitual exposure to the infrasonic and LFN haven't allowed yet to substantiate generally accepted hygienic standards for these physical factors. National standards vary from country to country and differ from each other by established limits and measuring methods. Most of the published articles

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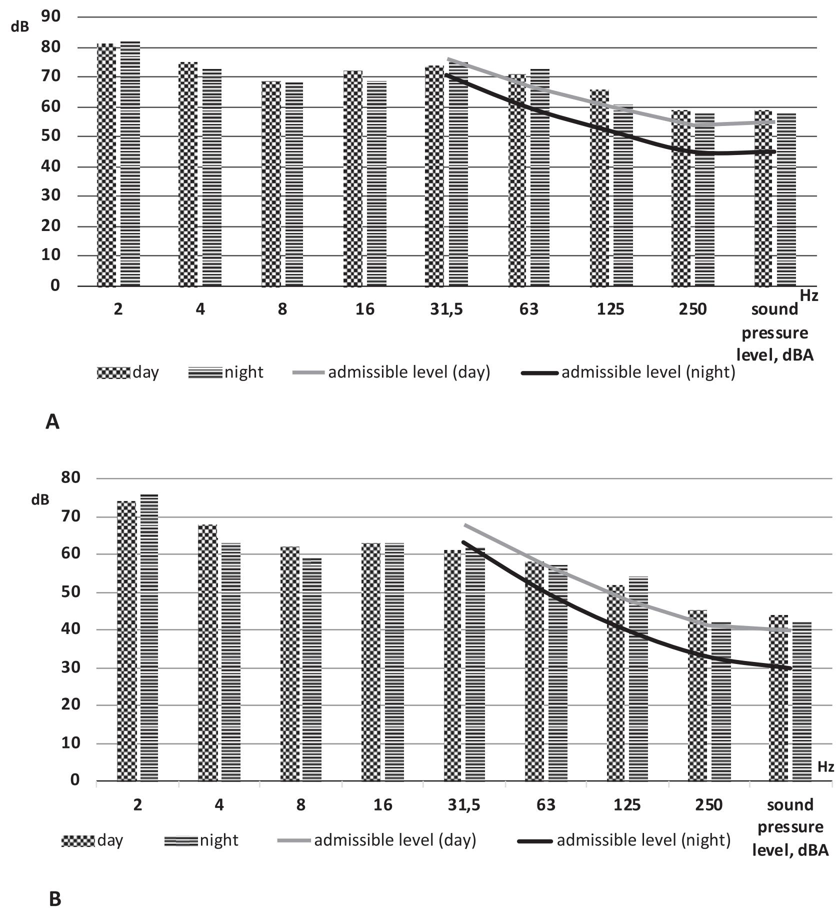

Figure 3. Sound pressure levels in octave bands with geometric mean frequencies measured at the residential area «Nova Darnitsia» (Kyiv) in the near vicinity of the house (A) and in the living premises (B) in comparison to admissible levels

consider results of measurements using A-, C- and G-weighting characteristics, which do not provide objective information about spectral characteristics of the exposure hazard level.

2. Based on the literature review and the analysis of obtained results, the authors suggest that the further identification of the problem should start from a common approach.
3. The methodology of data acquisition brought into practice by our research team is measuring in the 1–500 Hz range using 1/3 octave bands, linear scale and linear RMS, Min and Max detector for the purpose of profound identification of low frequency sources and for objective analysis of human organism reactions to its exposure.

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Maslakiewicz M. (ORCID ID 0000-0001-5325-0634) – literature review, work on graphic and tabular material, discussion of results.

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