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ENVIRONMENTAL NOISE IN THE VICINITY OF THE BREWERY - A CASE STUDY

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Abstract. *Industrial plants can noticeably affect environmental noise pollution. In addition to the noise generated by industrial processes, vehicles used for transporting raw materials and finished products represent a significant noise source. As production capacity increases, particularly in the case of modern factories that evolved from traditional family manufactories, the problem becomes more pronounced within the existing infrastructure. This paper specifically analyzes environmental noise in the immediate vicinity of a brewery, located in the central part of one city in Serbia. Through analysis of noise monitoring results, certain machines and processes within the brewery that significantly impact environmental noise indicator values were identified. Accordingly, recommendations were provided for implementing appropriate measures within the brewery aimed at enhancing acoustic comfort in the surrounding environment near the brewery. Environmental noise measurements were repeated after the acoustic treatment of the dominant noise source in the brewery, after which the effect of the measures taken in terms of reducing the noise levels in the immediate vicinity of the source was examined.*

Key words: *industrial noise, environmental noise monitoring, environmental noise indicators, environmental noise limit values*

1. INTRODUCTION

Life in cities often takes place under conditions of compromised environmental quality, primarily characterized by polluted air and noise [1,2]. The consequence of living in noisy environments can be impaired health in multiple segments, considering the confirmed

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physiological and psychological impact of noise [3]. Noise may lead to sleep disturbance, annoyance, anxiety, hearing damage, and stress-related cardiovascular problems [4].

The primary source of noise in cities is certainly noise traffic [5]. However, due to poor urban planning, it sometimes happens that residential buildings are located in close proximity to industrial facilities (factories, heating plants, etc.), making industry the primary source of noise in such situations [6]. The overall noise levels in such environments are further exacerbated by the transport of raw materials and products, which involves the use of large trucks or trains.

European Noise Directive (END) [7] serves as the basis for noise management in the environment within EU member states. To describe environmental noise, in accordance with the END, noise indicators are used that are associated with its harmful effects on public health.

The assessment of environmental noise from individual sources or any combination of sources is performed based on the guidelines provided in the ISO 1996-1 standard [8]. In situations where specific noise is present, the primary metric used to describe the noise is the rating equivalent continuous sound pressure level, $L_{\mathrm{Req},T}$, in dB (hereinafter referred to as the rating noise level) [8]. The limit values for noise levels are set by the competent authorities based on knowledge of the impact of noise on human health [9]. These limits are influenced by the time of the day (day, evening, or night), the type of living space (open or closed space), the type of human activities carried out within the given space, the type of noise source, as well as the potential for new situations within existing circumstances. Procedures for verifying compliance with regulations can be based either on calculations from sound prediction models or on measurements.

Standard ISO 1996-2 [10] contains guidelines for determining sound pressure levels that are intended as a basis for assessing environmental noise. The standard can be applied to all types of environmental noise sources, such as road and rail traffic noise, aircraft noise and industrial noise.

Addressing the problem of noise in residential areas caused by nearby industrial facilities, without the presence of a buffer zone between areas with significantly different noise indicator limit values, often represents a serious engineering challenge. The generally accepted approach to solving this type of problem is based on taking measures primarily at the noise source itself (enclosing the source, replacing the existing source, or changing the operating mode of the source if possible), taking measures on the noise transmission paths from the source to the receiver (installing noise barriers), or taking measures at the receiver location itself (improving the acoustic characteristics of the façade and windows of the affected building) [11-15].

The paper presents the results of research on the impact of industrial noise from a brewery in Serbia on the surrounding environment. The reason for the research is the complaints from residents about the increasing noise from the brewery, which is a result of the continuous increase in production capacities, as well as the introduction of new products according to market demands, which requires the installation of new technologies and machines that further burden the environment with noise. The objectives of the research are: 1) to identify the noise sources in the brewery that affect the noise levels in the environment, 2) to examine the compliance of the existing noise levels with the environmental noise limit values, and 3) to verify the effectiveness of the technical measures taken to reduce noise in the brewery by examining the compliance of noise levels after the measures were implemented with the environmental noise limit values.

2. METHODOLOGY

2.1. Location and description of noise sources

The brewery is located in the central area of the city and borders a residential area on one side (Fig. 1).

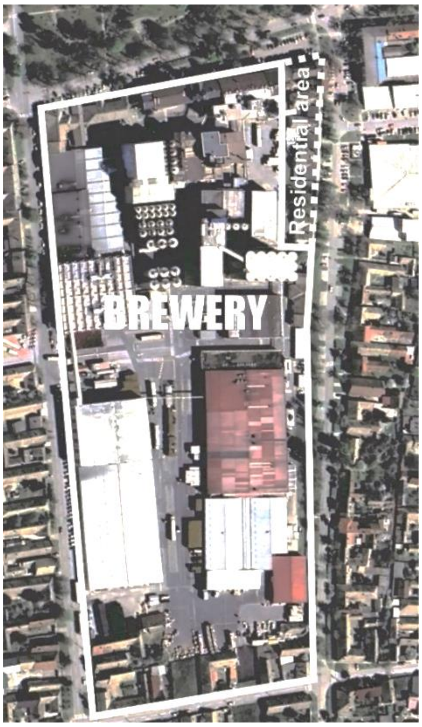

Fig. 1 Locations of the brewery and residential area in the immediate vicinity of the brewery (Source: Google Earth)

In the immediate vicinity of the residential buildings marked in Fig. 1, noise sources have been identified within the brewery that significantly impact the noise levels in the residential area (Tab. 1).

Table 1 Noise sources in the brewery that affect the environmental noise levels

No.	Brewery noise source
1.	Cogenerator
2.	Compressor station
3.	Old system for pneumatic malt transport
4.	New system for pneumatic malt transport
5.	Spent hops transport system
6.	Fermentation plant
7.	Tankers for corn grits unloading

The locations of the mentioned noise sources in the brewery (Tab. 1) are shown in Fig. 2.

Fig. 2 Locations of noise sources in the brewery (positions 1 ÷ 7); Locations of areas in the environment affected by noise from the brewery (A and B); Locations of measurement points MP1 ÷ MP4 (Source: Google Earth)

2.2. Noise measurement conditions

Noise measurements were conducted for two situations with characteristics described below. The reason for applying different noise measurement techniques in situations 1 and 2 lies in the fact that the measurement results in the first case (situation 1) showed exceedances of noise indicator limit values during the night period, but without the possibility of precise identification of the noise sources and processes causing it.

Situation 1:

- Normal daily execution of all work activities in the brewery (technological and transport) continuously for 24 hours, in operating modes of the plants (Tab. 1) dictated by the production process;
- No restriction on the operating time (stopping) of certain processes and plants in the brewery during noise-sensitive periods of the day;
- No measures taken to reduce the noise produced by the brewery's processes and plants in the environment;
- At measurement points MP1 and MP2 (Fig. 2), due to the mutual positioning of buildings, roads and the measurement points themselves, no audible noise sources unrelated to the brewery (road traffic and other communal activities) are registered;
- Simultaneous 24-hour continuous automated unattended noise measurement at two locations in the open space within the brewery (measurement points MP1 and MP2 – Fig. 2), in the immediate vicinity of the areas potentially affected by noise from the brewery (locations A and B in Fig. 2).

Situation 2:

- Scheduled execution of certain technological activities in the brewery over 24 hours, in operating modes dictated by the production process;
- No operation of the cogenerator during the reference night time interval, 22:00 ÷ 06:00 (Tab. 3);
- A sound barrier installed in front of the brewery's cogenerator;

- At measurement points MP3 and MP4 (Fig. 2), due to the mutual positioning of buildings, roads and the measurement points themselves, no audible noise sources unrelated to the brewery (road traffic and other communal activities) are registered;
- Series of short-term environmental noise measurements in the open space (measurement points MP3 and MP4 – Fig. 2), for different combinations of simultaneous operation of certain plants and processes listed in Tab. 1, during the reference time intervals.

Based on the defined operational times of individual noise sources and the specific technological production process in the brewery, possible operating modes of plant equipment (noise sources) during a four-hour brewing cycle for day and evening (Tab. 2) and for night (Tab. 3) have been defined for situation 2. Each mode includes four different combinations of active noise sources.

Table 2 Operating modes of noise sources in the brewery during one production cycle for day and evening

Mode	Combination of active sources	Mark of active noise sources (Tab. 1)						
		1	2	3	4	5	6	7
Normal day-evening mode	DE/C1	✓	✓				✓	
	DE/C2	✓	✓	✓			✓	
	DE/C3	✓	✓			✓	✓	
	DE/C4	✓	✓	✓		✓	✓	
Reserve day-evening mode	DE/C1	✓	✓				✓	
	DE/C2.1	✓	✓		✓		✓	
	DE/C3	✓	✓			✓	✓	
	DE/C4.1	✓	✓		✓	✓	✓	
Normal day-evening mode + Tankers for corn grits unloading	DE/C1	✓	✓				✓	
	DE/C2.2	✓	✓	✓			✓	✓
	DE/C3	✓	✓			✓	✓	
	DE/C4	✓	✓	✓		✓	✓	

Table 3 Operating modes of noise sources in the brewery during one production cycle for night

Mode	Combination of active sources	Mark of active noise sources (Tab. 1)						
		1	2	3	4	5	6	7
Normal night mode	N/C1		✓				✓	
	N/C2		✓	✓			✓	
	N/C3		✓			✓	✓	
	N/C4		✓	✓		✓	✓	
Reserve night mode	N/C1		✓				✓	
	N/C2.1		✓		✓		✓	
	N/C3		✓			✓	✓	
	N/C4.1		✓		✓	✓	✓	

The choice of short-term measurement strategy is motivated by the need to determine the noise levels generated in the environment during various operating modes of noise sources in the brewery and to identify the loudest events. This information is essential for implementing technical and organizational measures aimed at reducing environmental noise pollution from the brewery. The main difference between the day-evening modes and night modes (Tab. 2 and 3) is that the cogenerator is only used during the day and evening.

This operational schedule of the cogenerator results from decisions made by the brewery authorities after analyzing the measurement results for situation 1.

The normal mode and reserve mode (Tab. 2 and 3) differ in their use of different systems for pneumatic malt transport. In situations where there is an issue with the operation of the old system for pneumatic malt transport in the normal mode, typically due to pipe blockages, the brewery switches to the reserve mode and utilizes the new system for pneumatic malt transport. The new system is used until the old system is restored to normal functioning.

2.3. Noise measurements results

For noise measurements, Brüel&Kjær Hand-held Analyzer Type 2250D and Brüel&Kjær Hand-held Analyzer Type 2250-S-G4 were used. Utility Software for Hand-held Analyzers BZ 5503 was used for processing and managing the measurement results.

Situation 1:

Figure 3 shows the noise measurement results at measurement points MP1 and MP2 for situation 1, represented as 15-minute values of equivalent continuous sound pressure levels (hereinafter referred to as equivalent noise levels). The noise measurements included records of active noise sources, which are also depicted in Fig. 3.

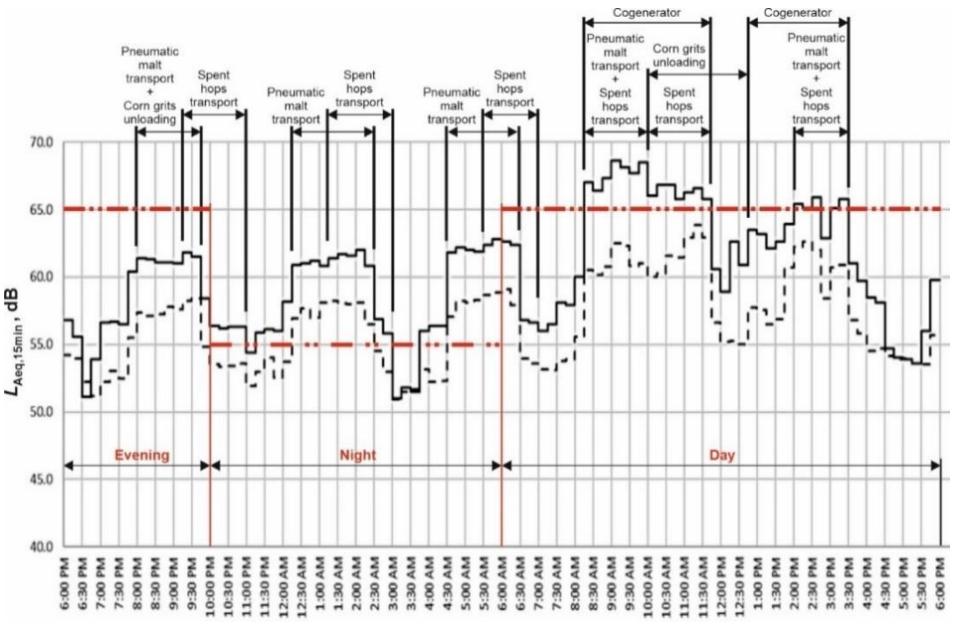

Fig. 3 15-minute values of equivalent noise levels, $L_{Aeq,15min.}$ in dB, at MP1 (solid line) and MP2 (dashed line), noise indicator limit values for day, evening and night (dash-dot line), along with records of the operation of different noise sources during measurements

The measurement results at measurement points MP1 and MP2 were considered as if these points belonged to the environment, because noise at the boundary of any zone must not exceed the noise indicator limit values for the zone it borders.

Situation 2:

The results of noise level measurements at measuring points MP3 and MP4 during the reference time intervals of day, evening and night are shown in Tab. 4.

Table 4 The average values of equivalent noise levels, $L_{Aeq,5min.}$ in dB, at MP3 and MP4 for different combinations of active noise sources in the brewery

Reference time interval	Combination of active noise sources (Tabs. 2 and 3)	$L_{Aeq,5min.}$	
		MP3	MP4
Day / Evening	DE/C1	55.1 dB	58.1 dB
	DE/C2	60.2 dB	60.7 dB
	DE/C2.1	58.2 dB	56.9 dB
	DE/C2.2	60.2 dB	60.7 dB
	DE/C3	58.7 dB	59.2 dB
	DE/C4	60.1 dB	60.2 dB
	DE/C4.1	60.1 dB	60.2 dB
Night	N/C1	49.8 dB	49.3 dB
	N/C2	50.9 dB	54.4 dB
	N/C2.1	53.6 dB	56.7 dB
	N/C3	57.8 dB	58.0 dB
	N/C4	58.6 dB	57.1 dB
	N/C4.1	59.2 dB	60.4 dB

The results represent the energy average values of equivalent noise levels, $L_{Aeq,5min.}$ in dB, obtained based on multiple noise measurements for one combination of active noise sources.

Considering that in the case of all combinations of active noise sources (Tabs. 2 and 3), it is steady noise (noise level changes over time less than 5 dB), a measurement time interval of 5 minutes was used.

2.4. Results of the rating noise levels calculation and noise rating

The purpose of environmental noise measurement is its rating. The rating of environmental noise at the positions of measuring points MP1 ÷ MP4 was performed by comparing the values of rating noise levels with the limit values of environmental noise indicators for the corresponding reference time intervals for the observed acoustic zone [9]. Measurement uncertainty is not taken into account during noise rating.

Situation 1:

According to the measurement technique, the values of rating noise level during the reference time intervals correspond to the rounded values for the day sound level ($L_{day,12h}$), evening sound level ($L_{evening,4h}$), and night sound level ($L_{night,8h}$), which are calculated as energy average values of 15-minute equivalent noise levels during specific reference time intervals (Fig. 3). The calculation results are given in Tabs. 5 and 6.

Table 5 Results of the calculation of rating noise levels and noise rating for MP1

Measurement point:	MP1		
Reference time interval, duration T in h:	Day 06:00 ÷ 18:00 T_d = 12 h	Evening 18:00 ÷ 22:00 T_e = 4 h	Night 22:00 ÷ 06:00 T_n = 8 h
Equivalent noise level:	$L_{day,12h}$ = 64.0 dB	$L_{evening,4h}$ = 59.3 dB	$L_{night,8h}$ = 59.5 dB
Rating noise level:	$L_{Req,12h}$ = 64 dB	$L_{Req,4h}$ = 59 dB	$L_{Req,8h}$ = 60 dB
Noise indicator limit value [9]:	65 dB	65 dB	55 dB
Exceeding the limit value:	-	-	5 dB
Noise rating:	Not exceed	Not exceed	Exceed

Table 6 Results of the calculation of rating noise levels and noise rating for MP2

Measurement point:	MP2		
Reference time interval, duration T in h:	Day 06:00 ÷ 18:00 T = 12 h	Evening 18:00 ÷ 22:00 T = 4 h	Night 22:00 ÷ 06:00 T = 8 h
Equivalent noise level:	$L_{day,12h}$ = 59.2 dB	$L_{evening,4h}$ = 55.8 dB	$L_{night,8h}$ = 56.0 dB
Rating noise level:	$L_{Req,12h}$ = 59 dB	$L_{Req,4h}$ = 56 dB	$L_{Req,8h}$ = 56 dB
Noise indicator limit value [9]:	65 dB	65 dB	55 dB
Exceeding the limit value:	-	-	1 dB
Noise rating:	Not exceed	Not exceed	Exceed

Situation 2:

The values of rating noise levels at the measurement points were calculated based on the duration of the noise of defined combinations of active noise sources (Tabs. 2 and 3) during the reference time intervals, and on the values of equivalent noise levels produced by the combinations of active specific noise sources at the measurement points during the reference time intervals.

As each cycle/mode consists of four combinations of active noise sources, the rating noise level for one cycle is determined based on the duration and measured values of the noise levels of individual combinations using the equation:

$$L_{\mathrm{Req},T} = 10\log\sum_{i=1}^{4}\frac{t_i}{T}10^{0.1L_{\mathrm{Aeq,5min},i}} \text{ dB}, \quad (1)$$

where: t_i – duration of the i-th combination of operating modes in minutes, $L_{\mathrm{Aeq,5min},i}$ – averaged noise level in dB for the i-th combination of operating modes (Tabs. 7 ÷ 10), and T – duration of the beer production technological cycle in minutes (T = 4 h = 240 min).

The results of the calculation of rating noise levels for each cycle/mode (Tabs. 2 and 3) at measurement points MP3 and MP4, as well as the noise rating, are presented in Tabs. 7 ÷ 10. During all measurements, the noise had a wide frequency range, was steady, and did not contain impulses. In the time intervals when the noise was tonal, a correction of 5 dB was added to the measured/averaged values. Tonal noise occurs during the operation of the new system for pneumatic malt transport as a result of adjusting transport parameters (speed and material flow through the pipeline), as well as the fact that the pipeline of the new system, unlike the old one, is not soundproofed.

Table 7 Rating noise levels and noise rating at MP3 for day and evening

Measurement point:	MP3							
Reference time interval:	Day / Evening							
Mode:	Reserve mode				Normal mode + Tankers for corn grits unloading			
Combination of active noise sources:	DE/ C1	DE/ C2.1	DE/ C3	DE/ C4.1	DE/ C1	DE/ C2.2	DE/ C3	DE/ C4.1
i:	1	2	3	4	1	2	3	4
Duration t_i, min:	60	90	60	30	60	90	60	30
Noise level $L_{Aeq,5min,i}$, dB:	55.1	58.2	58.7	60.1	55.1	60.2	58.7	60.1
Rating noise level $L_{Req,4h}$, dB:	58				59			
Noise indicator limit value [9], dB:	65				65			
Exceeding the limit value Δ, dB:	-				-			
Noise rating:	Not exceed				Not exceed			

Table 8 Rating noise levels and noise rating at MP4 for day and evening

Measurement point:	MP4							
Reference time interval:	Day / Evening							
Mode:	Reserve mode				Normal mode + Tankers for corn grits unloading			
Combination of active noise sources:	DE/ C1	DE/ C2.1	DE/ C3	DE/ C4.1	DE/ C1	DE/ C2.1	DE/ C3	DE/ C4.1
i:	1	2	3	4	1	2	3	4
Duration t_i, min:	60	90	60	30	60	90	60	30
Noise level $L_{Aeq,5min,i}$, dB:	58.1	61.9*	59.2	60.2	58.1	65.7*	59.2	60.2
Rating noise level $L_{Req,4h}$, dB:	60				63			
Noise indicator limit value [9], dB:	65				65			
Exceeding the limit value Δ, dB:	-				-			
Noise rating:	Not exceed				Not exceed			

* An additional correction of 5 dB due to the tonal noise.

Table 9 Rating noise levels and noise rating at MP3 for night

Measurement point:	MP3							
Reference time interval:	Night							
Mode:	Normal mode				Reserve mode			
Combination of active noise sources:	N/ C1	N/ C2	N/ C3	N/ C4	N/ C1	N/ C2.1	N/ C3	N/ C4.1
i:	1	2	3	4	1	2	3	4
Duration t_i, min:	60	90	60	30	60	90	60	30
Noise level $L_{Aeq,5min,i}$, dB:	49.8	50.9	57.8	58.6	49.8	53.6	57.8	59.2
Rating noise level $L_{Req,4h}$, dB:	55				56			
Noise indicator limit value [9], dB:	55				55			
Exceeding the limit value Δ, dB:	-				1			
Noise rating:	Not exceed				Exceed			

Table 10 Rating noise levels and noise rating at MP4 for night

Measurement point:	MP4							
Reference time interval:	Night							
Mode:	Normal mode				Reserve mode			
Combination of active noise sources:	N/ C1	N/ C2	N/ C3	N/ C4	N/ C1	N/ C2.1	N/ C3	N/ C4.1
i:	1	2	3	4	1	2	3	4
Duration t_i, min:	60	90	60	30	60	90	60	30
Noise level $L_{\text{Aeq,5min},i}$, dB:	49.3	54.4	58.0	57.1	49.3	56.7	58.0	60.4
Rating noise level $L_{\text{Req,4h}}$, dB:	55				57			
Noise indicator limit value [9], dB:	55				55			
Exceeding the limit value Δ, dB:	-				2			
Noise rating:	Not exceed				Exceed			

3. Conclusion

The existence and operation of industrial plants in an urban environment potentially threaten the quality of the environment, with noise pollution in most cases representing a serious problem. Solving such problems requires a detailed analysis of the existing noise conditions, which involves identifying all noise sources (machines, plants, processes) that contribute to this state and assessing the contribution of each to the overall noise level. The contribution of individual noise sources to the tonal noise depends on the noise level generated by the source and the duration of the noise from each source. This approach enables noise control through recommendations on the duration of operation of individual sources, their use during noise-sensitive periods, and technical measures that may be taken to remediate the current situation.

In the case analyzed in the study, after the first noise measurement in the environment, in the immediate vicinity of the brewery, it was determined that operation of the cogenerator had the dominant influence on the noise level at both measurement points. Additionally, there were exceedances of the noise indicator limit values during the night. To reduce the noise originating from the brewery's noise sources in those locations, a sound-absorbing barrier was placed in front of the cogenerator, and the operation of the cogenerator was stopped during the night. Subsequent noise measurements at the same measurement points were repeated in a series of short-term measurements in all reference time intervals. Based on the noise measurement results and the calculation of rating noise levels, it was found that exceedances of the noise indicator limit values for the night occur during the technological process of beer production in reserve night mode. Since normal night mode and reserve night mode differ in the use of different systems for pneumatic malt transport, it was concluded that the use of the new system for pneumatic malt transport is the primary cause of the exceedance of the noise indicator limit values for the night. The use of the new system for pneumatic malt transport contributes to an increase in noise levels at the given measurement points during the day and evening, but there are no exceedances due to the higher limit values of the noise indicators for those reference time intervals.

The conducted research indicates the importance of the proper selection of machines and technological processes in terms of noise emission, as well as planning their location within the production conditions, especially in situations where industrial activity can threaten the quality of the environment.

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