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Environmental impact of noise from mining operations

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Abstract

The article presents the results of measurements of environmental noise caused by devices operating in the surface facilities of hard coal mines and by the technological processes related to the loading and transport of spoil and materials necessary for production. The research results are part of the program "Consequences of excessive noise in the mining environment of hard coal mines", the overarching goal of which is to reduce the emission of industrial noise. A sampling method was used to determine the actual values of noise levels emitted to the external environment from mines and mining plants as well as to identify the acoustic power levels of devices and processes constituting the main sources of noise in mines. The results showed that mines and mining plants are often not fully aware of the scale of the environmental impact of the undesirable noise they emit. Therefore, the current periodic measurements of environmental noise should be replaced with permanent monitoring, which will be beneficial not only for the environment and residents of housing estates located near mines but also for the mining plants themselves.

Introduction

Inhabitants of towns in the region of Silesia and Malopolska, whose houses are located in close proximity to the industrial infrastructure of hard coal mines and mining plants, often complain of excessive noise emitted by the mine's main fan stations and technological processes accompanying the loading and unloading of materials or backfilling of mining excavations taking place in the mine ventilation shafts. Excessive noise emitted 24 hours a day and seven days a week, prevents the inhabitants not only from having a good night's sleep but also makes it impossible for residents to rest in front of their houses during the day. Therefore, due to the bothersome noise, they have not opened their windows for years. According to the accounts of residents, in many districts located in the vicinity of ventilation shafts, for many hours you can hear excessive noise of high intensity, which in the evening and night hours turns into a very loud low sound reflecting off the walls of blocks and tenement houses, which is commonly referred to as "hum". The noise emitted not only irritates them, but in their opinion also affects their health by impairing the nervous system and the ability to concentrate. Living in constant noise, the inhabitants become exhausted, their movements slow down, and their reaction speed and willingness to work decrease. According to various researchers dealing with the impact of industrial noise on the human body (Babisch, 2006; Cai et al., 2022; Li et al., 2022), prolonged exposure even at low noise levels contributes to the occurrence of diseases such as circulatory disorders (Monazzam Esmaielpour et al., 2022), cognitive impairment, sleep problems (Silva et al., 2021), tinnitus, and hearing impairment (Magiera & Solecka, 2021). Unfortunately, environmental noise, including that generated by industrial plants, is often underestimated due to its coexistence with other noise sources such as road, air, rail noise, power lines, or municipal noise, and the residents of buildings located in the vicinity of industrial plants are left to themselves. Meanwhile, the principles of environmental protection (including against excessive noise) and the conditions for using its resources, taking into account the requirements of sustainable development, are specified in the Environmental Protection Law of 27 April, 2001 (Journal of Laws No. 62 of 2001, item 627). The latest amendment of this law introduces changes to Directive 2002/49/EC relating to common noise assessment methods (European Commission, 2020) and new obligations imposed on environmental protection authorities and entities obliged to minimize the effects of excessive environmental noise (European Commission, 2021). The issues of permissible noise levels in the environment are, in turn, regulated by the Regulation of the Minister of the Environment of 14 June, 2007 (Journal of Laws of 2014, item 112) on permissible noise levels in the environment, modeled on the solutions of the European Union.

Pursuant to Article 112 of the aforementioned Act and the recommendations of the European Union, protection of the environment against noise consists in ensuring the best acoustic state of the environment by keeping the noise level below the permissible level or at least at this level, and in the event that it is not kept, reducing the noise level to an acceptable level. This provision shows that one of the obligations of industrial plants, the side effect of which may be excessive noise emission, is to monitor this phenomenon and reduce it.

In order to meet this need, employees of the Department of Safety Engineering of the Silesian University of Technology, as part of the research project "Consequences of excessive noise in the mining environment of hard coal mines", have been monitoring the volume of noise emissions generated during technological processes in the mine and the effect of this noise on the external environment, especially residential buildings, for 4 years. Its main purposes are the indentation of noise-generating phenomena and processes, the elimination of noise by proposing technical solutions that enable soundproofing of the noisiest subassemblies of mining machines and devices, and the development of systems for continuous noise hazard monitoring.

Review of the literature

As defined in Directive 2002/49/EC, environmental noise means "undesirable or harmful noises caused by human activities in the open air, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and noise from areas industrial activity". Exposure to environmental noise is therefore associated with an increased risk of negative physical and psychological health effects and deterioration of the well-being of many people not only in Poland but also in Europe (Hänninen et al., 2014; WHO, 2011; 2018). According to the reports of the European Agenda of the World Health Organization (WHO), it is estimated that approximately 40% of the population in European Union countries is exposed to noise levels exceeding 55 dB LDN in the "day-night" approach, and over 30% is exposed to noise levels exceeding 55 dB late at night, between 11 p.m. and 7 a.m. (Münzel et al., 2014). The main reason for this is road noise associated with the increase in the number of cars and the increase in road traffic (Brink, 2011; Babisch et al., 2014), of which, on over 60% of the length of national roads and 92% of the length of interregional roads, the noise exceeds 70 dB (Babisch et al., 2008; Sanok et al., 2022; Wang, 2021). The dynamic development of air transport is also of no minor importance to the level of environmental noise (Omlin, Bauer & Brink, 2011; Baudin et al., 2020). Airplanes taking off and landing at a distance of a few to several kilometers from airport borders generate noise up to 100 dB, which is particularly annoying at night and has a degradative effect on the health of people living in the vicinity of airports (Babisch et al., 2009; Correia et al., 2013; Preisendörfer, Herold & Kurz, 2020). Industrial noise is less important than the two previously mentioned sources of environmental noise, but the scale of this phenomenon depends on the region and voivodship. Reports of the Chief Inspector of Environmental Protection (Chacińska et al., 2018; 2020) show that the inhabitants of industrialized provinces are the most exposed to industrial noise, which is confirmed by publications of scientists from around the world (Kerketta et al., 2011; Ibraev et al., 2016; Lutyński, 2016). The average noise in the vicinity of industrial plants and construction sites ranges from 50 to 90 dB and is associated with such industries as the automotive industry (Mohammadi et al., 2019), textile industry (Shabani et al., 2020), machine industry (Vardhan, Karmakar & Rao, 2006), metallurgy (Kerketta, Dash & Narayan, 2009), and construction (Ravichandran, Rakesh Sharma & Alagappa Moses, 2012). However, the most burdensome for residents are plants extracting mineral and rock resources, which, due to the technologies used and size, generate noise with high acoustic power 24 hours a day (Kisku et al., 2002; Castilla-Gomez, Herrera-Herbert & Qinglong, 2014; Biały et al., 2020) often exceeding the value of 90 dB (Lutyński, 2017a; 2017b; Biały, Bołoz & Sitko, 2021; Mocek, 2022b).

Due to the scale of environmental noise throughout Europe, a dynamic development of research on the impact of noise on humans, coordinated by the WHO, has been observed since the 1990s. Therefore, research on the identification of noise sources and establishing the criteria for its assessment plays an important role here, which allows for effective monitoring of the risk and investigation of ways to reduce it, which is the subject of the research presented in the article.

Characteristics of the research object

The exploitation of hard coal in Poland is a complex and multi-stage process, based mainly on deep mining up to 1200 m. Extraction takes place through at least two vertical shafts (intake and exhaust) through which the output (hard coal and waste rock) is transported for exploitation and hollow walls of faces through a network of mining excavations to the surfaces of coal mechanical processing plants, where, after pre-treatment, enrichment, and sorting, the hard coal is prepared for rail and road transport. The necessary condition for the proper functioning of each underground mine is to provide its active mining excavations with an appropriate amount of fresh air with a chemical composition suitable for human breathing and climatic conditions allowing for safe work. Therefore, hot and humid air containing harmful substances and gases is discharged to the surface because of technological processes and the process of carbon oxidation. The airflow in the mine workings is achieved by means of fans that are built on the surface near the so-called ventilation shafts. Fresh air is brought through the intake shafts to the lowest level and then flows through the mine workings from the bottom to the top. Finally, the used air is discharged outside through the main fans station, where it is forced into the atmosphere (Figure 1). At this point, it is worth mentioning that the ventilation shafts are usually built on the outskirts of the mining area of the mines, several kilometers from its main infrastructure.

Next to the ventilation shafts on the surface are also installations for filling mining excavations with sand to protect surface objects (Figure 2a) and installations for feeding smoke dust serving as a means of fire prevention (Figure 2b).

In addition to the abovementioned processes, the ventilation shafts are loaded and unloaded with materials and equipment needed in the mining process, especially large-size ones, and the transport of mining crews down and up to the surface. All of the above processes are noise-generating processes that may affect the local population living in the vicinity of hard coal mines, especially in the vicinity of the ventilation shaft infrastructure.

To assess the scale of this phenomenon, employees of the Department of Safety Engineering of the Silesian University of Technology, in cooperation with the Central Laboratory for Work Environment Research "Stanisław Bielaszka", have been testing noise emitted by machines and devices of hard coal mines in octave bands between 31.5 and 8000 Hz for over two years to determine the actual exceedances of sound limit values at the workplace and in the environment. These tests were inspired by the results

Figure 1. Main fan station of mine Y

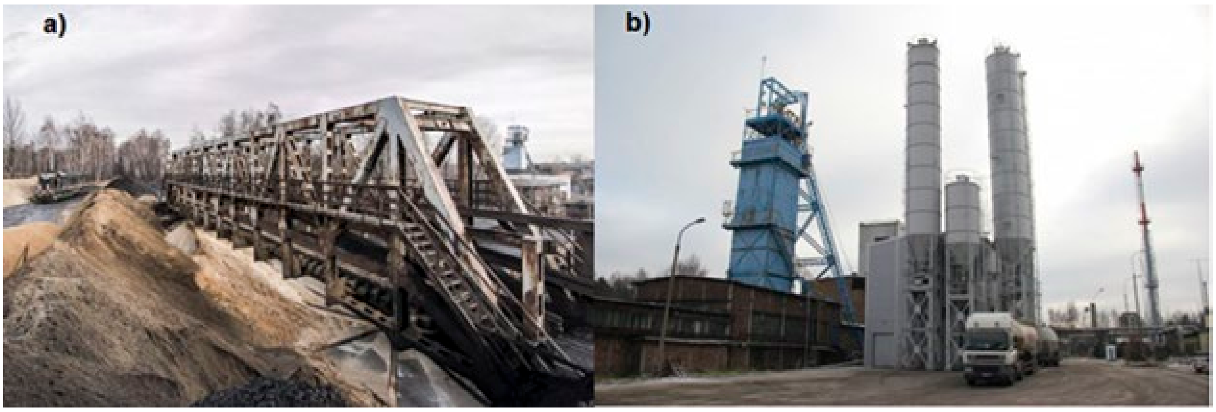

Figure 2. Surface devices located near ventilation shafts: a) filling system, b) a flue dust feeding system

of the hearing screening test carried out between 2018 to 2019 in cooperation with the company ACS Skutmed Sp. z o.o. from Lublin on a group of 3265 active and former employees of Silesian and Malopolska mines, which confirmed the negative impact of industrial noise generated by mines and mining plants on the hearing of an average miner and the scale of this phenomenon.

Methodology of the conducted research

Measurement conditions and test apparatus

All acoustic measurements were carried out using the Sonopan DSA-50 integrating sound level meter (serial number 545/2019, calibration certificate No. L3.55.2019.01; 18/02/2019), which allows measurement in octave bands, the Sonopan KA-50 acoustic calibrator No. 108/06 with (current calibration certificate No. L3.43.2019.05; 02/11/2019), the LB-706B/LB-701 thermohigrobarometer (serial number 657/3069, calibration certificate No. 42424/2016, 12/02/2016), and a vane anemometer with a CHY 361 probe (serial number 080396, probe No. 081139, calibration certificate No. 228/A/15, 13/04/2015). During the measurements, depending on the time of night and day, the wind speed ranged from 0 to 3.2 m/s, the temperature from 12.0 to 22.0°C, air humidity from 73.6% to 78.2%, and pressure from 1100 to 1112 hPa.

Normative restrictions

In accordance with the Regulation of the Minister of the Environment of 14.07.2007 on permissible noise levels in the environment (Journal of Laws 2007, No. 120, item 826), as amended (Journal of Laws 2012, item 1109), the permissible noise level, expressed equivalent sound level A, is respectively:

- for single-family housing development areas
  - 50 dB during the daytime, from 6:00 a.m. to 10:00 p.m.,
  - 40 dB at night, from 10:00 p.m. to 6:00 a.m.,
- for residential and service and farm development areas, areas for multi-family housing and collective housing, areas in the downtown area of cities with over 100,000 residents
  - 55 dB during the daytime, from 6 a.m. to 10 p.m.,
  - 45 dB at night, from 10 p.m. to 6 a.m.

Industrial, production, and storage areas are not acoustically protected areas.

When calculating the normative values, it should be remembered that for industrial noise the reference time is $T = 8$ consecutive hours of the daytime (e.g., from 7 a.m. to 3 p.m. $\Rightarrow T = 480$ min = 28,800 seconds); $T = 1$ most unfavorable hour of the night (i.e., between 10 p.m. and 6 a.m. $\Rightarrow T = 60$ min = 3600 seconds).

Noise measurement by sampling method

The high volume of traffic around the studied objects of the main fan stations of selected hard coal mines between 6:00 a.m. and 10:00 p.m. and the occurrence of numerous additional noise sources generated by other facilities, including neighboring industrial plants, made it difficult to verify noise sources in continuous measurement during reference time *T*.

Measurements of noise resulting from the operation of machines, devices, and installations of the surface part of hard coal mines were also made on the basis of the “Reference methodology of periodic measurements of ambient noise from installations or devices, except impulse noise” constituting Annex 7 to the Regulation of the Minister of Climate and Environment of 7 September, 2021 on requirements for emission measurements’ (Regulation, 2021). The measurements were performed using the sampling method (registration of elementary noise samples at reference time T). The average noise level LA was calculated on the basis of elementary noise samples from formula (1):

$$L_{A\text{av}} = 10\log\left(\frac{1}{n}\sum_{k=1}^{n}10^{0.1L_{Ak}}\right) \text{ [dB]} \qquad (1)$$

where:

n – number of samples in the measurement series,

L_{Ak} – measured sound level over time t_o (noise sample measurement result) [dB].

The noise emission level $L_{A\text{eq}}$ was obtained by subtracting from the average level value given by formula (1), the acoustic background level value, according to formula (2):

$$L_{A\text{eq}} = 10\log\left(10^{0.1L_{A\text{av}}} - 10^{0.1L_{At}}\right) \text{ [dB]} \qquad (2)$$

where:

$L_{A\text{av}}$ – the average sound level A for the period t_p or the average sound level for the source [dB],

L_{At} – the average A-level of the background noise [dB],

The noise level at the measuring point, expressed in A-weighted sound level for the reference time T ($L_{A\text{eq},T}$), was calculated from formula (3):

$$L_{A\text{eq},T} = 10\log\left(\frac{1}{T}\sum_{j=1}^{m}t_j 10^{0.1L_{A\text{eq}\,j}}\right) \text{ [dB]} \qquad (3)$$

where:

m – number of time slots t_p or number of sources measured,

$L_{A\text{eq}\,j}$ – level of $L_{A\text{eq}}$ for j-th time interval t_p or j-th source [dB],

t_j – duration of the j-th time interval t_p or work time of the j-th source [min],

T – reference time [min], where: for the daytime (6:00 a.m. to 10:00 p.m.) T = 480 minutes, for the nighttime (10:00 p.m. to 6:00 p.m.) T = 60 minutes.

The value of $L_{A\text{eq},T}$ calculated in accordance with formula (3) corresponds to the value of the noise index $L_{A\text{eq},D}$ and/or $L_{A\text{eq},N}$. If the measuring point is located at the facade of the building, at a distance of 0.5 to 2 m from a closed or tilted window, the test result is reduced by 3 dB.

The adopted research method allowed the elimination of sources of password generated by other objects. In turn, the acoustic background used in measurements due to the inability to turn on mining machines and management operating in a round-the-clock rhythm was determined on the basis of the measurement and calculation method (actual measurements of the working installation) in accordance with the Regulation of the Minister of the Environment of 14 June 2007 on permissible noise levels in the environment. In addition, the measurement points of the acoustic background were established in the acoustic shadow of residential buildings where the impact of noise generated by mining installations is omitted, and the acoustic background includes noise from traffic, natural sources, and other nearby industrial installations not related to the tested object.

Description of how to determine the measurement uncertainty

The tests assumed the expanded uncertainty for the noise test result for a 95% confidence level and contains the following:

- an estimation of the B-type standard uncertainty – the equipment used to measure the sound level, that considers the information on the uncertainty/limit errors of the measuring instruments declared by the manufacturer, compliance with the requirements of PN-EN 61672-1 (PKN, 2014), calibration results, metrological requirements, and impact of environmental conditions;
- an estimation of the A-type standard uncertainty – based on a series of elementary measurements (noise samples).

Results and discussion

Three hard coal mines located in the Śląskie Voivodeship, whose ventilation shafts are located in the vicinity of municipal buildings, were selected to present the results of this article. Due to limitations in the use of proper names, the names of the mines for the purposes of this article have been hidden under the designations X, Y, Z.

To identify the most important sources of noise emitted by the noise-generating processes of selected hard coal mines to the external environment, a number of activities were carried out to enable the proper implementation of the research:

- conducting a local inspection of the area of selected hard coal mines, where the research area and the range of noise limit values in the acoustically protected areas around the mine were determined;
- determination of representative control points in acoustically protected areas around the mine enabling the performance of control measurements of the A sound level;

- an inventory of the main noise sources in the mines, combined with the measurements of their acoustic emissions;
- determining the range of acoustic impact of mines in areas with residential buildings;
- indication of noise sources in the mines responsible for exceeding the limit values at the observed control points.

After conducting an on-site visit, three mines with similar infrastructure and location in relation to residential buildings were selected for research to compare the results of environmental noise measurements. In the main plant of these mines, the same main sources of noise were selected for comparison purposes:

- preparation plant,
- mining, downhill, and material shafts,
- conveyor belts transporting coal to the preparation plant,
- a railway siding intended for loading coal,
- place of coal storage.

Example results of acoustic measurements of the main noise sources located in the facilities of the surface part of mines are presented in Table 1. The measurement was made using the DSA-50 digital sound analyzer from Sonopan (serial number 545/2019) operating in a 24-hour system due to the built-in internal battery. External batteries compatible with the meter were also used as a backup power source. The analyzer, due to the use of 9 digital

Table 1. Examples of noise sources located at the ventilation shafts of mines X, Y, Z

No.	Mine plant	Noise source	Average sound pressure L_A [dB]									
			L_{Aeq}	31.5	63	125	260	500	1000	2000	4000	8000
1.	X	Diffuser	91.1	59.3	64.8	67.7	71.7	78.9	86.1	87.3	81.5	80.2
	Y		91.4	53.7	62.4	72.8	76.3	83.2	85.4	87.3	82.4	77.3
	Z		91.9	60.3	63.4	72.4	75.4	81.3	86.5	89.1	79.6	74.1
2.	X	Air intake	93.3	51.7	63.5	72.6	82.4	85.7	87.3	88.1	85.5	76.9
	Y		94.8	57.3	65.7	72.6	81.6	84.4	89.2	91.7	83.2	77.2
	Z		94.6	56.1	63.3	71.2	81.1	84.7	88.5	91.1	86.4	75.7
3.	X	Building of the fan station	90.5	53.8	65.3	75.0	77.4	83.2	85.1	85.6	81.2	72.3
	Y		90.7	51.1	53.2	68.3	72.1	84.3	88.1	82.3	77.3	69.9
	Z		91.1	51.4	55.3	64.4	77.5	82.2	89.2	83.1	71.2	58.3
4.	X	Lift	86.0	60.4	68.7	76.7	76.9	81.2	80.3	73.8	73.4	69.5
	Y		86.9	65.2	71.3	75.4	77.4	80.6	83.0	77.8	69.1	62.0
	Z		88.8	60.2	64.8	76.1	80.1	85.6	83.2	74.3	67.5	63.1
5.	X	Gantry	90.3	54.1	63.4	71.5	75.8	82.7	86.4	84.2	80.5	73.2
	Y		89.8	54.3	64.1	73.5	79.8	81.4	85.5	82.4	80.1	77.6
	Z		90.5	58.6	64.5	66.8	70.7	75.9	87.1	83.9	83.5	79.7
6.	X	Hoisting machine	107.5	54.4	57.3	63.4	79.4	88.4	97.3	98.1	102.7	104.0
	Y		106.8	66.1	76.4	85.3	95.2	101.5	102.1	96.6	96.8	97.0
	Z		107.7	58.3	72.2	87.5	97.8	99.1	99.3	99.7	100.9	101.3
7.	X	Surface shaft loading devices	94.5	49.8	53.1	62.0	72.8	84.6	88.1	90.3	88.4	80.0
	Y		92.7	54.1	58.6	63.4	71.6	84.7	90.5	84.2	81.0	73.1
	Z		93.5	48.1	49.1	54.3	71.7	85.6	89.5	87.2	85.1	80.3
8.	X	Filling bridge	96.0	53.4	63.2	81.8	84.7	89.6	92.1	88.7	84.3	71.3
	Y		94.2	53.7	66.6	77.4	81.6	87.3	89.5	89.4	78.3	76.2
	Z		95.6	57.1	60.9	65.8	76.8	88.2	92.5	90.2	80.4	70.8
9.	X	Shunting locomotive	100.1	76.9	79.6	80.8	88.6	92.6	95.2	93.1	90.7	89.7
	Y		100.0	61.5	72.0	76.3	84.4	90.3	96.6	92.4	91.5	89.7
	Z		100.5	63.2	69.1	72.4	77.8	92.5	96.5	93.6	92.1	89.5
10.	X	Equipment of the smoke dust station	92.1	59.2	67.4	74.6	79.4	85.1	87.2	86.1	83.3	75.6
	Y		91.3	55.3	58.4	72.7	76.3	82.6	87.4	86.1	81.2	70.3
	Z		92.3	57.2	64.8	71.2	73.1	80.1	87.7	86.5	86.3	79.1
11.	X	Unloading of dust tanks	93.2	56.1	66.6	75.9	79.3	86.1	87.4	88.2	84.2	77.6
	Y		92.7	59.8	62.1	73.1	71.3	85.3	87.5	87.1	85.0	80.2
	Z		92.2	52.3	53.6	56.1	76.4	82.1	88.3	87.2	83.0	78.4

filters with central frequencies determined according to the octave quotient with base 2 and nominal frequencies: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz, meets the requirements of PN-EN 61260-1:2015-01 for class 1. For each frequency (and for the entire band) it allows simultaneous measurement using one correction characteristic (selected from three available in the device: A, C, Z) of the quantity: L_F – instantaneous effective value using the FAST time constant; L_S – instantaneous effective value using the time constant SLOW, L_{eq} – value equivalent to the sound level. If characteristic A is selected as the correction characteristic, the following are additionally measured: $L_{AS\mathrm{max}}$ – maximum effective value using the time constant SLOW, correction A; $L_{A\mathrm{eq}}$ value equivalent to sound level, A correction. Noise measurement of individual machines and devices is based on the previously described sampling method and the orientation method at the place of operation of the device. The study of the variability of noise parameters in octave bands generated by working mining machines and equipment testifying to the degree of their wear and deterioration of acoustic conditions at individual workplaces are the subject of other publications by the author (Mocek, 2020; 2022a).

Characteristics of the mine ventilation shaft environment X

1. Type of development:
- to the west of the mine, there are multi-family housing developments and areas for residential and service development;
- to the east of the dump site, there are single-family and multi-family housing developments as well as residential and service development areas;
- to the north, there are multi-family residential buildings and service points;
- to the south, in the immediate vicinity of the mine, there are industrial plants: a producer of foundry and blast furnace coke, and a producer of stone wool insulation materials.

2. Estimated distance of the first building line from the mine boundary:
   - westwards approx. 10 m;
   - eastwards approx. 120 m;
   - towards the north approx. 20 m;
   - southwards approx. 250 m.
3. Estimated height of the first building line or the number of stories:
   - from the east, west, and north – 4 stories.
4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:
   - the slope of the railway embankment on the eastern side;
   - on the north side, buildings of a producer of stone wool insulation materials and a producer of foundry coke.
5. Measurement points.

Noise measurements in the external environment of mine X were carried out at 10 measuring points located in the vicinity of single- and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are shown on the situational plan in Figure 3, and their coordinates and the results of measurements carried out during the day and at night are shown in Table 2.

Figure 3. Location of measuring points around mine X

Table 2. Example results of measurements of the noise emission level within the ventilation shaft of mine X

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (dd°mm'ss.s")	Longitude (dd°mm'ss.s")	Day [dB]	Night [dB]
P1	N: 50°21'23.2"	E: 18°55'57.5"	63.2	55.6
P2	N: 50°21'21.7"	E: 18°55'56.8"	65.4	57.7
P3	N: 50°21'19.5"	E: 18°55'56.0"	66.3	56.7
P4	N: 50°21'17.2"	E: 18°55'55.3"	64.2	55.3
P5	N: 50°21'16.4"	E: 18°55'54.9"	62.6	51.4
P6	N: 50°21'14.6"	E: 18°55'54.4"	60.5	47.4
P7	N: 50°21'22.0"	E: 18°55'55.1"	62.6	50.1
P8	N: 50°21'18.7"	E: 18°55'54.1"	65.3	52.6
P9	N: 50°21'16.8"	E: 18°55'53.4"	58.2	48.2
P10	N: 50°21'17.0"	E: 18°55'51.4"	56.1	46.0
P Background	N: 50°21'19.7"	E: 18°55'50.0"	54.6	44.8

All measurement points were located above the ground level at a height of 18 m in the vicinity of multi-family buildings and at a height of 4 m in the vicinity of a single-family residential building

Characteristics of the environment of the ventilation shaft of mine Y

1. Type of development:
   - towards the west from the area of the ventilation shaft of mine Y, there are single and multi-family residential buildings as well as residential and service development areas;
   - to the east from the area of the ventilation shaft of mine Y, there is a coal storage facility and individual single-family buildings;
   - towards the north, there are multi-family buildings, a poultry farm, and industrial plants: metal structures and machines for the production of candles;
   - towards the south, there are single-family houses and residential and service buildings.
2. Estimated distance of the first building line from the border of the mine site:
   - westwards approx. 20 m;
   - eastwards approx. 300 m;
   - northwards approx. 250 m;
   - southwards approx. 40 m.
3. Estimated height of the first building line or the number of stories:
   - on the west side – 4 floors;
   - from the east and south – 2 floors.
4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:
   - on the eastern and northern sides, there is a small strip of trees.
5. Measurement points.

Noise measurements in the external environment of mine Y were carried out at 10 measuring points located in the vicinity of only residential and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are shown on the situational plan in Figure 4, and their coordinates and the results of measurements carried out during the day and at night are shown in Table 3.

Characteristics of the environment of the ventilation shaft of mine Z

1. Type of development:
   - towards the west, there are single-family and multi-family housing developments, as well as residential and service development areas;
   - to the east of the ventilation shaft of mine Z, there are single-family residential development areas and a complex of allotment gardens;
   - towards the north, there is a housing cooperative and single-family housing development;
   - towards the south, there is a single-family and multi-family housing development, with a predominance of multi-family housing with service points.
2. Estimated distance of the first building line from the mine boundary:
   - westwards approx. 250 m;
   - eastwards approx. 10 m;
   - northwards approx. 20 m;
   - southwards approx. 20 m.
3. Estimated height of the first building line or the number of stories:
   - from the north, east, and west – 2 floors;
   - on the south side – 5 floors.

Figure 4. Location of measuring points around the fan station of mine Y

Table 3. Sample results of measurements of the noise emission level within the ventilation shaft of mine Y

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (dd°mm'ss.s")	Longitude (dd°mm'ss.s")	Day [dB]	Night [dB]
P1	N: 50°16'52.9"	E: 18°49'28.7"	61.1	51.2
P2	N: 50°16'53.0"	E: 18°49'27.6"	62.4	52.4
P3	N: 50°16'54.1"	E: 18°49'19.9"	57.3	49.0
P4	N: 50°16'56.3"	E: 18°49'20.7"	62.6	52.3
P5	N: 50°16'58.0"	E: 18°49'20.6"	60.3	50.4
P6	N: 50°17'00.6"	E: 18°49'20.8"	61.4	51.7
P7	N: 50°17'01.9"	E: 18°49'20.5"	60.2	51.0
P8	N: 50°17'01.6"	E: 18°49'18.8"	58.5	49.3
P9	N: 50°16'58.2"	E: 18°49'19.1"	59.8	50.4
P10	N: 50°16'54.9"	E: 18°49'18.0"	56.3	48.5
P Background	N: 50°16'58.7"	E: 18°49'14.1"	55.0	51.2

All measurement points were situated above the ground level, at a height of 4 m in the vicinity of a residential building and 18 m in the vicinity of multi-family buildings

4. Objects reflecting acoustic waves in the vicinity of the source and the measuring point:
   - on the eastern side, this object is a cemetery;
   - on the west, north, and south sides, there are no objects reflecting the waves.
5. Measurement points.

Measurements of noise in the external environment of mine Z were carried out at 10 measuring points located in the vicinity of only residential and multi-family residential buildings most exposed to mine noise. The locations of selected measurement points are shown on the situational plan in Figure 5, and their coordinates and the results of measurements carried out during the day and at night are shown in Table 4.

Sample calculation results

Due to the size of the computational data, the article presents the measurement results of the tests for mine X made in June 2021 at day and night for four sample measurement points (Table 5). Before taking individual measurements, the measuring instruments were calibrated. The calibration correction for measurements during the daytime was 0.1 dB, and for measurements at night – 0.0 dB.

Figure 5. Location of measurement points around the ventilation shaft of mine Z

Table 4. Examples of measurement results of the noise emission level within the ventilation shaft of mine Z

Marking the measuring point	Geographical coordinates		Noise emission level L_{Aeq}	
	Latitude (dd°mm'ss.s")	Longitude (dd°mm'ss.s")	Day [dB]	Night [dB]
P1	N: 50°12'05.3"	E: 18°58'43.9"	54.6	43.3
P2	N: 50°12'04.6"	E: 18°58'44.9"	53.3	39.8
P3	N: 50°12'03.4"	E: 18°58'46.5"	52.2	39.6
P4	N: 50°12'02.6"	E: 18°58'46.6"	52.3	39.2
P5	N: 50°12'02.1"	E: 18°58'43.8"	54.2	40.0
P6	N: 50°11'58.9"	E: 18°58'45.8"	54.3	44.3
P7	N: 50°11'58.0"	E: 18°58'43.0"	50.0	43.8
P8	N: 50°11'58.1"	E: 18°58'40.3"	49.8	40.0
P9	N: 50°11'57.8"	E: 18°58'37.8"	52.3	39.6
P10	N: 50°11'58.8"	E: 18°58'33.3"	50.6	43.3
P Background	N: 50°11'57.3"	E: 18°58'44.9"	49.5	39.6

All measurement points were located above the level of the area at a height of 4 m in the vicinity of a residential building and 18 m in multi-family buildings

Final statement of results

Determination of the A-weighted sound level for the reference time T in terms of the noise index L_{AeqD} or L_{AeqN}, together with the measurement uncertainty (expanded uncertainty estimated for the confidence level of 95% (U_{95}). The results are summarized in Table 6.

The analysis of the obtained measurement results (Tables 2, 3, and 4) showed that the devices installed on the ventilation shafts of mines, as well as the technological processes taking place around them, emit noise to the outside environment more than the permissible values at day and night. The highest noise level in residential buildings is found in single and multi-family buildings grouped around the ventilation shaft of mine X. The maximum noise levels during the day and night are over 16 dB for single-family housing and over 12 dB for multi-family housing. This is due to the very close vicinity of residential buildings in relation to the area of the ventilation shaft (approx. 20 m), but also the lack of adequate infrastructure to suppress noise emitted by mining machinery and equipment installed on the ventilation shaft of mine X. The equivalent A-sound level generated by them, as shown by the results in Table 1, often exceeds the value of 90 or even 100 dB. On the surface structures of the ventilation

Table 5. Examples of measurement results for the area of the ventilation shaft of mine X

Interval t_p or the source name	The measured sound level of the sample L_{Ak} [dB]	Sample measurement time t_o [s]	Average A-sound level for the t_p or source interval $L_{Aśr}$ [dB]	The average background noise level L_{At} [dB]	Noise emission level L_{Aek} [dB]	Duration of the interval t_p or source runtime t_j [s]
P1 Technological processes in the area of the ventilation shaft (undetermined noise)	Daytime measurement results from 5:00 p.m. to 6:00 p.m.					
	63.6	300	64.3	54.6	63.2	28800
	64.8	300				
	64.1	300				
	65.2	300				
	63.8	300				
	Nighttime measurement results from 10:00 p.m. to 11:00 p.m.					
	55.2	300	56.2	44.8	55.6	3600
	56.5	300				
	55.8	300				
	57.1	300				
	56.6	300				
P2 Technological processes in the area of the ventilation shaft (undetermined noise)	Daytime measurement results from 6:00 p.m. to 7:00 p.m.					
	66.6	300	66.2	55.4	65.4	2888
	66.2	300				
	65.9	300				
	66.8	300				
	65.7	300				
	Nighttime measurement results from 10:10 p.m. to 11:55 p.m.					
	58.6	300	58.1	48.5	57.7	3600
	57.9	300				
	57.5	300				
	58.7	300				
	57.8	300				
P3 Technological processes in the area of the ventilation shaft (undetermined noise)	Daytime measurement results from 7:10 p.m. to 8:00 p.m.					
	67.8	300	67.8	57.4	66.3	28800
	68.3	300				
	68.1	300				
	67.5	300				
	67.2	300				
	Nighttime measurement results from 00:10 a.m. to 1:00 a.m.					
	57.3	300	57.1	49.3	56.7	3600
	56.9	300				
	56.5	300				
	57.6	300				
	57.3	300				
P4 Technological processes in the area of the ventilation shaft (undetermined noise)	Daytime measurement results from 8:10 p.m. to 9:00 p.m.					
	66.4	300	65.9	55.3	64.2	28800
	65.2	300				
	66.0	300				
	66.2	300				
	65.5	300				
	Nighttime measurement results from 1:10 a.m. to 2:00 a.m.					
	56.9	300	56.2	46.2	55.3	3600
	55.4	300				
	56.8	300				
	55.6	300				
	56.7	300				

Table 6. Determined equivalent sound level A for reference time *T*, mine X

Measurement point number		A-weighted sound level value for reference time *T*, expressed as a noise index [dB]	A-weighted sound level value for reference time *T*, in terms of the corrected noise index [dB]	Measurement uncertainty U_{95} [dB]	
				symbol	value
P1	$L_{Aeq,D}$	63.2	61.6	U_{95}	1.6
	$L_{Aeq,N}$	55.6	54.0	U_{95}	1.6
P2	$L_{Aeq,D}$	65.4	63.8	U_{95}	1.6
	$L_{Aeq,N}$	57.7	56.1	U_{95}	1.6
P3	$L_{Aeq,D}$	66.3	64.7	U_{95}	1.6
	$L_{Aeq,N}$	56.7	55.1	U_{95}	1.6
P4	$L_{Aeq,D}$	64.2	62.6	U_{95}	1.6
	$L_{Aeq,N}$	55.3	53.7	U_{95}	1.6

shaft of mine X, leaks can be observed in the building of the main fans station and air intake. The gates and doors of the headroom rooms are also leaky, causing a characteristic whistling or humming. The process of backfilling mining excavations and feeding smoke ashes uses compressed air devices, the operation of which causes large losses of air under pressure when emptying road tankers and is characterized by loud noise. No less noise occurs when loading and unloading the material needed for mining operations. It is worth adding here that the infrastructure of mine X's ventilation shaft is largely old and worn out. However, this fact cannot explain the undesirable noise pollution in the immediate vicinity of mine X.

In the case of the ventilation shaft of mine Y, there are also reactions to the very close vicinity of multi-family residential buildings adjacent to the mine site. The noise level identified, however, is much less burdensome than in the ventilation shaft of mine X. The maximum noise levels for day and nighttime are slightly over 7 dB. This effect was achieved thanks to the modernization of the main fan station in 2006 and the elimination of the noise nuisance associated with the old main fan station. The current increased noise level is related to the operation of the second material and descent shaft around the ventilation shaft of mine Y and the process of feeding smoke dust to mine workings as a means of combating the fire hazard.

The ventilation shaft of mine Z is an example of appropriate actions in the field of environmental protection against noise pollution. In this intervention by the inhabitants and the Provincial Inspectorate for Environmental Protection in Katowice, the mine took appropriate measures, including construction of noise barriers along the shaft fence; planting a compact green belt; eliminating leaks in the building of the headroom and the fan station; building new silencers for the main fans. As a result, excessive night-time noise has been eliminated, and in the daytime the noise applies only to single-family buildings directly adjacent to the mine site.

Conclusions

As shown by the results of noise measurements for residential buildings located within the ventilation shafts of three hard coal mines, industrial noise generated by the main ventilator station as well as technological processes within the abovementioned shafts affect the inhabitants every day of their lives. The scale of this phenomenon depends on the degree of wear and tear of the equipment and machinery in the mine and the awareness of the risks involved.

Entrepreneurs, however, are reluctant to spend their funds on pro-ecological behavior, limiting their expenses in this area to ensure the necessary minimum according to the applicable legal acts.

Industrial noise, although it is a factor polluting the external environment, does not currently require the entrepreneur to obtain a separate administrative decision or an emission permit. Apart from the few cases related to the need to obtain an integrated permit for the installations operated in the enterprise, the aspect of the enterprise's acoustic impact on the external environment occurs only when planning a new project on the premises of the enterprise. Most often, this aspect is related to the modernization of the existing infrastructure, the expansion of the plant, or the construction of new facilities or installations.

The majority of industrial enterprises, whose technological processes generate excessive noise, still treat noise emitted to the environment and noise at the workplace separately, paying more attention to the latter. Meanwhile, research conducted by employees of the Department of Safety Engineering at the Silesian University of Technology shows that the sources of excessive noise are the same and their elimination will contribute to reducing the risk not only to employees but also to residents. Therefore, greater attention should be focused not on looking for improved measures to protect against noise but on solutions that enable its reduction.

The first step to improving the current situation is to create systems that allow for continuous monitoring of noise produced by mining machinery, equipment, and technological processes. This will not only increase the awareness of the hazard itself but also enable ongoing control and supervision of the efficiency of these devices and identify any irregularities. The second step of an effective fight against excessive noise is to identify the sources of noise, learn its causes, and eliminate or reduce the existing threat by replacing the machinery park or structural elements of devices that generate excessive noise. The third step of an effective fight against excessive noise is the economic calculation. With the current high energy prices, investing in the modernization of large-scale mining machinery and equipment to replace energy-consuming, obsolete high-power drive units that generate excessive noise simply pays off. These cost savings can in some cases even pay for themselves within a year. Given these observations and the results of the described research, the employees of the Silesian University of Technology in Gliwice continue to work on the creation of a permanent noise monitoring system in the mining plants and the constructional silencing of noisy elements of mining machines and devices, which will be presented in subsequent publications.

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