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Analysis of the level of sound noises imitted into the passenger compartment by road vehicles

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Abstract. This scientific paper presents an analysis carried out by the authors in order to implement some concepts, in which technical aspects (theoretical and practical) are presented concerning sound noises, imitated in the passenger compartment by road vehicles, determined on the basis of the second order active type experiment, under the conditions of their running in urban and extraurban environment at different speed regimes (30, 50 and 130 km/h). For the research, a sample of passenger cars from the national fleet of road vehicles, with spark ignition engines, with European pollution standard in the range [Euro 3 - Euro 6], cylinder capacities (cylinders displacement) in the range [1,400 – 1,600] cm^3 and manual and continuously variable transmissions (CVT), which includes all vehicles belonging to owners (natural persons) and legal persons (road transport organisations) at national level. Finally, the conclusions in the field are presented.

Keywords: *road vehicles, noise, immission, pollution, urban and extra-urban road traffic, traffic speed.*

Introduction

In everyday life, the effects of road transport noise are felt by people and sometimes become unbearable in large urban agglomerations where road traffic is heavy. Modern cars are getting quieter. However, when traffic is heavy, the noise is multiplied and amplified by the vertical walls of nearby buildings. Literature research shows that 20% of the European population is currently affected by road traffic noise, which means that noise pollution targets in Europe have not been met. High levels of noise and vibration have various effects on human health, creating discomfort (22 million cases per year), sleep disturbance (6.5 million cases per year), adversely affecting the cardiovascular system (48,000 cases of ischaemic heart disease per year), the metabolic system (12,000 premature deaths per year) and cognitive impairment in children (more than 12,000 children have difficulty reading) [1, p. 133]. Noises are sensations due to stimulation of the auditory nerves and auditory centres of the brain, usually by vibrations transmitted in a material medium (e.g. air), which affect the human auditory

organ (the ear). The vibrational energy that causes such a sensation is defined by sounds. They propagate through progressive longitudinal vibratory disturbances (sound waves) [2, pp. 950-951].

The comfort offered by a vehicle is defined as a state of well-being that positively influences the physical and mental state of the user, causing satisfaction. Acoustic comfort consists of passive sensory concepts rooted in the spectrum of civilisation, cleanliness, comfort, peace of mind, and warmth, making driving and travelling easy and convenient. The comfort of a car is not just about being comfortable in the seats or seats on which we sit and travel. Automobile comfort is also defined by the vibrations and noises transmitted by the engine, transmissions, axles and wheels of a car, but also by those systems, installations, mechanisms and functional elements of the car that support the driver and ease his load (e.g. power steering, power brakes, adjustable and heated or cooled seats, electronic assistance and safety systems for the driver or passengers, electronically controlled climate control systems in different zones, sound and entertainment systems in the passenger compartment, rain and parking assistance sensor systems, close-up camera systems, pleasant vibrations and noises produced by the engine or operating parts, the power provided by the engine(s) that we feel in the seats when accelerating, reduced fuel or energy consumption, etc.).

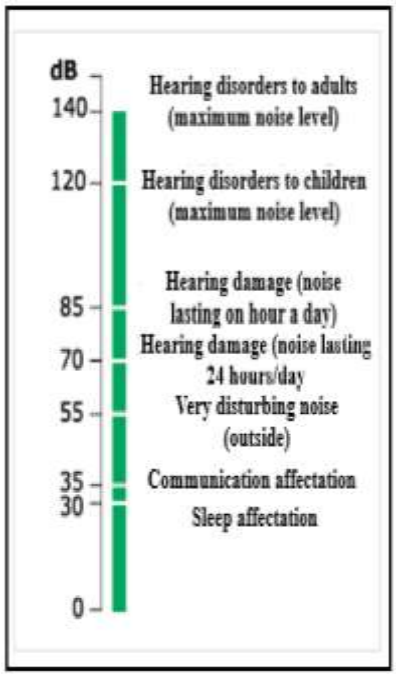

Figure 1. The negative effects of noise on human health [1, p. 78], [7].

The physical perception of sound by humans through their hearing organs (ears) is limited to a certain frequency range. Humans perceive sound waves at frequencies in the range [20-20,000 Hz], the upper limit decreasing with age [3, p. 249]. Most of the time sound refers only to those vibrations with frequencies that are included in the audible range of humans [4]. Figure 1 shows the negative effects of noise on human health. Acoustic comfort [5] is defined by engine noises, rotating or translational moving organs, frictional forces, tire contact with the ground, or the air frictional forces of the vehicle in motion [6, p. 106]. The noises produced by the motor vehicle are perceived by the human ear at a certain sound level, and if they exceed the value of 80 dB, they become dangerous to human health [7, p. 7]. The literature shows that, at European level, more than 20% of the inhabitants of EU countries are affected by road traffic noise [8, p. 117]. It is also estimated, according to the World Health Organization, that more than 40% of Europe's population is affected by road vehicle noise exceeding 55 dB [9].

Regarding EU policies on noise pollution, the Green Book refers to future noise policies. In relation to these policies, the EC has identified environmental noise as the main environmental problem on the European continent.

In view of the research objective, the following two components are of interest:

- acoustic comfort, defined by the level of noise produced by engines, rotating or translating parts, tyre contact with the ground or friction of the moving car with the air.
- vibrational comfort, defined as the resonance of mechanical waves in the structure of the car, perceived at body level by passengers, are caused by rotating or translating elements of the car's organs or by irregularities in the surfaces on which the car runs.

To date, the question of demonstrating these two components of car comfort (acoustics and vibration) has been more or less debated. In view of the above, I have set out to verify in practice, by means of a second-order active type experiment, at different engine speeds and revs in urban and extraurban environments, on conventional (internal combustion) and hybrid vehicles equipped with manual and continuously variable transmissions (CVT), the level of noise pollution in the passenger compartment. The vehicles used in the research have different comfort classes.

1. Literature review, legislative regulation and specific conditions for conducting experimental research

1.1 Reference data on noise emissions from road motor vehicles with spark ignition and compression ignition engines

Noise pollution is the noise produced by cars during operation and is created by frictional forces between moving parts or components. Noise pollution is also produced by cars in dynamic motion when tyres are in contact with the road surface and when air is rubbing against the outer bodywork.
The physical characteristics of noise are [1, pp. 117-118]:

- *intensity (or strength)* - depends on the properties of the generating source, space and the probability of transmission or multiplication. Its unit of measurement is the phonon or decibel (human ear perception), which is a logarithmic unit measured from the lower threshold of audibility (1,000 Hz = 0 dB);
- *duration* - the time the sound waves act on the analysis device (human ear or sound level meter);
- *frequency (sound pitch)* - number of vibrations/second. Its unit of measurement is the hertz (Hz).

The A-weighted decibel, or dB(A), is the unit of measurement used to evaluate the loudness as perceived by the human ear, since the sensitivity of hearing is not the same over the entire frequency range. A mechanical instrument, e.g. a microphone, will perceive all frequencies equally in decibels, whereas the human ear, while perceiving sounds between 20 Hz and 20 kHz, is much more sensitive to sounds with frequencies between 250 and 5,000 Hz. The A-weighting of sound level meter measurements gives a higher value to sounds in the frequency range where the ear is sensitive and a lower value to sounds outside this range. In terms of audibility, the perceived loudness of sounds ranges from 0 to 120 dB(A). Normal conversational noise is in the range 30-60 dB(A). The lower limit at which hearing is considered to suffer over time with prolonged exposure is 85 dB(A). Intensities of 140 dB(A) and above create a painful sensation and possible serious hearing damage.

The European Union has regularly amended its legislation on maximum noise levels emitted by road vehicles in an attempt to reduce noise pollution. The first piece of legislation regulating pollution standards for motor vehicles was Directive 70/157/EEC/06.02.1970, which regulated for the first time noise emission limits from motor vehicles and set out technical specifications for measurable levels of noise emitted outdoors by road vehicles during operation. The Directive was amended by UNECE Regulation No 51. Finally, on 09.12.2011, the European Commission proposes to the European Parliament and the Council a Regulation setting the noise threshold of road vehicles, repealing Directive 70/157/EEC/06.02.1970 [10] . Table 1 shows the legal sound level limit values as specified in Appendix III of the Regulation on the sound level of motor vehicles, issued by the European Commission on 16.04.2014.

Table 1. Legal limit values of the measured noise level as specified in Appendix III of the Regulation on the sound level of motor vehicles [10].

Vehicle category	**Description of vehicle category**	**Limit values expressed in dB(A) [decibels (A)]**		
		Stage 1, applicable to new types of vehicles from July 01. 2016	**Stage 2, applicable to new vehicle types from 1 July 2020 and for first registration from July 01. 2022**	**Stage 3, applicable to new vehicle types from 01 July 2024 and for first registration from July 01. 2026**
Vehicule pentru transportul de persoane din categoria M				
M_1	Power to mass ratio ≤ 120 kW/ 1,000 kg	72(*)	70(*)	68(*)

(*) M1 category vehicles derived from N1 category: vehicles with a mass of 2,500 kg must comply with the limit values for N1 category (2,500 kg < M1 category mass with R point > 850 mm above the ground and a total permissible mass ≤ 3,500 kg) [10].

For M1 vehicles, the higher limit values for off-road vehicles apply only if the maximum authorised mass is > 2 tonnes [10].
The yellow coloured column in Table 1 is the subject of the research. The noise produced by the cars used in the experimental research falls within the sound value of 72 dBA.

1.2 Power to mass ratio

In order to fit each car on which we conducted experimental research into the legal noise standard according to Annex III of the Motor Vehicle Noise Regulation issued by the European Commission on April 16. 2014 (Table 2), it was necessary to calculate the Power to Mass Ratio (PMR).

The Power to Mass Ratio (PRM) is determined with the mathematical relation [10, p. 131]:

$$PRM = (P_n/m_t) \times 1.000 \quad [kW/kg] \qquad (1)$$

where,

P_n is the rated power and is measured in kilowatts (kW);

m_t - the total mass of the vehicle and shall be measured in kilograms (kg),

but,

$$m_t = m_{ro} \quad [kg] \qquad (2)$$

were,

m_{ro} means the mass of the vehicle in running order [11, p. 70].

Vehicle mass in running orde (m_{ro}) is defined as the weight of an unladen vehicle, with the box, freight container or passenger compartment/passenger compartment, with coupling or towing hitch in the case of a towing vehicle, with the weight of the rigid strength frame (chassis) and the driver's compartment (cab), if the vehicle is delivered without the box or bodywork and/or the manufacturer's towing device, including the full load of the cooling system, engine and transmission lubrication system, with the full load of the fuel tank (90%) and other special fluids (100%). Exceptions are waste water, dashboard and other instruments, spare wheel, driver with a maximum weight of 75 kg, and for public transport (minibuses, trolleybuses, buses, coaches) the weight of the accompanying person is taken into account, which must be a maximum of 75 kg (if the vehicle is equipped with a seat for an accompanying person) [11, p. 70]. The Power to Mass Ratio (PMR) is dimensionless.

Table 2 shows the power-to-mass ratio (PMR), calculated from the mathematical relation (1), for cars for which noise noises have been determined.

Table 2. Power to Mass Ratio (PMR) calculated for the vehicles for which noise was determined.

Type	**Make of vehicle, engine capacity and European pollution standard**	**Year of manufac-ture**	**Engine/ engines power** [kW]	**Own mass of the vehicle** [kg]	**PMR** [kw/1.000 kg]
A. Hybrid vehicles with spark ignition engines					
Car	Toyota RAV 4 - 2.5 L, Euro 6	2019	131	1,730	**75**
B. Motor vehicles with spark ignition engines					
Car	Volkswagen Jetta TSI 1.4 L, Euro 6	2015	92	1,341	**69**
Car	Volkswagen Jetta TSI 1.4 L, Euro 5	2009	125	1,440	**87**
Car	Dacia Logan 1.4 MPI, Euro 4	2009	55	1,105	**50**
Car	Volkswagen Golf 1.6 L, Euro 4	2006	75	1,283	**58**
Car	Ford Focus ZX 4, SUA 2.0 L, Euro 3	2007	165	1,685	**98**
Car	Dacia Solenza 1.4 MPI, Euro 3	2004	55	980	**56**

Immediate conclusion: The analysis of the data presented in Table 2 shows that all the passenger cars investigated for noise emissions fall into the category M1 passenger cars with a power to mass ratio ≤ 120 kW/1000 kg (Table 1). They fall under stage we which is applicable to new vehicles manufactured from July 01, 2016 at the noise, i.e. at the sound value to which the research relates – **72 dBA**.

1.3 Specific conditions for conducting experimental research

As regards the research on noise pollution measured inside the passenger compartment of motor vehicles, it was carried out in order to define the acoustic comfort provided to the driver and passengers while driving the vehicle. They were carried out by measuring and recording the sound waves and vibrations produced by the vehicle when driving in urban areas at different speeds (30 km/h and 50 km/h) and on motorways at the maximum legal speed limit (130 km/h) using a professional TROTEC SL 400 sound level meter (Fig. 2). All data were recorded in the internal memory of the sound level meter. The TROTEC SL 400 professional sound level meter is a device that meets the requirements for noise measuring instruments, accuracy class 2 according to IEC 61672-1 as well as ANSI S1.4, and is recommended for documenting road traffic noise, workplace measurements or environmental auditing [12]. The four-position display has bar graph representation, which can be easily read in all conditions, even in the dark, thanks to the backlit LCD display. The SL 400 professional sound level meter is a perfect solution for professional noise measurements. The practical size, low weight and one-hand operation due to the optimised layout of the keys makes this device the perfect equipment for sound level measurement in workshops and industrial halls, labour and environmental protection. The SL 400 professional sound level meter has an additional live logging function and a data memory for up to 32,700 values. The data obtained from the experimental investigations are related to the legislative provisions shown in Table 2 and were transferred to a computer system, through which the experimental data were processed [13], using Excel software. The processing of noise data was also done using the SL-400 sound level meter's own software. Following the processing of the noise data, the results were analysed and interpreted and conclusions and further research directions were drawn.

Figure 2. Professional Sound Level Meter SL 400 and aspects during the research.

The following conditions were respected during the experimental research:

- the test was carried out on routes consisting of streets of all categories within Sibiu and on the A1 motorway, over distances of 5-30 km;
- accelerations and decelerations were not programmed, but were those required by compliance with road traffic rules, the principles of preventive traffic and eco-driving;
- speed on urban streets: 30 km/h and 50 km/h respectively, and 130 km/h on motorways (in compliance with road traffic rules);
- the vehicle was equipped with a portable noise emission measurement system (SL 400 sound level meter), mounted inside the passenger compartment;
- test time was within the range 15-45 minutes;
- outside ambient temperature was between +20 and +25 °C;
- the experimental route, both urban and extraurban, was the same for all vehicles

2. Centralisation of experimental results

The experimental research was carried out on vehicles of different makes. Experimental investigations were carried out on motor vehicles with petrol engines, with cylinder capacities in the range [1,400-2,500] cm^3, with European pollution standards in the range [Euro 3-Euro 6].

The experimental investigations were carried out for each type of vehicle by driving on predetermined routes in urban areas at a relatively constant speed of 30 km/h and 50 km/h respectively, and on motorways at a constant speed of 130 km/h. They were carried out at different times of the day, under the same outdoor temperature and traffic conditions. To see if there was a difference in chemical and noise noxious emissions, a hybrid car with a cylinder capacity of 2,500 cm^3 and a European Euro 6 pollution standard was also tested.

The physical wear of each vehicle used for the experiments is defined by the number of kilometres driven, and the moral wear is defined by the age in years. The exception was the Ford Focus ZX 4 USA car, which has 81,525 km of mileage, although it has a considerable amount of moral wear. For this car, the average actual kilometres driven per year of age is 5,435 km/year.

The average actual kilometres travelled per year of age for the other cars with spark ignition engines used in the experiments is as follows: Toyota RAV 4 hybrid car, Euro 6 - 8,566 km; Volkswagen Jetta 1.4 liters, Euro 4 car - 9,327 km; Dacia Solenza 1.4 MPI, Euro 3 car - 9,509 km; Dacia Logan 1.4 litres, Euro 4 car - 10,264 km; Volkswagen Jetta 1.4 liters TSI, Euro 6 car - 11,317 km; Volkswagen Golf 1.6 liters, Euro 4 car - 14,909 km.

I specify these aspects because the physical wear and tear of a vehicle can lead to a different level of noise pollution (a vehicle whose engine mechanism is in an advanced state of physical wear and tear, whose parts or components are worn out, produces much greater vibrations and noise than a new one).

The sound level data measured with the SL 400 sound level meter in the passenger compartment cars are presented as follows:

- in Table 3 for passenger cars with hybrid and spark ignition engines at 30 km/h in urban areas;
- in Table 4 for passenger cars with hybrid and spark ignition engines at 50 km/h in urban areas;
- in Table 5 for passenger cars with hybrid and spark ignition engines at 130 km/h on motorways in extraurban areas.

Table 3. Centralizer with minimum, average and maximum noise values measured in the passenger compartment of cars with hybrid and spark ignition engines when driving in urban areas at 30 km/h.

Type and make of vehicle	European pollution standard	Cylinder capacity (cm^3)	Kilometre at board (actual km)	Age (years)	Sound values measured inside the passenger compartment dB(A)		
					Minimum	Average	Maximum
A. Hybrid cars with spark ignition engines							
TOYOTA RAV 4 hibrid car	Euro 6	2,500	25,696	3	51.7	57.2	66.6
B. Cars with spark ignition engines							
VOLKSWAGEN JETTA TSI car	Euro 6	1,400	79,217	7	56.1	61.5	77.7
VOLKSWAGEN JETTA TSI car	Euro 5	1,400	121,244	13	53.0	65.0	79.6
DACIA LOGAN car	Euro 4	1,400	133,426	13	45.8	57.7	72.7
VOLKSWAGEN GOLF car	Euro 4	1,600	238,897	16	58.9	68.7	86.1
FORD FOCUS ZX 4 SUA car	Euro 3	2,000	81,525	15	56.9	64.9	76.4
DACIA SOLENZA car	Euro 3	1,400	171,161	18	59.2	68.1	83.3

Table 4. Centralizer with minimum, average and maximum noise values measured in the passenger compartment of cars with hybrid and spark ignition engines when driving in urban areas at 50 km/h.

Type and make of vehicle	European pollution standard	Cylinder capacity (cm^3)	Kilometre at board (actual km)	Age (years)	Sound values measured inside the passenger compartment dB(A)		
					Minimum	Average	Maximum
A. Hybrid cars with spark ignition engines							
TOYOTA RAV 4 hibrid car	Euro 6	2,500	25,696	3	47.8	59.1	72.8
B. Cars with spark ignition engines							
VOLKSWAGEN JETTA TSI car	Euro 6	1,400	79,217	7	55.2	63.0	75.3
VOLKSWAGEN JETTA TSI car	Euro 5	1,400	121,244	13	56.2	61.9	72.2
DACIA LOGAN car	Euro 4	1,400	133,426	13	44.3	58.1	76.9
VOLKSWAGEN GOLF car	Euro 4	1,600	238,897	16	58.1	69.2	86.8
FORD FOCUS ZX 4 SUA car	Euro 3	2,000	81,525	15	52.6	66.9	84.3
DACIA SOLENZA car	Euro 3	1,400	171,161	18	55.8	70.6	85.6

Table 5. Centralizer with minimum, average and maximum noise noises measured in the passenger compartment of cars with hybrid and spark ignition engines when driving on the extraurban motorway at 130 km/h.

Type and make of vehicle	European pollution standard	Cylinder capacity (cm^3)	Kilometre at board (actual km)	Age (years)	Sound values measured inside the passenger compartment dB(A)		
					Minimum	Average	Maximum
A. Hybrid cars with spark ignition engines							
TOYOTA RAV 4 hibrid car	Euro 6	2,500	25,696	3	67.1	73.1	77.6
B. Cars with spark ignition engines							
VOLKSWAGEN JETTA TSI car	Euro 6	1,400	79,217	7	67.1	73.2	89.3
VOLKSWAGEN JETTA TSI car	Euro 5	1,400	121,244	13	64.8	71.0	87.0
DACIA LOGAN car	Euro 4	1,400	133,426	13	52.1	72.0	82.1
VOLKSWAGEN GOLF car	Euro 4	1,600	238,897	16	64.6	76.1	89.0
FORD FOCUS ZX 4 SUA car	Euro 3	2,000	81,525	15	64.1	73.7	83.1
DACIA SOLENZA car	Euro 3	1,400	171,161	18	76.3	81.1	85.5

The legend

Legal rule in Appendix III of the ***Regulation on the sound level of motor vehicles***, issued by the European Commission on April 16. 2014	**EUROPEAN VEHICLE POLLUTION STANDARD**	**Maximum permissible sound limit dB(A)**	Normal values, not exceeding legal limit
	Vehicles for the carriage of passengers of category M1 having a Power to Mass Ratio (PMR) ≤ 120 kW/1,000 kg	72	Values above the legal limit

3. Research hypotheses

Research hypothesis no. 1: *Hybrid cars, although part of the environmentally friendly road transport category, generate noise emissions due to the thermal engine fitted to them, which produces noise and vibration during operation/dynamics;*

***Research hypothesis no.* 2:** *At low speeds (30 km/h and 50 km/h), car engines run at higher revs and noise pollution increases;*

***Research hypothesis no.* 3:** *When vehicles are driven on a motorway route, the thermal engine running at higher engine speeds, tyre-road contact and friction of the car with the air increase noise levels;*

4. Results and discussions

4.1 Noise in the passenger compartment of the Toyota RAV 4 hybrid, Euro 6 car

Figure 3 shows the graph of the evolution of the noise perceived in the passenger compartment of the Toyota RAV 4 hybrid car 2.5 liters, Euro 6 car, during urban and highway driving.

An analysis of the development of noise in the passenger compartment of the Toyota RAV 4 hybrid 2.5 liters, Euro 6 car emission standard shows the following data:

- when driving the urban route at 30 km/h, minimum noise value = 51.70 dBA, average value = 57.20 dBA, maximum value = 66.60 dBA;
- when driving the urban route at 50 km/h, minimum noise value = 47.80 dBA, average value = 59.10 dBA, maximum value = 72.80 dBA;
- when driving on the A1 - Sibiu motorway, minimum noise value = 67.10 dBA, average value = 73.10 dBA, maximum value = 77.60 dBA.

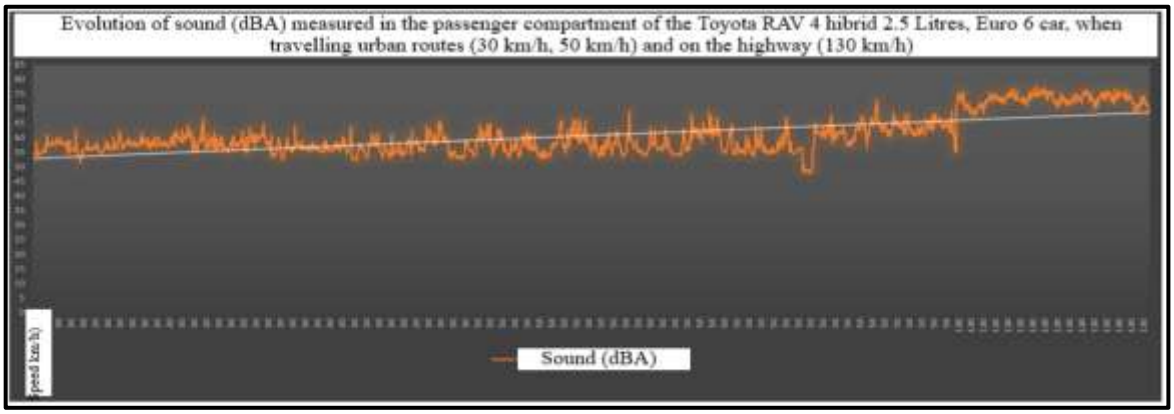

Figure 3. The evolution of sound (dBA) measured in the passenger compartment of the Toyota RAV 4 hibrid 2.5 liters, Euro 6 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

4.2 Noise in the passenger compartment of the Volkswagen Jetta, 1,4 l, TSI, Euro 6 car

Figure 4 shows the graph of the evolution of the noise perceived in the passenger compartment of the Volkswagen Jetta 1.4 liters TSI, Euro 6 car, when driving in urban areas and on motorways.

An analysis of the development of noise in the passenger compartment of the Volkswagen Jetta, 1.4 liters TSI, Euro 6 car, the following data are available:

- when driving the urban route at 30 km/h, minimum noise value = 56.10 dBA, average value = 61.50 dBA, maximum value = 77.70 dBA;
- when driving the urban route at 50 km/h, minimum noise value = 55.20 dBA, average value = 63.00 dBA, maximum value = 75.30 dBA;
- when driving on the A1 - Sibiu motorway, minimum noise value = 67.10 dBA, average value = 73.20 dBA, maximum value = 89.30 dBA.

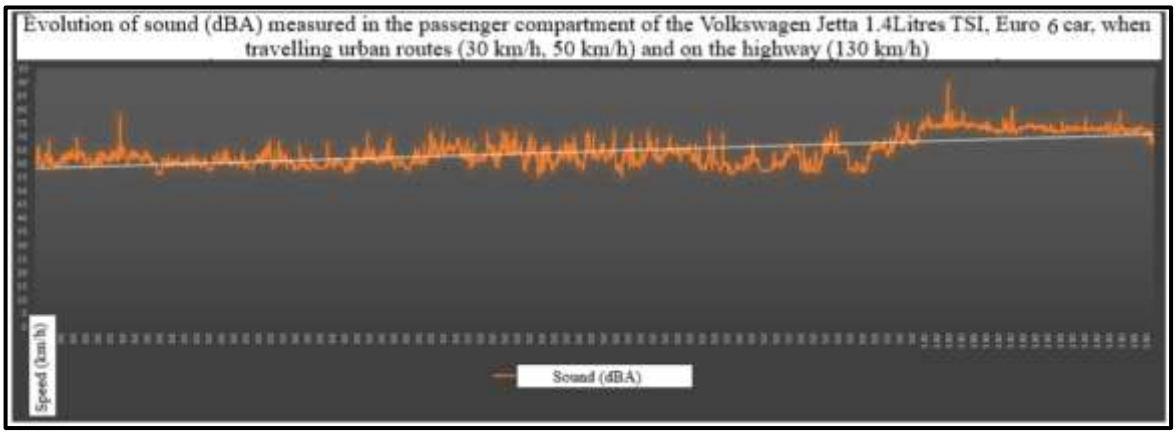

Figure 4. The evolution of sound (dBA) measured in the passenger compartment of the Volkswagen Jetta 1.4 liters TSI, Euro 6 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

4.3 Noise in the passenger compartment of the Volkswagen Jetta, 1,4 liters, Euro 5 car

Figure 5 shows the graph of the evolution of the sound received in the passenger compartment of the Volkswagen Jetta, 1.4 liters, Euro 5 car, during urban and motorway driving.

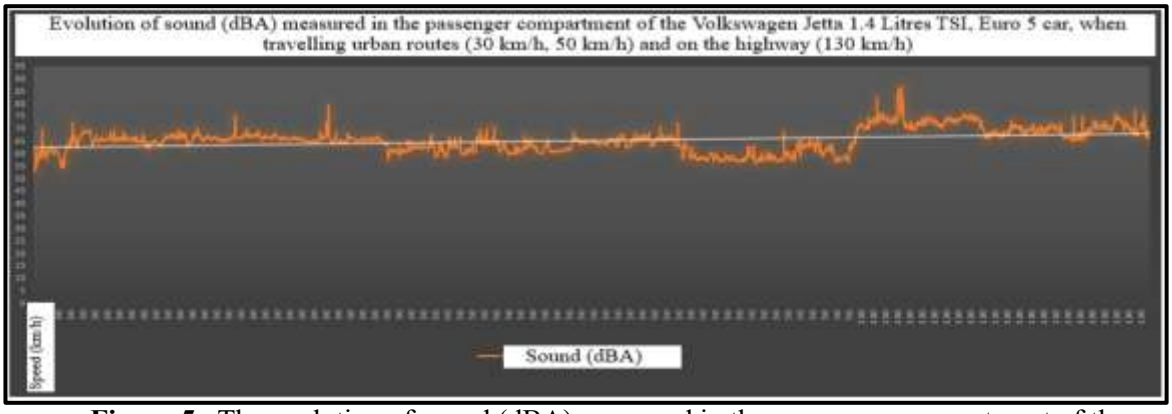

Figure 5. The evolution of sound (dBA) measured in the passenger compartment of the Volkswagen Jetta 1.4 liters TSI, Euro 5 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

An analysis of the evolution of the sound in the passenger compartment of the Volkswagen Jetta 1.4 liters TSI, Euro 5 car, shows the following data:

- when driving the urban route at 30 km/h minimum sound value = 53.00 dBA, average sound value = 65.00 dBA, maximum sound value = 79.60 dBA;
- when driving on the urban route at a speed of 50 km/h minimum sound value = 56.20 dBA, average sound value = 61.90 dBA, maximum sound value = 72.20 dBA;
- when driving on the A1 - Sibiu motorway at a speed of 130 km/h minimum sound value = 64.80 dBA, average sound value = 71.00 dBA, maximum sound value = 87.00 dBA.

4.4 Noise in the passenger compartment of the Dacia Logan, 1,4 liters MPI, Euro 4 car

Figure 6 shows the graph of the evolution of the sound received in the passenger compartment of the Dacia Logan 1.4 liters, Euro 4 car, while driving in urban areas and on motorways.

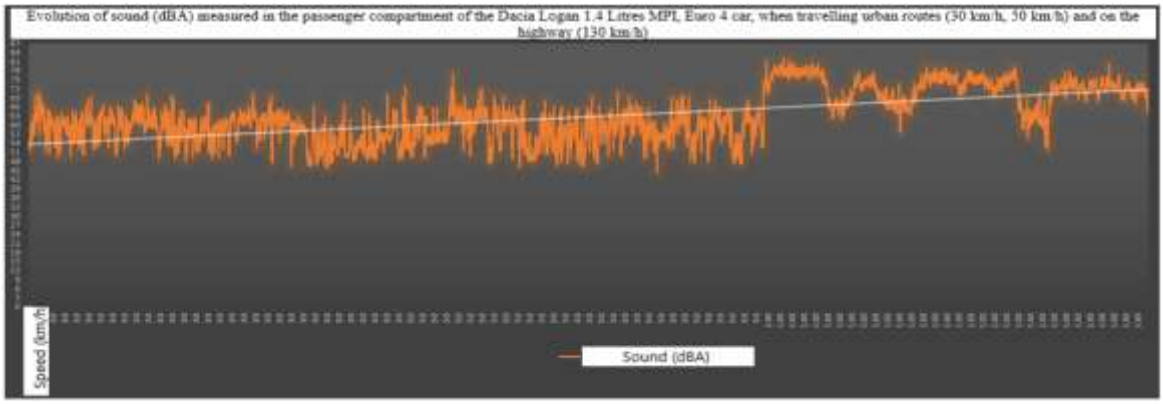

Figure 6. The evolution of sound (dBA) measured in the passenger compartment of the Dacia Logan 1.4 liters MPI, Euro 4 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

An analysis of the evolution of the sound in the passenger compartment of the Dacia Logan 1.4 liters, Euro 4 car shows the following data:

- when driving the urban route at 30 km/h minimum sound value = 45.80 dBA, average sound value = 57.70 dBA, maximum sound value = 72.70 dBA;
- when driving on the urban route at a speed of 50 km/h minimum sound value = 44.0 dBA, average sound value = 58.10 dBA, maximum sound value = 76.90 dBA;
- when driving on the A1 - Sibiu motorway at a speed of 130 km/h minimum sound value = 52.10 dBA, average sound value = 7.00 dBA, maximum sound value = 82.10 dBA.

4.5 Noise in the passenger compartment of the Volkswagen Golf 1,6 liters, Euro 4 car

Figure 7 shows the graph of the evolution of the sound received in the passenger compartment of the Volkswagen Golf 1.6 liters, Euro 4 car, during urban and motorway driving.

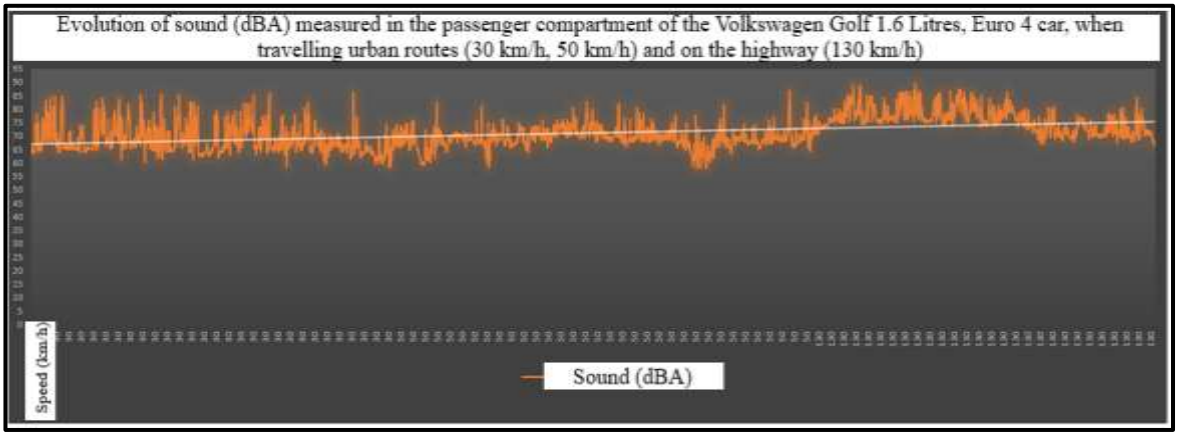

Figure 7. The evolution of sound (dBA) measured in the passenger compartment of the Volkswagen Golf 1.6 liters, Euro 4 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

An analysis of the evolution of the sound in the passenger compartment of the Volkswagen Golf 1.6 liters, Euro 4 car, shows the following data:

- when driving through the urban route at a speed of 30 km/h minimum sound value = 58.90 dBA, average sound value = 68.70 dBA, maximum sound value = 86.10 dBA;

- when driving on the urban route at a speed of 50 km/h minimum sound value = 58.10 dBA, average sound value = 69.20 dBA, maximum sound value = 86.80 dBA;
- when driving on the A1 - Sibiu motorway at a speed of 130 km/h minimum sound value = 64.60 dBA, average sound value = 76.10 dBA, maximum sound value = 89.60 dBA.

4.6 Noise in the passenger compartment of the Ford Focus ZX4 SUA 2,0 liters, Euro 3 car

Figure 8 shows the graph of the evolution of the sound received in the cabin of the Ford Focus ZX4 USA 2.0 liters, Euro 3 car, when driving in urban areas and on motorways.

An analysis of the evolution of sound in the passenger compartment of the Ford Focus ZX 4 USA, 2.0 liters, Euro 3 car, shows the following data:

- when driving through the city at a speed of 30 km/h minimum sound value = 56.90 dBA, average sound value = 64.90 dBA, maximum sound value = 76.40 dBA;
- when driving on the urban route at a speed of 50 km/h minimum sound value = 52.60 dBA, average sound value = 66.90 dBA, maximum sound value = 84.30 dBA;
- when driving on the A1 - Sibiu motorway at a speed of 130 km/h minimum sound value = 64.10 dBA, average sound value = 73.70 dBA, maximum sound value = 83.10 dBA.

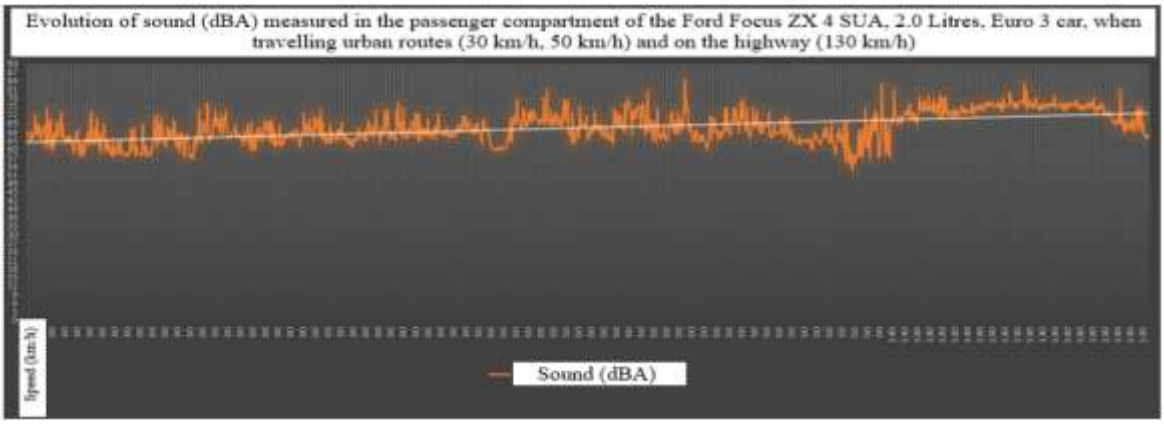

Figure 8. The evolution of sound (dBA) measured in the passenger compartment of the Ford Focus ZX 4 SUA, 2.0 liters, Euro 3 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

4.7 Noise in the passenger compartment of the Dacia Solenza 1,4 MPI, Euro 3 car

Figure 9 shows the graph of the evolution of the sound received in the passenger compartment of the Dacia Solenza 1,4 MPI, Euro 3 car.

An analysis of the evolution of the sound in the passenger compartment of the Dacia Solenza 1.4 liters MPI, Euro 3 car, shows the following data:

- when driving through the city at a speed of 30 km/h the minimum sound value = 59.20 dBA, the average sound value = 68.10 dBA, the maximum sound value = 83.30 dBA;
- when driving on the urban route at a speed of 50 km/h minimum sound value = 55.80 dBA, average sound value = 70.60 dBA, maximum sound value = 85.60 dBA;
- when driving on the A1 - Sibiu motorway at a speed of 130 km/h minimum sound value = 76.30 dBA, average sound value = 81.10 dBA, maximum sound value = 85.50 dBA.

za 1.4 MPI, Euro 3 car, while driving in urban areas and on motorways.

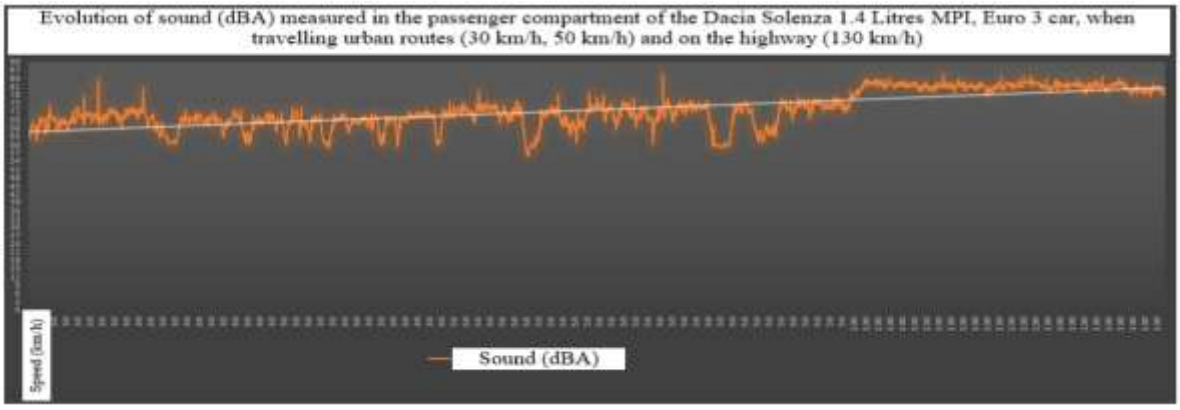

Figure 9. The evolution of sound (dBA) measured in the passenger compartment of the Dacia Solenza 1.4 liters MPI, Euro 3 car, when travelling urban routes (30 km/h, 50 km/h) and on the highway (130 km/h).

5. Conclusions

1. The trend in cabin noise in the **Toyota RAV 4 hybrid 2.5 liters, Euro 6 car**, on both urban and motorway routes is increasing. The level of cabin noise increases with increasing speed. When driving the urban route at a speed of 30 km/h, the noise levels do not exceed the legal standard (72 dBA), which does **not confirm** research hypothesis No 1. When driving the urban route at 50 km/h, the minimum and average values of imis noise do not exceed the legal norm, which does **not confirm** research hypothesis No. 1. The maximum values exceed the legal norm, which **confirms** research hypothesis 1. When driving on the A1 - Sibiu motorway, the minimum noise values do not exceed the legal standard, but the average and maximum values exceed it, which **confirms** research hypothesis No 1. The noise imitted by the car increases with the increase in urban traffic speed from 30 km/h to 50 km/h and thus to 130 km/h. The linear evolution of the noise emitted on the three routes shows a rapid increase in values.

2. The trend in cabin noise in the **Volkswagen Jetta 1.4 liters TSI, Euro 6 car**, on both urban and motorway routes is increasing. The level of cabin noise increases with increasing speed. When driving the urban route at a speed of 30 km/h, the minimum and average values of the noise level do not exceed the legal standard of 72 dBA. The maximum values exceed the legal standard, which **confirms** research hypothesis No 2. When driving on the urban route at 50 km/h, the minimum and average values of imis noise do not exceed the legal standard. The maximum values exceed the legal standard. When driving on the A1 - Sibiu motorway, the minimum imis noise values do not exceed the legal standard. The maximum and average values exceed the legal standard, which **confirms** research hypothesis No 3. The noise imitted by the car decreases with the decrease of the urban traffic speed from 50 km/h to 30 km/h. The linear evolution of noise on the three routes shows a rapid increase in values.

3. The trend in the sound level in the passenger compartment of the **Volkswagen Jetta 1.4 liters, Euro 5 car** on both urban and motorway routes is slightly increasing. The level of noise in the passenger compartment increases with increasing speed. When driving the urban route at a speed of 30 km/h the minimum and average values of the noise level do not exceed the legal standard of 72 dBA. The maximum imis sound values exceed the legal norm, which **confirms** research hypothesis No 2. When driving the urban route at a speed of 50 km/h the minimum and average values of immis sound do not exceed the legal standard. The maximum values of imis exceed the legal standard. When driving on the A1 - Sibiu motorway at a speed of 130 km/h the minimum and average values of the immis sound do not exceed the legal norm. The maximum imis sound values exceed the legal norm, which **confirms** research hypothesis No 3. The noise imitted by the car in the passenger compartment

decreases slightly with the decrease of the driving speed in the urban environment from 30 km/h to 50 km/h. The linear evolution of the noise on the three routes shows a slow increase in values.

4. The trend of the sound in the passenger compartment of the **Dacia Logan 1.4 liters, Euro 4 car**, on both urban and motorway routes is increasing. The level of cabin noise increases with increasing speed. When driving the urban route at a speed of 30 km/h the minimum and the average value of the noise immission does not exceed the legal standard of 72 dBA. The maximum imis values exceed the legal standard, which **confirms** research hypothesis No 2. When driving the urban route at a speed of 50 km/h the minimum and average values of immis sound do not exceed the legal standard. The maximum values of imis exceed the legal norm. When driving on the A1 - Sibiu motorway at a speed of 130 km/h the minimum and average values of the immis sound do not exceed the legal norm. The maximum imis sound values exceed the legal norm, which **confirms** research hypothesis No 3. The noise imitted by the car in the passenger compartment decreases with the decrease of the driving speed in urban areas from 30 km/h to 50 km/h. The linear evolution of the noise on the three routes shows a rapid increase in values.

5. The trend in the sound level in the passenger compartment of the **Volkswagen Golf 1.6 liters, Euro 4 car**, on both urban and motorway routes is increasing. The level of noise in the passenger compartment increases with increasing speed. When driving the urban route at a speed of 30 km/h, the minimum noise level and the average noise level do not exceed the legal standard. The maximum imis sound values exceed the legal standard, which is 72 dBA, wich **confirms** research hypothesis No 2. When driving the urban route at a speed of 50 km/h, the minimum sound values and the average immission value do not exceed the legal standard. When driving on the A1 - Sibiu motorway at a speed of 130 km/h, the minimum sound values do not exceed the legal standard. The maximum and average values of imis sound exceed the legal norm, which **confirms** research hypothesis No 3. The noise imitted by the car in the passenger compartment decreases with the decrease of the driving speed in the urban environment from 30 km/h to 50 km/h. The linear evolution of the noise on the three routes shows a slow increase in values.

6. The trend in the sound development in the cabin of the **Ford Focus ZX 4 SUA 2.0 liters, Euro 3 car**, on both urban and motorway routes is increasing. The level of cabin noise increases with increasing speed. When driving the urban route at a speed of 30 km/h the minimum values and the average value of the noise immission do not exceed the legal norm. The maximum values of imis exceed the legal standard of 72 dBA, which **confirms** research hypothesis No 2. When driving the urban route at a speed of 50 km/h the minimum and average values of immis sound do not exceed the legal standard. The maximum values of imis exceed the legal standard. When driving on the A1 - Sibiu motorway at a speed of 130 km/h the minimum values of immis sound do not exceed the legal standard. The maximum and average values of imis exceed the legal norm, which **confirms** research hypothesis No 3. The noise imitted by the car in the passenger compartment decreases with the decrease of the driving speed in the urban environment from 30 km/h to 50 km/h. The linear evolution of the noise on the three routes shows a rapid increase in values.

7. The trend of the sound in the passenger compartment of the **Dacia Solenza 1.4 liters MPI, Euro 3 car**, on both urban and motorway routes is increasing. The level of cabin noise increases with increasing speed. When driving the urban route at a speed of 30 km/h the minimum values and the average value of the noise immission do not exceed the legal norm. The maximum values of imis exceed the legal standard of 72 dBA, which **confirms** research hypothesis No 2. When driving the urban route at a speed of 50 km/h the minimum and average values of immis sound do not exceed the legal standard. The maximum values of imis exceed the legal standard. When driving on the A1 - Sibiu motorway at a speed of 130 km/h, all the imis sound values exceed the legal norm, which **confirms** research hypothesis No 3. The noise imitted by the car in the passenger compartment decreases with the decrease of the driving speed in urban areas from 30 km/h to 50 km/h. The linear evolution of the noise on the three routes shows a rapid increase in values.

Analysed in terms of average values, for noise noises that are regulated by legislation, for **hybrid** and **spark ignition cars**, the situation is as follows:

- cars that exceeded the legal standard of 72 dBA in the extraurban environment on the motorway: Toyota Rav 4 hybrid Euro 6 car (73.10 dBA); Volkswagen Jetta 1.4 TSI, Euro 6 car (73.20 dBA); Volkswagen Golf 1.6 l, Euro 4 car (76.10 dBA); Ford Focus ZX4 USA, Euro 3 car (73.10 dBA) and Dacia Solenza 1.4 MPI, Euro 3 car (81.10 dBA);
- Dacia Solenza 1.4 MPI, Euro 3 car is the most polluting car in terms of noise in the passenger compartment. When driving on the motorway, the minimum, average and maximum values were exceeded (minimum value = 76.3 dBA; average value = 81.10 dBA; maximum value = 85.5 dBA);
- peak noise levels in the passenger compartment in the urban environment, when driving at 30 km/h, were reached by: Volkswagen Jetta 1.4 TSI, Euro 6 car = 77.7 dBA; Volkswagen Jetta 1.4 TSI, Euro 5 car = 79.6 dBA; Dacia Logan 1.4 MPI, Euro 4 car = 72.7 dBA; Volkswagen Golf 1.6 l, Euro 4 car = 86.10 dBA; Ford Focus ZX4 USA, 2.0 liters, Euro 3 car = 76.4 dBA; Dacia Solenza 1.4 MPI, Euro 3 car = 83.3 dBA;
- peak noise levels in the passenger compartment in the urban environment, when driving at 50 km/h, were reached by: Toyota RAV 4 hybrid 2.5 liters, Euro 6 car = 72.8 dBA; Volkswagen Jetta 1.4 TSI, Euro 6 car = 75.3 dBA; Volkswagen Jetta 1.4 TSI, Euro 5 car = 72.2 dBA; Dacia Logan 1.4 MPI, Euro 4 car = 76.9 dBA; Volkswagen Golf 1.6 liters, Euro 4 car = 86.8 dBA; Ford Focus ZX4 USA, 2.0 l, Euro 3 car = 84.3 dBA; Dacia Solenza 1.4 MPI, Euro 3 car = 85.6 dBA;
- peak noise levels in the passenger compartment in the extra-urban environment, when driving on the motorway at 130 km/h, were reached by: Toyota RAV 4 hybrid 2.5 liters, Euro 6 car = 77.6 dBA; Volkswagen Jetta 1.4 TSI, Euro 6 car = 89.3 dBA; Volkswagen Jetta 1.4 TSI, Euro 5 car = 87.00 dBA; Dacia Logan 1.4 MPI, Euro 4 car = 82.1 dBA; Volkswagen Golf 1.6 l, Euro 4 car = 89.6 dBA; Ford Focus ZX4 USA, 2.0 liters, Euro 3 car = 83.1 dBA; Dacia Solenza 1.4 MPI, Euro 3 car = 85.5 dBA;

In the case of the cars used in this research, from the analysis of the data presented, the level of noise pollution imitted in the passenger compartment is determined by the level of engine speed, the type and profile of the tyres, the condition and degree of deterioration of the road surface, the state of maintenance, the level of noise produced by the transmission components and organs, the soundproofing level of the bodywork, the age in years (moral wear) and physical wear.

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