FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 21, Nº 4, Special Issue, 2024, pp. 447 - 454
https://doi.org/10.22190/FUWLEP240924043B

Original scientific paper

ENSURING AN ACOUSTICALLY UNPOLLUTED LIVING ENVIRONMENT

UDC 534.321.9

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Abstract. *Human beings are always concerned with living in an unpolluted environment. Noise pollution is one type of pollution that can arise. To address this issue, the acoustic properties of the environment are studied. This is done through periodic measurements, identifying the sources of pollution at the same time. The impact on the environment is then evaluated based on the collected data. Based on this, pollution reduction measures are established, and measures to reduce pollution are implemented accordingly. The methodology, measurement procedures, development of reduction strategies, and their effectiveness are thoroughly outlined.*

Key words: *environmental pollution, noise reduction*

1. INTRODUCTION

In the urban environment, human life and activity are constantly affected by noise and vibrations. These are mostly generated by means of transport participating in road, rail, and air traffic. This is a very actual and important research direction, and many researchers were recently concerned with investigating specific problems [1-5]. In this sense, we focused on the identification of the most important sources of noise from transportation means, specifying the harmful effects, the admissible limits, and the way of propagation. Starting from the results of the performed measurements and their analysis, some methods of achieving acoustic comfort were established, and following their implementation, the obtained effect was researched.

Received September 24, 2024 / Accepted November 7, 2024
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2. Noise Sources of Vehicles

The noise generated by means of transport in the urban environment is characterized by specific frequency spectra, acoustic pressure levels, and their variation over time. This can also be seen in Fig. 1, which shows the average spectra of the noise generated by different categories of means of transport: 1 - trucks with diesel engines; 2 - trucks with gasoline engines; 3 - trams; 4 - buses; 5 - cars; 6 - trolleybuses; 7 - motorcycles.

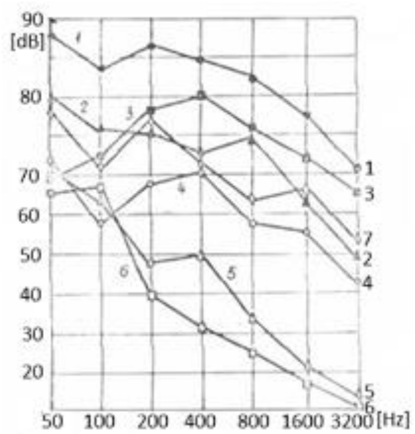

Fig. 1 Average spectra of noise generated by different transportation means [6]

In general, it can be said that the means of transport in road traffic have a low-frequency and partially medium-frequency character. Noise depends on the intensity and composition of the traffic, as well as the speed of travel, and is generated by three important sources: the engine, the transmission system, and the contact between the wheel and the track.

The means of railway transport generate noise and vibrations due to the variation of the movement speed, the play at the ends of the rails (joints), the unevenness, the curves, and the elasticity of the tracks, the conicity, the eccentricity, and the deviations from the proper shape of the tires, the guidance of the rolling wheel on the rail through the lip of the bandage, and the jerks during the maneuver during braking and acceleration.

The most important sources of noise and vibrations in air traffic are the explosion engine, the propeller, and, in the case of modern aircraft, jet engines, turboprops, or stators.

3. The Harmful Effects of Noise

Noise is extremely harmful to human life and activity. Thus, in the case of noise with the equivalent level of 70 dB, during the day, 60 % of the population is disturbed.

Noise affects the human nervous system, producing psycho-physiological changes, blood circulation, and sleep disorders, negatively influencing the visual function and endocrine glands, and producing biochemical disorders. Noise also causes hearing fatigue and sound trauma.

In order to reduce the effects of noise, limit values were provided, exceeding which is prohibited. The equivalent acoustic level and noise curves (Cz) are used as elements to characterize these limits. The equivalent continuous acoustic level corresponds to an equivalent intensity over a time interval considered T and is defined by the relation

$$L_{ech} = 10\lg\left[\frac{1}{T}\int_0^T 10^{0,1L(t)}\,dt\right] \quad (1)$$

where L(t) is the instantaneous sound level.

Noise curves (Cz) define the relationship between the characteristic frequency of a sound and the corresponding level of acoustic pressure under the conditions of an equivalent subjective sensation [7,8].

In this sense, according to SR 10009, "Urban Acoustics", admissible limits of the noise level in the urban environment were established, differentiated by zones and functional equipment by technical categories of streets, established on the basis of the specific technical regulations in force regarding environmental protection surrounding.

Table 1 Admissible limits for noise

Street type (STAS 10144/1-90)	Leq [dB]	Cz [dB]	L10 [dB]
type I – thoroughfare	75-85	70-80	85-95
type II – street of connection	70	65	75
type III – street of collection	65	60	75
type IV – street of local service	60	55	70

Admissible limits have been established for the noise level on the streets (Tab. 1). At the same time, the location of residential buildings on streets of different technical categories or the border of functional zones or facilities, as well as the organization of traffic, will be done in such a way as to ensure the value of 50 dB(A) of the noise level outside the building, measured at 2 m from the front of the building, respectively, the noise curve Cz45.

In the same way, to avoid the effects of the noise produced by the railway traffic in the urban environment, it was established that it should not exceed 70 dB at the limit of the railway zone, respectively the noise curve Cz65. Also, in order to limit the noise generated by air traffic, it is recommended that its level during the day between 7.00 and 19.00 should not exceed 90 dB, 85 dB in the evening between 19.00 and 23.00, and 80 dB during the night between 23.00 and 7.00.

The noise generated by means of transport affects both their drivers and passengers and people in the surrounding environment.

4. STUDY OF THE ACOUSTIC FIELD

During the operation of the various sources, their vibrations propagate in the surrounding environment in the form of spherical waves and cylindrical waves, and at a great distance from the source, as plane waves. If the environment in which the waves propagate is considered to be perfectly elastic, homogeneous, and isotropic, choosing as a parameter the potential velocity Φ, the equation of the spherical wave, in the case of a harmonic disturbance, considering the movement only along the vector radius is

$$\phi = \frac{A_c}{r} e^{jk(ct-r)} \tag{2}$$

where A_c is the complex amplitude of the wave, having the frequency $f = \frac{\omega}{2\pi}$, c is its propagation speed, and $k = \frac{\omega}{c}$ is the wave number. If it is considered, $A_c = Ae^{j\alpha}$ then the pressure at a point of the acoustic field is determined by the relation

$$p = \rho_0 \omega \frac{A}{r} \sin(\omega t - kr + \alpha) \tag{3}$$

At the same time, if the vibrations of the sources produce cylindrical waves, considering that all points of the environment move in a direction perpendicular to the source, the equation of such a wave is:

$$\phi = \left[AJ_m(kr) + jBY_m(kr) \right] e^{-jm\varphi} e^{-j\omega t}, \tag{4}$$

where r and φ are the cylindrical coordinates of the volume element, and A and B are constants of integration, J_m is the Bessel function of the first kind and order m, and Y_m is the Bessel-Neumann function of the second kind and order m.

Considering that the waves are produced due to radial and uniform vibrations of the source, the expression of the acoustic pressure at a point of the medium can be written

$$p = A\left[J_0(kr) + jY_0(kr) \right] e^{-j\omega t}, \tag{5}$$

where J_0 and Y_0 are respectively the zero-order Bessel and Neumann functions.

Taking into account the approximation of the functions J_0 and Y_0 for small values of the variable r, expression (5) becomes

$$p = j\left(\frac{2A}{\pi} \right) \ln(kr) e^{-j\omega t} \tag{6}$$

and at a great distance from the source

$$p = A\sqrt{\frac{2}{\pi kr}} e^{j\left[k(r-ct) - \frac{\pi}{4} \right]} \tag{7}$$

The pressure variation at a point of the acoustic field is due to the propagation of both spherical and cylindrical waves and plane waves at a large distance from the source.

If the pressure at a certain time during wave propagation is p, then the sound pressure level is

$$L = 20 \lg \frac{p}{p_0}, \tag{8}$$

where $p_0 = 2 \cdot 10^{-5}$ [N/m2] is the reference sound pressure.

In the case of the propagation of acoustic waves in closed spaces, considering the case of real rooms, the delimiting surfaces are not perfectly reflective, but when they are hit by the acoustic waves, a certain energy dissipation occurs, and the waves that are formed in the closed space will be damped. The damping term $e^{-\delta t}$ can be introduced into the standing wave equation by replacing the wave number k with a propagation constant, a complex quantity of the form $k + j\frac{\delta}{c}$, where δ is the wave-damping constant [9].

In the wave equation, the phase angles (φ_x, φ_y, φ_z) will also have to be introduced because they are different from zero, as a result of the fact that the bounding surfaces of the closed space are not rigid and perfectly reflective. In this way, the damped standing wave equation, choosing pressure as a parameter, is

$$p = Pch\left[(\delta_x - j\omega_x)\frac{x}{c} + \phi_x\right] ch\left[(\delta_y - j\omega_y)\frac{y}{c} + \phi_y\right] ch\left[(\delta_z - j\omega_z)\frac{z}{c} + \phi_z\right] e^{(j\omega-\delta)t} \quad (9)$$

The phase constants φ_x, φ_y, φ_z are determined by the boundary conditions x=0, y=0, z=0 that must be satisfied. Using this expression of the acoustic pressure, the acoustic pressure level at a point of the acoustic field can be determined using relation (8).

At the same time, it must be taken into account that in the case of noise propagation in closed spaces, the reflected ones are superimposed on the direct acoustic waves.

5. PERFORMING OF MEASUREMENTS

Taking into account the multitude and diversity of the sources that generate noise in the urban environment as well as the nature of the acoustic waves produced by them, the acoustic field is very complex, and its investigation is indicated to be done experimentally.

In this sense, noise level measurements were made using the Bruel & Kjaer 2250 investigator. Noise level measurements were carried out in 119 measurement points that were established in the most important intersections of traffic arteries in Timisoara. For the measurements of the noise generated by the railway traffic, the microphone was positioned at the limit of the railway zone, and for that generated by the air traffic in the area of the Timisoara Airport.

The measuring devices used allowed the recording and automatic calculation of the main physical noise indicators: L_{eq} (equivalent noise level), SEL (Sound Exposure Level), L_{max} (maximum noise level), L_{min} (minimum noise level), L_5, L_{10}, L_{50}, L_{90}, and L_{95} (percentage noise levels). These parameters were determined over a continuous period of 8 hours (7.30 - 15.30), divided into time intervals of one hour.

Using these measured parameters, other physical indicators characterizing the effect of noise were calculated, such as:

- the Noise Climate

$$\text{N.C.} = L_{10} - L_{90} \quad (10)$$

- the Traffic Noise Index

$$\text{T.N.I.} = 4(L_{10} - L_{90}) + L_{90} - 30 \quad (11)$$

- the Level of Noise Pollution

$$\text{L.N.P.} = L_{eq} + L_{10} - L_{90} \quad (12)$$

For measurements, the microphone was mounted on the edge of the sidewalk at 7.5 m from the axis of the first traffic lane, at a height of 1.3 m from the ground. Simultaneously with the recording of the noise levels, the intensity and composition of the traffic and the speed of the means of transport were determined.

Measurements of the noise level inside different types of vehicles were also carried out. The noise level inside trams, buses, trolleybuses, and cars during a complete route was measured. For this, the microphone was mounted near the passenger's ear at 0.6 m from the vehicle wall.

6. Analysis of Measurement Results

The values of the measured noise levels, those of the intensity and the composition of the traffic, were centralized in a database for the study of noise pollution in Timisoara.

Following the obtained data, the equivalent noise level at 95 of the 119 measurement points (79.85 %) exceeds the maximum value allowed by the SR 10009 standard on "Urban acoustics." The exceedances recorded values between 0.1 and 15.5 dB.

The intensity of road traffic had values between 9 veh/h and 2681 veh/h, and the travel speed was 50 – 60 km/h. The highest percentage of vehicles present in traffic at the measurement points was that of passenger cars, between 34.2 % and 95.87 %.

The presence of traffic of many trams, trucks, trains, and tractors contributed to the increase in the noise level. The damaged condition and the nature of the roadway superstructure favor the increase of the noise level values produced by different types of vehicles depending on the speed.

In most measurement points, the peak noise level was generally exceeded by 1 – 9.5 dB. The noise level of 50 dB allowed at 2 m from the wall of buildings was generally exceeded by 1.3 – 32.9 dB.

The results of measurements carried out inside different types of vehicles are presented in Tab. 2.

Table 2 Noise levels [dB]

Type of vehicles	Leq	SEL	L_{max}	L_{min}	L_5	L_{10}	L_{50}	L_{90}	L_{95}
Trams	68.1-75.3	95.9-104.2	83.2-90.1	43.1-61.4	73.1-80.7	72.2-78.7	64.3-78.2	49.5-70.0	47.9-69.1
Buses	70.9-73.0	100.4-100.8	82.0-89.5	49.4-68.1	76.9-77.8	76.0-76.7	70.0-71.6	65.6-70.0	60.7-69.8
Trolleys	71.0-73.8	98.0-101.3	85.0-88.2	44.0-45.7	75.0-80.7	74.0-78.7	65.1-66.8	57.1-61.0	58.1-60.2
Cars	64.1-68.2	91.2-93.5	88.2-90.1	42.5-45.1	71.6-73.2	69.1-71.3	63.2-65.4	53.4-55.2	50.2-53.4

The noise level generated by trains measured at the border of the railway zone exceeded the allowed value by 2.2 – 12.7 dB.

The increase in the noise level is mainly due to the traffic of cars, trains, and planes, changing the direction of travel, passing over the running path of trams, accelerations, and braking. During the movement of vehicles on corridor streets, the increase in noise level is also produced by the overlap of the reflected waves over the direct ones. Also, the high degree of damage to some vehicles is an important factor that contributes to the increase in the level of traffic noise.

The noise inside the means of transport is also largely influenced by the operations of closing and opening the doors, driving maneuvers, the unevenness of the roadway, the conversation of passengers, etc.

7. METHODS OF ACHIEVING ACOUSTIC COMFORT

Since in most of the points where measurements were made the permitted limits of the noise levels were exceeded, some noise reduction measures were required to achieve acoustic comfort. These measures would consist of organizing and systematizing traffic, improving or changing the superstructure of the roadway for vehicles, limiting travel speed, replacing some trams, improving the technical condition of vehicles and trains, applying a cushioning layer between the running line of the tram and sleepers, the construction of a bypass belt of the municipality of Timisoara, and the elimination of railway traffic from the city.

In order to reduce the noise generated by cars and trains, as well as by airplanes at Timişoara Airport, it is necessary to create acoustic screens and green areas near residential areas. An appropriate attenuation of the noise and the achievement of acoustic comfort inside the vehicles can be obtained by covering the ceiling and floor walls with sound-absorbing materials. At the same time, the drivers of the means of transport must drive them quietly.

Following these recommendations, the local public authorities of the municipality of Timisoara undertook an important program to reduce noise in the urban environment. In this sense, the old system of tram lines was completely replaced with a new one, quieter, with better insulation properties. The old Romanian trams have been replaced by a modern generation of trams. On many streets, the superstructure of the vehicle carriageway was improved or changed. Many intersections have been modernized, geometrically modified, and traffic lights introduced. On many streets one way was introduced, and speed was limited. The presence of large vehicles in the central area of the city was eliminated. On the other hand, in order to eliminate from the urban environment vehicles with a large mass in transit, the construction of the bypass belt of the municipality of Timişoara has begun.

To reduce the noise generated by railway traffic, new, quieter trains were introduced, many were also modernized between the tracks and residential areas, or acoustic screens and green areas were created.

The effects of these measures were evaluated through new measurements carried out in 46 measurement points that were established near the intersections where they were implemented.

From the obtained data, it follows that the equivalent noise level was reduced by 0.1 – 10.5 dB, and in 32 measurement points (69.56 %), the noise level does not exceed the maximum value allowed by SR 10009.

At the same time, in the 10 measurement points located at the border of the railway zone, the equivalent noise level was reduced by 0.1 – 9.3 dB, and in 6 of them (60 %) the noise level did not exceed the limit value allowed by the standard. The traffic intensity had values between 96 veh/h and 2822 veh/h, the travel speed was 50-60 km/h, and the highest percentage presence in the traffic was that of cars (66.65 % – 94.65 %).

8. CONCLUSIONS

The established noise reduction methods and their implementation have proven to be effective in contributing to the achievement of acoustic comfort in the urban environment. They can be applied in any situation regarding traffic or industrial noise.

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