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THE INFLUENCE OF TEMPERATURE ON SOUND WAVES

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Abstract

Sound waves are mechanical waves in the longitudinal direction that propagate in a variety of solid or gaseous media. The medium for the propagation of sound waves is the atmospheric environment. This medium consists of particles which are influenced by environmental conditions. The purpose of this paper is to show that atmospheric temperature can have an effect on the speed of propagation of sound waves. The measurements on which the study is based were made in the same areas and at the same time intervals, under the same atmospheric conditions, during periods of high and low temperature. The results confirm that the speed of sound waves is influenced by the parameters of the environment in which they propagate. The speed of sound is faster when temperatures are higher.

Key words: *environment, propagation, sound waves, temperature.*

INTRODUCTION

Noise pollution is an issue of current concern (Baudin et al., 2021; Marquart et al., 2021) and a major problem for the health of the general public (Ertugrul et al., 2021; Liu et al., 2021). Noise pollution is largely a by-product of industrialisation, urbanisation, and modern civilisation. Increasing population and vehicular activity have led to an increase in noise pollution. Traffic noise is a significant source of urban noise, stemming from the movement of people and goods in the city (Hänninen et al., 2014). Excessive exposure to urban noise causes various impairments such as cardiovascular, hearing, or cognitive impairment (Cueto et al., 2017; WHO, 2018). Environmental noise from urban traffic is currently a major health problem in Europe (WHO & JRC, 2011). Approximately 20% of Europe's population is exposed to noise levels harmful to health (EEA, 2019).

Sound is a form of energy. Or we can say that it is a vibration that travels through a medium such as air. Sound even travels through a gaseous medium. It is something that can be heard. The speed of sound is different in different media. A wave is something that carries energy from one place to another through a medium. Sound waves are mechanical waves that propagate through a medium. These waves are created by vibrations, which disturb the molecules in the medium causing them to oscillate back and forth. The disturbance travels through the medium in the form of a wave, carrying energy with it.

The speed of sound in air does indeed vary with temperature. At higher temperatures, air molecules move faster and can transmit sound more quickly, resulting in a higher speed of sound. Conversely, at lower temperatures, air molecules move more slowly, causing sound to propagate more slowly. This relationship between temperature and the speed of sound can be explained by the kinetic theory of gases, which describes how the motion of gas molecules affects the properties of the gas, including the speed of sound. In air, the speed of sound propagation is 340 m/s at 20ºC and 331 m/s at 0ºC respectively. The speed of sound is faster when temperatures are higher (Figure 1). The formula used to find the speed of sound in air is as:

$$v = 331\frac{m}{s} + 0.6\frac{m/s}{C}\times\mathrm{T}$$

where:
- v is the speed of sound;
- T is the temperature of the air.

The case study aims to carry out measurements to determine the influence of environmental conditions - air temperature, on urban traffic noise.

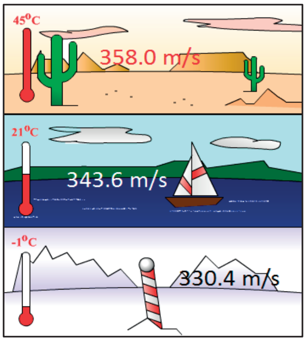


Figure 1. Temperature and the speed of sound (https://www.nde-ed.org/Physics/Sound/tempandspeed.xhtml)

MATERIALS AND METHODS

In urban areas in Romania there are a significant number of people exposed to high noise levels (Popescu, 2023) especially from traffic (Moscovici & Grecea, 2015) in Bucharest, Romania's capital city (Mihalache et al., 2023; Albu et al., 2019; Tăranu & Ioniță, 2019; Deaconu & Cioca, 2019; Rusu Boboc et al., 2018; Chiriac et al., 2017).

Romania's capital, Bucharest, is a growing city where noise levels in residential areas during the daytime vary between 55-75 dB, which exceeds the World Health Organization - WHO (WHO, 2018) recommended threshold of 55 dB.

The study area (Figure 2) is located in the south-western part of the city, at the boundary between district 5 and 6, at the intersection of Petre Ispirescu Street, Drumul Sării Street, Antiaeriana Street, Calea 13 Septembrie and Ghencea Boulevard.

The area near the intersection is a mixed area consisting of residential buildings, apartment blocks, houses, shops, restaurants, children's playgrounds, high schools, various institutions, office buildings, busy traffic arteries, as well as streets and pedestrian walkways. It is a congested area of the city with a high level of noise pollution due to heavy traffic, proximity to office buildings and various activities in the area.

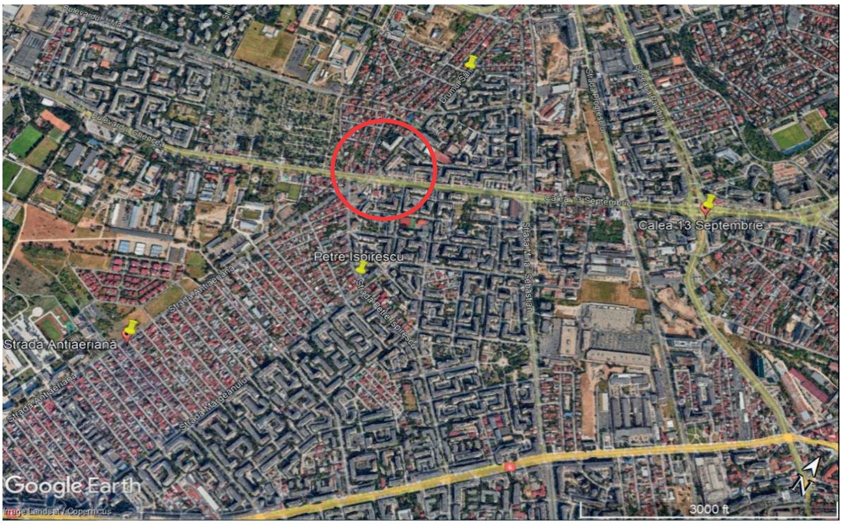


Figure 2. Study area

It was decided to carry out two sets of measurements with similar environmental characteristics, based on forecasts, but to be in two contrasting periods in terms of temperatures, September 2023, and January 2024. In the two measurement periods, September 2023 and January 2024, approximately the same noise sources were identified; They were mainly produced by public transport in the area, namely buses, trolleybuses and trams that run at approximately equal intervals depending on the time of day or night, intense pedestrian traffic due to existing institutions in the area such as schools, high schools, kindergartens, playgrounds, office buildings, commercial spaces, shops, as well as various types of vehicles such as motorcycles, bicycles, scooters, etc. In addition to these noises, there are other random sources produced by horns, vehicles that stop suddenly, alarms or various noises of nature, all these sources continuously producing noises.

The environmental conditions at the time of the measurements were as follows: wind speed averaged between 1 and 30 km/h, clear skies, and low precipitation between 0 and 10 mm, atmospheric pressure varied around 1000 hPa. In the first phase, measurements were taken to quantify the noise level and related temperatures and then the measurement sets were compared.

The location of the measurements was at the intersection of the Salt Road and the 13 September Road, with measurements taken from the pavement in the immediate vicinity about 30 m from the 13 September Road and about 2 m from the Salt Road. The coordinates of the site, in the 1970 stereographic system, are: East = 584462.00 and North = 324902.00 and Latitude = 44.4189 and Longitude = 26.0591.

Environmental measurements were made using the Lutron sound level meter - Model SL-4012 (Figure 3).

Figure 3. Lutron Sound Level Meter, model SL-4012

The Lutron Sound Level Meter - Model SL-4012 is a high-precision digital instrument with IEC 61672 accuracy class 2, A & C frequency weighting, high-precision condenser microphone and measurement range from 30 to 130 dB. The instrument is designed for measuring urban noise and road traffic. Measurements were made according to the specific requirements for road noise measurements in the immediate vicinity of vehicle traffic at intersections with the microphone directed towards the main noise source (SR ISO 1996-1 regulation).

The first stage was carried out in September 2023, three times each day at 7 am, 12 pm and 9 pm. The data were taken from the pavement in the immediate vicinity of the intersections mentioned, at a height of 1 metre above the ground. Temperatures at the time of the measurements ranged from a minimum of 8 to 19ºC and a maximum of 24 to 34ºC.

Depending on the time at which the measurements were taken, they varied as follows: at 7 am temperatures ranged from 10 to 22ºC; at 12 noon temperatures ranged from 22 to 31ºC; at 9 pm temperatures ranged from 21 to 29ºC. As for the ambient noise measurements, they varied according to the time they were taken, as follows: at 7 o'clock, the sound level meter readings ranged from 65.5 dB to 70.4 dB respectively; at 12 o'clock, the sound level meter readings ranged from 63.2 dB to 70.3 dB; at 21.00, the sound level meter readings were between 66.9 dB and 72.5 dB respectively. The second measurement phase was carried out in January 2024, three times a day at the same times 7, 12 and 21. The data were also taken under the same conditions as in the first set of measurements, from the pavement in the immediate vicinity of the intersections mentioned, at a height of 1 metre above the ground. Temperatures at the time of the measurements had minimum values varying between -12ºC and 4ºC and maximum values between -5ºC and 16ºC. Depending on the time at which the measurements were taken, they varied as follows: at 7 am temperatures ranged from -9ºC to 2ºC; at 12 o'clock, temperatures ranged from -2ºC to 12ºC; at 9 pm temperatures ranged from -6ºC to 9ºC. The ambient noise measurements varied according to the time of day as follows: at 7 o'clock, the values measured with the sound level meter ranged from 64.9 dB to 69.9 dB respectively; at 12 noon, the sound level meter readings ranged from 62.9 dB to 70.1 dB respectively; at 21.00, the sound level meter readings ranged from 66.6 dB to 71.9 dB. It should be noted that three different times were chosen each being significant because the noise level differs according to the time of day. All the values presented are centralised in Table 1.

Table 1. Measurements taken in September 2023 and January 2024

Date/ Sep.2023	T(°C)-max. values	T(°C)-min. values	T(°C)/hour 7/2023	noise level(dB)/hour 7/2023	T(°C)/hour 12/2023	noise level(dB)/hour 12/2023	T(°C)/hour 21/2023	noise level(dB)/hour 21/2023	Date/ Jan.2024	T(°C)-max. values	T(°C)-min. values	T(°C)/hour 7/2024	noise level(dB)/hour 7/2024	T(°C)/hour 12/2024	noise level(dB)/hour 12/2024	T(°C)/hour 21/2024	noise level(dB)/hour 21/2024
1	31	14	18	66.5	28	66.6	27	69.8	1	11	-4	-2	65.5	6	66.3	3	69.5
2	32	15	19	68.9	29	65.5	28	70.2	2	11	-2	0	68.6	6	66.4	5	69.1
3	34	13	15	68.9	30	66.5	29	69.9	3	8	-3	-1	68.2	4	66.3	2	69.5
4	26	17	21	67.3	24	65.4	21	68.9	4	14	4	0	67.0	11	65.2	7	68.4
5	28	18	22	69.9	25	65.5	22	69.9	5	16	1	2	69.5	12	65.3	9	69.4
6	30	16	19	70.1	28	65.0	25	69.6	6	12	0	1	69.9	10	64.8	8	69.1
7	31	16	19	66.7	29	65.5	25	68.9	7	8	0	1	66.2	6	65.4	5	68.3
8	29	10	12	65.5	27	64.2	23	70.1	8	3	-5	-2	64.9	2	64.1	1	69.8
9	31	8	10	68.9	28	65.2	22	70.0	9	-2	-8	-6	68.1	0	65.0	-4	69.2
10	29	12	15	68.7	26	66.4	24	69.9	10	1	-9	-6	68.0	0	66.1	-4	69.1
11	29	9	11	70.0	27	64.4	23	69.8	11	3	-7	-4	69.4	0	64.1	0	69.0
12	32	10	14	68.9	28	66.4	25	71.0	12	1	-4	-3	68.2	1	66.2	-2	69.2
13	33	12	15	68.7	30	67.5	27	69.4	13	3	-8	-5	68.1	1	67.1	-3	69.1
14	34	12	14	68.9	31	66.2	27	70.3	14	5	-6	-4	68.2	3	66.0	1	69.5
15	30	18	20	69.6	27	68.1	26	71.1	15	7	-5	-3	68.9	5	67.9	3	70.5
16	24	19	22	70.4	22	68.7	20	72.5	16	8	-4	-2	69.7	7	68.4	3	71.9
17	28	14	18	70.2	26	68.4	23	71.5	17	6	-9	-6	69.5	5	68.1	1	71.0
18	27	11	16	69.7	25	65.3	21	70.5	18	11	-1	0	69.4	10	65.1	6	70.1
19	26	10	14	69.8	25	66.3	20	70.7	19	13	1	2	69.6	11	66.1	7	70.2
20	28	13	16	68.9	26	65.6	23	72.2	20	1	-6	-3	68.2	0	65.2	-1	71.6
21	31	12	14	69.8	29	63.2	25	71.5	21	-1	-10	-7	68.9	-2	62.9	-4	70.8
22	32	14	18	69.9	30	66.3	27	71.2	22	-2	-12	-9	68.1	-2	65.9	-5	70.7
23	34	16	19	68.9	32	67.0	27	71.1	23	-5	-10	-7	68.1	-4	66.7	-6	70.5
24	32	19	22	69.8	30	66.4	26	70.2	24	-2	-5	-2	69.3	-2	66.1	-3	69.8
25	29	16	19	68.5	27	65.6	23	69.7	25	8	-6	-4	68.1	6	65.2	4	69.2
26	30	14	18	66.3	28	67.8	25	69.8	26	7	-3	-1	65.9	6	66.8	4	69.2
27	29	18	21	70.1	26	70.3	24	69.2	27	4	-5	-2	69.8	3	70.1	1	69.1
28	29	14	17	69.2	27	66.6	24	66.9	28	6	-4	-2	69.0	4	66.2	2	66.6
29	30	12	16	66.9	27	61.8	24	69.9	29	5	-5	-2	66.6	4	61.4	2	69.5
30	30	11	15	68.8	27	65.6	25	69.6	30	5	-6	-3	68.4	5	65.2	3	69.2
									31	8	-6	-3	68.4	7	65.2	4	69.3
max	34	19	22	70.4	32	70.3	29	72.5	max	16	4	2	69.9	12	70.1	9	71.9
min	24	8	10	65.5	22	61.8	20	66.9	min	-5	-12	-9	64.9	-4	61.4	-6	66.6
Average	29.9	13.8	17.0	68.8	27.5	66.1	24.4	70.2	Average	5.4	-4.8	-2.7	68.3	4.0	65.8	1.5	69.6

RESULTS AND DISCUSSIONS

Two sets of measurements under similar environmental conditions were carried out for further comparison of the results.

The first set of measurements was carried out in September 2023. In terms of temperatures, it was found that the average of the minimum values at which the measurements were taken was 13.8°C and the average of the maximum values was 29.9°C, these varying according to the times at which they were taken, as follows: at 7 am, the average temperature value was 17°C; at 12 noon, the average temperature was 27.5°C; at 21.00, the average temperature was 24.4°C. In terms of ambient noise produced by traffic in the area, it was found that the average of these varied according to the time of day, as follows: at 7 am, the average value was 68.8 dB; at 12 noon, the average value was 66.1 dB; at 21.00, the average value was 70.2 dB.

The second measurement phase was carried out in January 2024. In terms of temperatures, it was found that the average of the minimum values at which the measurements were taken was -4.7°C and the average of the maximum values was 5.6°C, these varying according to the times at which they were taken, as follows: at 7 am, the average temperature value was -2°C; at 12 noon, the average temperature was 4°C; at 9 p.m., the average temperature was 1.6°C. In terms of ambient noise produced by traffic in the area, it was found that the average of these varied according to the time of day, as follows: at 7 o'clock, the average value was 68.2 dB; at 12 noon, the average value was 65.8 dB; at 21.00, the average value was 69.6 dB.

The systematization of data was achieved by grouping and classifying values into homogeneous groups/classes. For choosing the number of groups/classes we used the relationship:

$$k = 1 + \log_2(n)$$

where:

- n = number of values; for our case resulted a no. of 7 classes.

After ordering the data into classes and calculating the frequencies (number of occurrences of a value), graphical representations were made to analyze noise levels correlated with the temperatures recorded at the three hours of the day (at 7 o'clock, at 9 o'clock and at 21 o'clock) for the 2 stages of registration (September 2023 and January 2024). Thus, the data obtained were systematized at 7 o'clock/September 2023 - January 2024 (Table 2).

In the same way, the data obtained were grouped at 12 o'clock/September 2023 - January 2024 (Table 3). Similarly, data for the third band were grouped and ordered at 21 o'clock/September 2023 - January 2024 (Table 4).

In order to obtain a spatial image of the data and to highlight the evolution of noise as a function of temperature, the values in (Table 2) found in (Figure 4) were represented. In Figure 4 it is observed that noise values increase at higher temperatures, correlation (interdependence) between the 2 values (temperature/noise) at 7 o'clock/September 2023 - January 2024 is powerful.

Table 2. The grouped results of the period (T (ºC)/noise level (dB)/hour 7 sept. 2023 and T (ºC)/noise level (dB)/hour 7 Jan. 2024); 7 groups/intervals

T (ºC)/hour 7 Sept. 2023	Noise level (dB)/hour 7 Sept. 2023	T (ºC)/hour 7 Jan. 2024	Noise level (dB)/hour 7 Jan. 2024
12	65.5	-4	68.2
15	68.8	-3	68.2
18	66.5	-2	69.3
18	66,3	-2	66.6
20	69.6	-1	65.9
21	67.3	0	67.0
22	70.4	1	69.9

Table 3. The grouped results of the period (T (ºC)/noise level (dB)/hour 12 sept. 2023 and T (ºC)/noise level (dB)/hour 12 Jan. 2024); 7 groups/intervals

T (ºC)/hour 12 Sept. 2023	Noise level (dB)/hour 12 Sept. 2023	T (ºC)/hour 12 Jan. 2024	Noise level (dB)/hour 12 Jan. 2024
22	68.7	-2	62.9
26	70.3	1	67.1
27	64.4	2	64.1
27	61.8	3	70.1
29	63.2	4	61.4
30	67.5	6	65.4
31	66.2	7	68.4

Table 4. The grouped results of the period (T(ºC)/noise level(dB)/hour 21 sept. 2023 and T(ºC)/noise level(dB)/hour 21 Jan. 2024); 7 groups/intervals

T (ºC)/hour 21 Sept. 2023	Noise level(dB)/hour 21 Sept. 2023	T(ºC)/hour 21 Jan. 2024	Noise level (dB)/hour 21 Jan. 2024
20	72.5	1	71.0
20	70.7	2	66.6
21	68.9	3	71.9
23	71.5	4	69.3
23	69.7	5	68,3
24	66.9	7	68.4
25	68.9	7	70.2

This association between variables is given by coefficient of determination $R^2 = 0.9344$ (R-square) (Figure 4). Thus, we can say that (R-square) assign a weight of 93.44% influence of each of the 2 independent variables and 6.56% random factors.

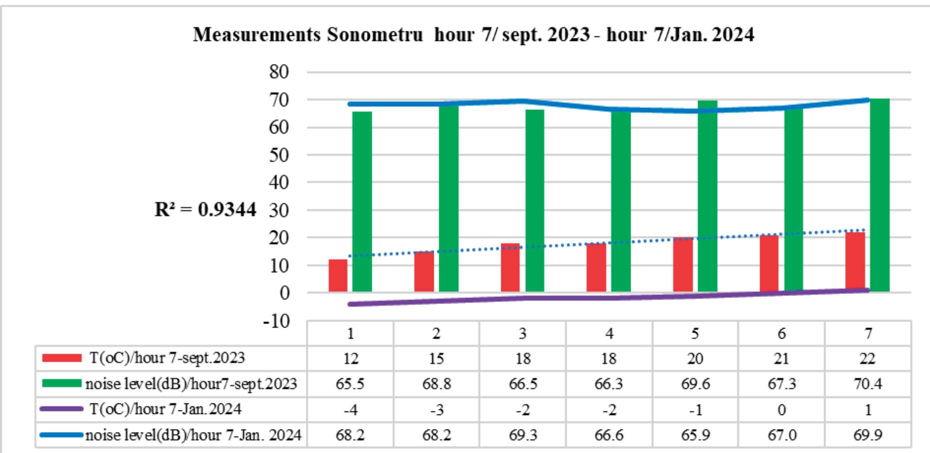
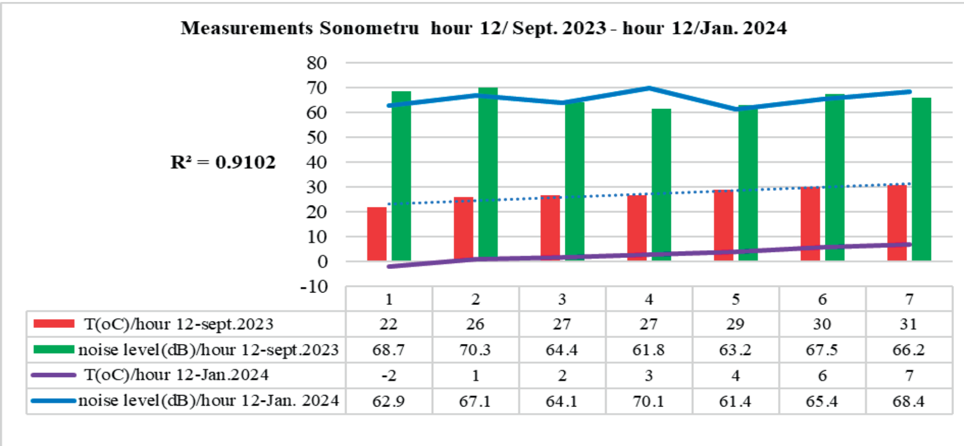


Figure 4. Noise variation as a function of temperature (hour 7/ September 2023 - hour 7/January 2024)

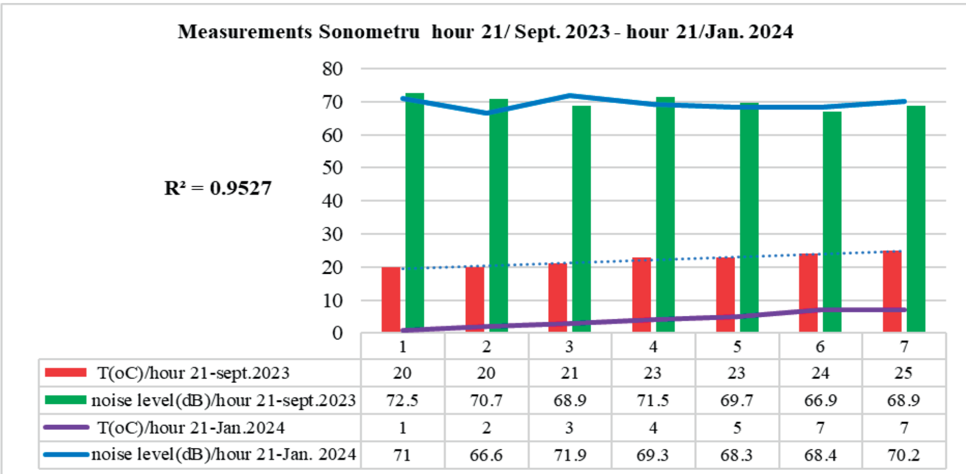
The graphical image of the data (Table 3) is shown in (Figure 5) showing the distribution of noise values according to temperatures. In the graphical representation for grouping data at 12 o'clock/September 2023 - January 2024 also sees the distribution of noise values according to recorded temperatures. The link between the 2 variables (temperature/noise) at 12 o'clock/ September 2023 - January 2024 is strong but slightly weaker due to a relatively smaller drop in traffic at 12 o'clock/September 2023 -January 2024. The degree of connection between these 2 variables is given by coefficient of determination R^2 = 0.9102 (R-square) (Figure 5). For the data group (Figure 5) (R-square) assigns 91.02% weight to the influence of each of the 2 independent variables and 8.98% to random factors.

The grouped data (Table 4) can be found in the graphical representation (Figure 6) in which the interdependence between the 2 values (temperature/noise) at 21 o'clock/September 2023 - January 2024 is seen to be strong. Thus, we can say that in this case too, the connection between the 2 variables is related and the dependence is observed in the coefficient of determination R^2 = 0.9527 (R-square) (Figure 6). From the representation on the distribution of values (Figure 6) (R-square) assigns 95.27% weight to the influence of each of the 2 independent variables and 4.73% to random factors.



	1	2	3	4	5	6	7
T(oC)/hour 12-sept.2023	22	26	27	27	29	30	31
noise level(dB)/hour 12-sept.2023	68.7	70.3	64.4	61.8	63.2	67.5	66.2
T(oC)/hour 12-Jan.2024	-2	1	2	3	4	6	7
noise level(dB)/hour 12-Jan. 2024	62.9	67.1	64.1	70.1	61.4	65.4	68.4

Figure 5. Noise variation as a function of temperature (hour 12/September 2023 - hour 12/January 2024)



	1	2	3	4	5	6	7
T(oC)/hour 21-sept.2023	20	20	21	23	23	24	25
noise level(dB)/hour 21-sept.2023	72.5	70.7	68.9	71.5	69.7	66.9	68.9
T(oC)/hour 21-Jan.2024	1	2	3	4	5	7	7
noise level(dB)/hour 21-Jan. 2024	71	66.6	71.9	69.3	68.3	68.4	70.2

Figure 6. Noise variation as a function of temperature (hour 21/September 2023 - hour 21/January 2024)

In Table 5 are centralized the max./min./average values of the data set used in the study.
With the data grouped in Table 5 we obtained the graphical representation (Figure 7) on the distribution of max./min./average values that highlight the evolution of noise depending on temperatures for the period September 2023 - January 2024.

Table 5. Max./min./average values of temperatures and noise level - September 2023 - January 2024

(min / max / average)values	T(°C)/hour 7	noise level(dB)/hour 7	T(°C)/hour 12	noise level(dB)/hour 12	T(°C)/hour 21	noise level(dB)/hour 21
max.(T(°C)/(dB)-sep.2023	22.0	70.4	32.0	70.3	29.0	72.5
min. (T(°C)/(dB)-sep.2023	10.0	65.5	22.0	61.8	20.0	66.9
Average/ sep.2023	17.0	68.8	27.5	66.1	24.4	70.2
max.(T(°C)/(dB)-jan 2024	2.0	69.9	12.0	70.1	9.0	71.9
min.(T(°C)/(dB)-jan 2024	-9.0	64.9	-4.0	61.4	-6.0	66.6
Average/ Jan.2024	-2.7	68.3	4.0	65.8	1.5	69.6

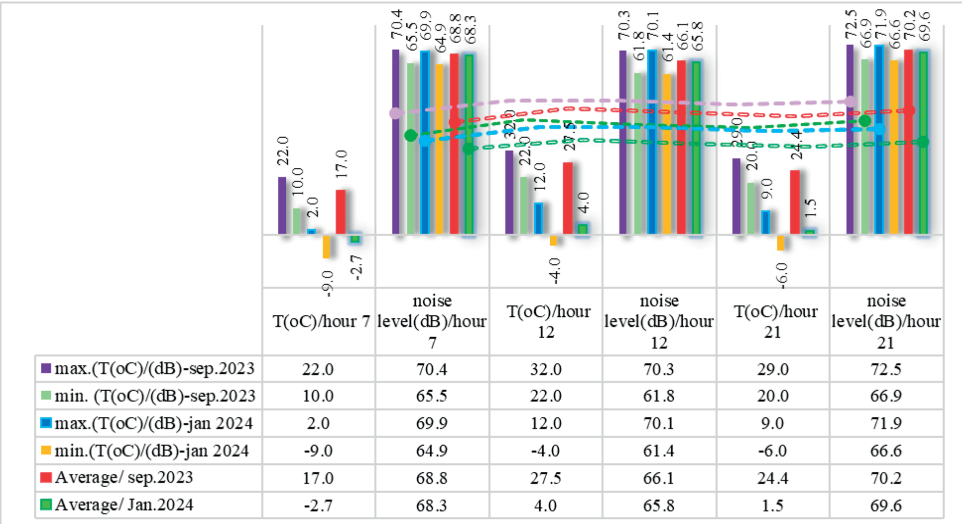


Figure 7. Representation of max./min./average values - September 2023 - January 2024

CONCLUSIONS

Having similar characteristics in both sets of measurements, the values obtained were compared, the aim being to determine the level of traffic noise as a function of ambient temperatures. Also, taking in to account the fact that traffic is different depending on the time of the day, comparisons of the respective values were made according to the period when they fluctuate, being correlated with the corresponding temperatures. From both sets of measurements, it was found that the noise values are lowest around 12 noon, highest in the morning around 7 am, and highest in the evening around 9 pm. However, it should be noted that the values obtained exceed the threshold recommended by the World Health Organization - WHO (WHO, 2018) of 55 dB. From the point of view of temperatures, it was found that the average temperature varies depending on the time of day, as follows: at 7 am in September 2023, at a temperature of 17°C, a noise value of 68.8 dB was determined. At the same time in January 2024, a noise value of 68.3 dB was determined at an ambient temperature of -2.7°C. Table 1 shows the noise variation as a function of temperature. At 12 o'clock in

September 2023, at a temperature of 27.5ºC, a noise value of 66.1 dB was determined. At the same time in January 2024, a noise value of 65.8 dB was determined at an ambient temperature of 4ºC. Table 1 shows the noise variation as a function of temperature at 9 pm in September 2023, at a temperature of 24.4ºC, a noise value of 70.2 dB was determined. At the same time in January 2024, a noise value of 69.6 dB was determined at an ambient temperature of 1.6ºC. If we take the average value of all measurements, for the month of September 2023, for both temperature and noise, we can conclude that at an average temperature of 22.97ºC we have an average noise value of 68.4 dB. Similarly, for January 2024, at an average temperature of 0.97ºC we have an average noise value of 67.97 dB. Comparing the above values, we can see that at a temperature difference of 22ºC between September 2023 and January 2024 respectively, we have a noise difference of 0.43 dB, i.e. at each degree Celsius we have a difference of 0.019 dB. In conclusion, at an average temperature of 22.97ºC the traffic noise is more pronounced than at 0.97ºC by 0.43 dB. It can therefore be concluded that higher temperatures favour the propagation of sound waves in the atmospheric environment.

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REFERENCES

Albu, C., Olaru, M. & Gavrilă, A.G. (2019). Noise pollution in Bucharest: A case study. *In Proceedings of the International Conference on Noise and Vibration Engineering*, pp. 1969-1976.

Baudin, C., Lefèvre, M., Champelovier, P., Lambert, J., Laumon, B., Evrard, A.-S. (2021). Self-Rated Health Status in Relation to Aircraft Noise Exposure, Noise Annoyance or Noise Sensitivity: The Results of a Cross-Sectional Study in France. *BMC Public Health 21*, 116.

Chiriac, C.R., Chiriac, A.E. & Popa, V. (2017). Environmental noise monitoring in Bucharest using GIS technology. *Energy Procedia, 111*, 553-562.

Cueto, J.L., Petrovici, A.M., Hernández, R. & Fernández, F. (2017). Analysis of the impact of bus signal priority on urban noise. *Acta Acustica United Acustica, 103*(4), 561–573. https://doi.org/10.3813/ AAA.919085.

Deaconu, S. & Cioca, L.I. (2019). Noise pollution and urban planning in Bucharest, Romania. In Proceedings of the 16th International *Multidisciplinary Scientific GeoConference SGEM*, pp. 63-70.

EEA Report (2019). Environmental noise in Europe — 2020. ISSN 1977-8449. https://www.courthousenews.com/wp-content/uploads/2020/03/Environment-noise-in-europe-2020_TH-AL-20-003-EN-N.pdf

Ertugrul, E., Sercan, E., (2021). GIS based mapping and assessment of noise pollution in Safranbolu, Karabuk, Turkey. Environment, *Development and Sustainability, 23*, 15413–15431.

Hänninen, O. (2014). Environmental burden of disease in Europe: assessing nine risk factors in six countries, *Environmental Health Perspectives, 122*(5), pp. 439-446 DOI: https://doi.org/10.1289/ehp.1206154.

Liu, S., Lim, Y.-H., Pedersen, M., Jørgensen, J.T., Amini, H., Cole-Hunter, T., Mehta, A.J., So, R., Mortensen, L.H., Westendorp, R.G.J. (2015). Long-Term Exposure to Ambient Air Pollution and Road Traffic Noise and Asthma Incidence in Adults: The Danish Nurse Cohort. *Environ. Int., 152*, 106464.

Marquart, H., Ueberham, M., Schlink, U. (2021). Extending the Dimensions of Personal Exposure Assessment: A Methodological Discussion on Perceived and Measured Noise and Air Pollution in Traffic. *J. Transp. Geogr. 93*, 103085.

Mihalache, C., Erghelegiu, B., Sandu, M.A. (2023). Noise Pollution: A Gis-based approach to mapping and assessment. *Scientific Papers Series E, Land Reclamation, Earth Observation & Surveying, Environmental Engineering, XII*, 2285-6064.

Moscovici, A.-M. & Grecea, O. (2015). Results of research in noise pollution in urban areas. *AgroLife Scientific Journal, 4*(2).

Popescu, D.I. (2023). A Study of the Romanian Framework and the Challenges in Implementing the Noise Mapping Legislation. *Archives of Acoustics, 48*(2), DOI:10.24425/aoa.2023.145233.

Rusu, C.M., Roșu, E., Georgescu, L.P. (2015). Assessment of urban noise pollution in Bucharest, Romania. *Journal of Environmental Protection and Ecology, 16*(3), 1293-1303.

Tăranu, N. & Ioniță, I. (2019). Mapping noise pollution in Bucharest using GIS technology. *Environmental Engineering and Management Journal, 18*(11), 2593-2601.

WHO & JRC (2011). Burden of Disease from Environmental Noise - Quantification of healthy life years lost in Europe. https://apps.who.int/iris/ handle/10665/326424.

World Health Organization - WHO, (2018). Environmental noise guidelines for the European region, WHO Regional Office for Europe, Copenhagen, http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/environmental-noise-guidelines-for the-european-region-2018.

https://www.nde-ed.org/Physics/Sound/ tempandspeed.xhtml