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Research Paper

An Overview of the Noise Levels Measured in Industrial Facilities in Serbia and Implemented Methods of Protection

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Noise is one of the most significant factors which not only disturbs working conditions, but has a large impact on workers' health. This problem has existed in industries since the beginning and, despite technical and other solutions, it has not been solved. There is a large number of papers, supported with very detailed analyses, that investigate noise levels in industry or contain questionnaires about the impact of noise on workers' overall health and work abilities. The purpose of this paper is to contribute to the global picture of sustainability and the development of strategies for improving the quality of working environment, with special attention to the generation of noise in different production processes in thirteen different industries in Novi Sad, Serbia. The paper also seeks to examine the advantages and drawbacks of the implemented protective methods and to provide some recommendations for their better implementation in order to contribute to solving this significant problem of today.

Keywords: noise; industry; sound pressure level (SPL); frequency analysis; noise protection.

1. Introduction

When we talk about noise as one of the leading pollutants of living and working spaces, we usually think about the unwanted sound pressure level which is above the prescribed or recommended value and which damages human health and life quality. It is a common opinion that noise is only a problem in the industries which use the machines and equipment that produce high intensity noise or, in the case of the living environment, in busy city roads. However, today the problem of noise is present in places where it is least expected, such as banks, IT companies and other organisations which require quiet and calm surroundings in order to operate successfully. In addition, significant noise levels are also generated in public places such as restaurants and coffee shops, which defies the original purpose of these establishments, i.e. rest, relaxation and relaxed conversation. Why is noise a rising modern-day problem and is it possible to avoid or decrease it?

Industries aspire to apply new generations of machines and equipment which are technically designed to minimise noise levels. However, big markets demand capacity increase and reduced production time, which is achieved by introducing more machines. Compressors, generators, vacuum pumps are examples of machines which during use create noise level which is almost impossible to decrease. In the case of office work, because of the rationalization of space and equipment, and in order to improve communication and cooperation between co-workers, offices are designed as a co-working space (Brennan *et al.*, 2002). Conversations between employees and between employees and customers increase noise and disturb the working environment. The use of computers, phones, printers and equipment for maintaining the required ambient conditions such as temperature, moisture, fresh air flow and lighting, all create new disturbing sources of noise (Banbury, Berry, 2005).

In everyday life people's habits also change. Young people tend to listen to music through headphones more frequently. Even though there are warnings about the damage that the increase of sound level can cause, these warnings are often ignored. Rock concerts, night clubs and music festivals generate noise intensity of up to 100 dB(A), which most certainly results in adverse consequences. Also, population increase and migrations to urban areas increase environment noise in big cities (Hunashal, Patil, 2012). Such lifestyle produces a negative cumulative effect of noise which damages not only hearing but also overall health. For instance, over the years the increase in growth rate of hearing loss is evident (Śliwińska-Kowalska, 2015).

All the above facts show that noise in living and working environments does not decrease, but in fact increases. In accordance with that, a logical question is: what is the current situation in industries where the problem has existed since the beginning (Glorig, 1961). Noise in the working environment is a major cause for concern regarding the safety and health of industrial workers (Alberti, 1998; Jabbari *et al.*, 2016; Omokhodion *et al.*, 2008; Prasanna Kumar *et al.*, 2009; Singh *et al.*, 2010) The impact of noise is primarily localised on hearing damage called noise induced hearing loss (NIHL), which has a profound social and occupational impact on the affected individuals and substantially reduces their quality of life (Metidieri *et al.*, 2013; Mrena, 2006; Singh *et al.*, 2013). The development of NIHL depends on a combination of several causes where the predominant one is the total acoustic energy of noise exposure. Hearing damage is first caused by exposure to high tones, especially those around 4000 Hz (Willcox, Artz, 2007). Later, after years of noise exposure, hearing damage is caused by low frequencies as well.

Damage risk criteria for noise vary in different countries, mostly between 85–90 dB(A), however, any level of sound which is annoying or exceeds 75 B(A) may be considered noise (Mokhtar *et al.*, 2007). Additionally, there are noise-related non-auditory effects, such as loss of concentration, speech interference, headache, sleeping disorder, social isolation, high blood pressure and tachycardia (Singh *et al.*, 2010; Lusk *et al.*, 2002; Stansfeld, Matheson, 2003; Van Dijk *et al.*, 1987). Hence, we can say that prolonged exposure to high noise levels has a significant impact not only on physical and mental health, but also on human productivity. The solution of this problem would be beneficial for both employees and employers. Considering the great number of papers which point out the negative effects of increased noise levels on human health (Schneider, 2005; Fredriksson *et al.*, 2015; Reinhold, Tint, 2009), it is very important to maintain permanent monitoring of noise in the industrial environment.

The purpose of this paper is to investigate the sound pressure levels (SPL) during various manufacturing processes in different processing industries in Novi Sad, and to analyse the measures implemented for the protection of the workers in their workstations. In view of the fact that lately a great number of public companies have undergone the process of privatisation, it is of great interest to analyse new working conditions under different types of ownership. Noise was measured in different areas of light and heavy processing industries in which higher values were expected. Close attention was paid to job description, working hours, age of equipment and implementation of protective measures. Having in mind that exposure to continuous noise of 85–90 dB(A), particularly over a lifetime in an industrial setting, can have adverse effects on health (Stansfeld, Matheson, 2003), the threshold level was set to 85 dB(A). Every time when the sound pressure level exceeded the specified threshold level, frequency analyses at 1/1 and 1/3 octave band were done.

The results of noise measurements which are presented in this paper indicate the presence of a significant number of machines and working places with increased measured sound pressure levels that require the implementation of appropriate protective measures. In addition, our octave analysis confirms the maximum noise level on critical frequencies, which is in accordance with the results of other authors (Harris, Piersol, 1968; Rachiotis *et al.*, 2006). However, a significant fact is the low level of workers' awareness of the negative effects of noise on their wellbeing, and consequently, their failure to use the protective equipment provided. Throughout the data collection process, we actively worked to raise awareness of both employers and employees about the importance of using noise protection and all the possible health consequences of not using them.

2. Materials and methods

The research was conducted in thirteen different processing industries: printing, chemical, car, metal, meat, plastic, rubber, wood, shoe, floor, textile, furniture and energy. Three industrial plants are in foreign ownership (textile, floor and processing plant for the production of plastic and rubber parts in the automotive industry). For each industry either the machine type or the workstation for which the noise level was measured was defined. According to Serbian guidelines about measures and norms of protection in the workplace (Official Gazette, 2015), the equivalent L_{eq} values with filter A, should be measured over the effective time period of daily duration of a worker's individual exposure to noise in order to calculate a daily dose, $L_{\text{ex,8h}}$ (Directive 2003/10/EC, 2003). However, long-term measurements to evaluate daily doses while working with particular machines can be expensive and difficult to manage, especially when noise is measured for a single machine, or at a single workstation. In cases when the sound pressure levels are variable, noise exposure is corrected for factors known to increase annoyance (penalties for impulses and noise with tones, certain sources and situations). In fact, most of these factors contribute to increasing the measured value of L_{eq} (except intermittent noise). Basically, when noise has no pulse and no tone, the measured (relevant) level is the same as the average level of L_{eq}, measured with a precision phonometer using an A-characteristic correction filter and with a fast response during the measurement interval. Considering that the aim of this study is the evaluation of industrial noise generated during certain industrial processes, the equivalent sound pressure level was measured over the given time interval. The determined minimal measurement time interval was long enough to involve the whole cycle of noise changes for the observed manufacturing process (Official Gazette, 2015). The working process was usually repetitive during the working hours.

Based on all that has previously been said, the measurement interval was set to thirty seconds or one minute, depending on the type of process. Measurements were repeated five times for each position at different times of day during an eight hour shift, while other machines were not being operated. When noise level was measured for the same workstation or for the same type of machine, if measured values were within the range of 6 dB(A), the average value of noise level was taken as the measurements' result (Official Gazette, 2015). The same principle was applied for measurements at 1/1 and 1/3 octave bands that were made when the mean value of measured sound pressure levels for each machine was above the threshold level of 85 dB(A). The dB(A) means of L_{eq} at 1/3 octave bands were then compared with interpolated NR-80[1] curve.

During noise measurement in a workstation, the microphone of the phonometer was placed at the height of the workers' ears, i.e. at the distance of 0.20 m from the ear. If the workstation was not precisely defined, the measurement was done at the place where the work is typically performed, at the height of 1.6 m when the employee worked in a standing position or at the height of 1.2 m when the employee worked in a sitting position. Sound pressure level was measured within the range of frequencies between 25 Hz and 10 kHz using TES 1358A Sound Level Meter (SLM) with the RS-232 connection which complies with the IEC 651 Type 1 standard.

Calibration was done before the measurement with the use of a standard acoustic calibrator, recommended by the SLM manufacturer (TES Electrical). SPSS, IBM program was used for statistical data analysis.

3. Results and discussion

3.1. Noise measurement

The sound pressure level was measured in thirteen processing industries for every type of machine or working position in the production section of the factories. It is important to mention that some of these factories are small workshops specialised for the production of specific products because of which we classified them according to their respective industries. In these cases, the number of measurements was limited by the number of machines or working positions. The mean values of L_{eq}, L_{min} and L_{max} SPL in dB(A) with standard deviations (SD) are shown in Table 1. In the column workstation/machine the type of workstation or the name of the machine is listed, depending on the information obtained from the employee in that working position.

It can be seen in Table 1 that the measured values for the L_{eq} in industrial processes usually vary between 70 and 100 dB(A), which is in accordance with other authors (Al-Dosky, 2014; Mokhtar *et al.*, 2007; Morata *et al.*, 1997; Salehin *et al.*, 2014; Yang *et al.*, 2016), with the mean value of 83.28 (8.22) dB(A). The mean maximum value of 118.56 (1.30) dB(A) is reached during metalworking processes where a hammer is used in metal industry.

The production line in the chemical plant represents a set of three sequential operations: containers washing, mixing fluids in a reservoir with electric drive and packaging of final chemical products. The processes in the meat packing industry include slaughter, cutting and packaging. The textile factory has a hall with approximately fifty similar working positions for the processing of a variety of textiles on sewing machines. The mean value of 76.78 (1.85) dB(A) was calculated on the basis of average L_{eq} for three different types of sewing machines, and for each machine L_{eq} value was measured in five repetitive uniform intervals at different times of day during the eight hour shift. Only the compressor which releases air under pressure used for cleaning the machines and the work stand generates elevated noise values, but it is turned on only two or three times for 60 s in a one-hour interval. In all the abovementioned industries, together with plastics and rubber products industry (automotive industry), the measured mean values of L_{eq} were below 80 dB(A) (Fig. 1).

Maximum measured values were observed in the sawmill and furniture industries, and they are significantly higher than the threshold value of 85 dB(A) (Fig. 1). Both of these facilities are actually specialised workshops which have around twenty employees with an intention to expand the production. The mean value of noise in the sawmill is L_{eq} = 92.05 (1.37) dB(A) and in the furniture factory L_{eq} = 92.82 (6.19) dB(A). Several problems arise here. Generally, all of the machines produce high levels of noise and an aggravating circumstance is that they are all placed close to each other. This implies that workers are exposed to unpleasant noise at all times during working hours. Also, it is well known that more sources of noise produce higher levels

[1]The Noise Rating or NR curves (at 1/1 octave) were developed by the International Organization for Standardization (ISO, 2003) to determine the acceptable indoor environment for hearing preservation, speech communication and annoyance.

Table 1. Noise level in operator position for a range of different industrial machinery and processes.

Industry	Workstation/machine	L means (SD) [dB(A)]		
		L_{eq}	L_{max}	L_{min}
1. Chemical	Chemical liquid packaging	64.92(1.21)	71.24(0.94)	62.86(1.53)
	Rinsing packaging under pressure	85.67(1.40)	87.14(1.80)	80.00(2.67)
	Compressor	82.16(1.76)	84.34(1.84)	81.23(1.50)
2. Automotive	Pneumatic hammer	96.08(2.25)	103.07(3.66)	85.80(1.76)
	Pneumatic socket wrench	83.38(1.33)	86.40(1.28)	60.06(7.83)
	Mechanical car lift	81.20(1.66)	83.96(1.41)	76.56(2.31)
	Pneumatic car lift	68.67(0.87)	75.02(0.65)	59.56(1.96)
	Carwash	85.23(1.57)	92.34(1.10)	82.64(2.50)
3. Rubber	Lathe – rubber rollers processing	78.60(1.33)	83.17(1.89)	76.53(2.01)
	Final treatment/fine grinding	80.02(1.21)	82.80(1.65)	75.60(1.90)
	Lathe	78.80(1.40)	83.22(0.73)	76.20(1.98)
	Balancing	83.12(0.55)	84.93(1.45)	76.88(1.24)
	Double roller	82.35(0.61)	84.16(1.00)	78.68(2.45)
	Rubber Mixer (second speed)	81.37(1.20)	82.66(1.56)	77.00(0.98)
	Rubber Mixer (third speed)	86.81(0.35)	90.12(1.01)	85.30(0.46)
4. Meat	Slaughter	77.78(0.45)	84.04(0.36)	67.85(0.99)
	Boning	75.22(0.31)	88.07(0.57)	66.80(0.89)
	Packaging /vacuum machine	73.17(0.24)	77.56(0.18)	69.92(0.28)
5. Metal	Mechanical lathe	75.14(2.00)	78.89(3.86)	71.35(0.24)
	Drilling machine	75.34(0.61)	83.95(0.83)	64.52(0.40)
	Hammer	107.85(0.43)	118.56(1.30)	97.11(0.85)
	Grinder	87.96(0.88)	89.80(0.74)	85.30(0.95)
	Milling cutter	71.40(0.65)	75.74(0.34)	64.92(0.68)
6. Sawmill	Bandsaw	90.47(0.79)	93.80(0.29)	88.93(0.91)
	Motor chainsaw	92.87(0.48)	97.80(0.51)	88.70(0.34)
	Pneumatic hammer	92.81(1.15)	100.51(0.68)	84.06(1.36)
7. Furniture	Wood planer (wood)	95.90(0.22)	101.94(2.60)	91.54(0.98)
	Metal cutter (metal)	99.41(0.88)	108.00(0.57)	95.06(1.79)
	Circular saw (wood)	90.75(1.01)	92.77(0.76)	82.86(1.45)
	Compressor	85.23(0.17)	86.73(0.22)	82.38(0.29)
8. Footwear	Pounding machine	94.08(5.10)	108.48(4.22)	85.12(4.56)
	Upper trimming machine	86.32(0.74)	91.86(0.50)	83.48(1.13)
	Outsole stitching machine	83.80(1.03)	92.82(2.12)	75.10(0.83)
	Bottom channel closing machine	85.29(0.93)	91.20(0.62)	75.70(0.89)
	Bottom edge trimming machine	84.81(1.90)	89.68(1.87)	79.93(4.63)
	Folding machine for insole covering	89.10(5.90)	98.16(0.91)	82.65(6.50)
	Sewing machine	89.00(4.68)	92.80(1.03)	84.92(6.98)
	Skiving machine	75.84(0.57)	83.40(0.74)	67.66(2.95)
9. Flooring	Lacquering line/ exit/entry	79.92(1.30)	85.66(2.87)	76.88(1.26)
	Wood sanding machine	94.76(0.42)	97.35(0.35)	92.20(0.68)
	Edge profiling line	82.56(0.27)	87.91(0.52)	78.56(0.32)
	Grinder	83.32(0.31)	86.27(0.44)	81.90(0.27)
	Sorting and packaging line	85.50(0.52)	94.10(0.68)	78.71(0.19)
	Transporter	83.22(0.39)	86.50(0.38)	79.78(1.48)
	Cross-cut system machine	84.88(0.23)	87.34(0.40)	83.48(0.12)
10. Textile	Standard sewing machine	76.78(1.85)	82.30(1.34)	70.12(1.50)
	Compressor	92.45(0.49)	100.98(0.48)	75.86(1.97)
	Cutting machine	71.93(1.16)	74.76(0.73)	70.08(0.72)
	Surroundings (transporting line)	74.14(1.25)	75.68(0.45)	69.74(0.61)
	Packaging line	81.17(0.22)	89.76(0.63)	68.46(1.07)

Table 1. [Cont.]

Industry	Workstation/machine	L means (SD) [dB(A)]		
		L_{eq}	L_{max}	L_{min}
11. Plastics and rubber products (automotive)	Hydraulic Pipe Bending Machine	71.23(0.35)	80.61(0.41)	68.13(0.10)
	Thermoforming plastic pipes	73.10(0.27)	82.15(0.12)	68.41(0.42)
	Hose Assembly Connector process	72.54(0.46)	80.61(0.19)	67.88(0.78)
	Moulding processes	75.29(0.84)	81.42(0.40)	70.62(0.11)
	Grinding materials/processes	96.80(1.53)	100.51(0.87)	75.4 (1.78)
12. Printing*	Digital printing presses	70.66(4.17)	74.29(4.32)	67.48(4.53)
	Offset printing presses/Heidelberg/Rapida	82.70(3.92)	85.95(3.27)	78.39(5.60)
	Cutters	80.21(6.87)	90.80(4.77)	71.12(7.81)
	Folders	87.66 (3.14)	92.40(7.15)	81.24(2.91)
13. Energy	Steam Boiler	87.45(2.80)	95.62(3.64)	82.90(1.24)
	Turbine	84.60(2.54)	88.70(2.89)	79.60(0.98)
	Compressor	80.73(1.02)	83.10(1.47)	77.68(1.65)
	BFW pump/boiler feed water pump	91.21(1.89)	94.86(3.69)	85.82(1.22)
	Condenser	86.95(0.70)	90.20(0.88)	81.32(1.50)

*The results were taken from the previous research (Mihailovic *et al.*, 2011).

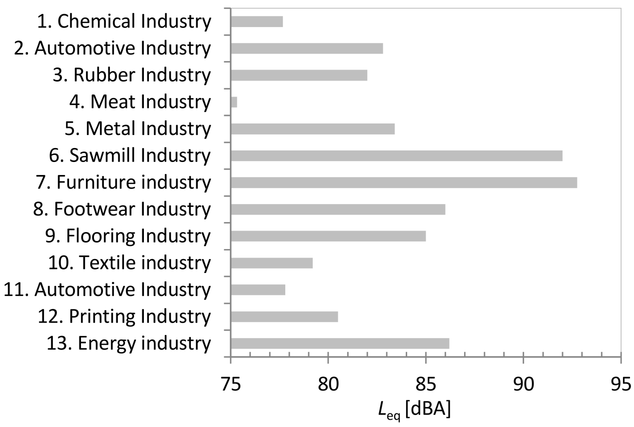

Fig. 1. Representation of mean noise levels L_{eq} in investigated industries as presented in Table 1.

of noise. Consequently, higher levels of noise result in a strong possibility that this kind of working environment will have a negative impact on employee's health and wellbeing.

One of the major factories (as far as the complexity of production is concerned), in which noise level was measured is the shoe industry. This production plant preforms all operations in the production line from processing raw materials to the final products; consequently, the largest number of measurements for different types of machines was done. Because the distances between workstations varied from one to two meters, workers often experienced noise from the nearby machines. As it can be seen in Fig. 1, the mean value of the equivalent sound pressure level is 86.03 (5.26) dB(A). All measured values are mostly high with the highest variance which is due to the processing of different types of materials.

The values of L_{max} and L_{min} in Table 1 represent the mean maximum and minimum levels of sound pressure in dB(A). An analysis of the statistical distributions of sound levels is a useful tool when assessing noise (Brüel, Kjar, 2001). The analysis not only provides useful information about the variability of noise levels, but is also prominent in many standards as the basis for assessing different reference values. The data on noise measurements gathered in this research have confirmed this finding. Connecting the mean values of L_{eq}, L_{max} and L_{min}, statistically significant positive Pearson's correlation was found between L_{eq} and L_{max}; $r = 0.943$ ($p < 0.01$), L_{eq} and L_{min}; $r = 0.864$ ($p < 0.01$) and L_{min} and L_{max}; $r = 0.764$ ($p < 0.01$). Figure 2a shows a scatter plot for L_{eq} and L_{max} that have a strongly positive linear relationship (adjusted R-square = 0.89). A correlation between variables indicates that as one variable changes in value, the other variable tends to change in a specific direction (Frost, 2019). Understanding this relationship is useful because we can use the value of one variable to predict the value of the other. In this particular case, statistical data analysis shows that noise equivalent values can be predicted measuring minimum or maximum values. Nevertheless, Pearson's correlations are usually done for normally distributed data. As can be seen in Fig. 2b, L_{eq} values are approximately normally distributed with the mean value of 83.28 (8.22) dB(A). Based on the results obtained, the threshold level in this study was set to 85 dB(A) (it falls within the standard deviation limit) and is in agreement with the value for damage risk criteria for noise (I-INCE 1997).

According to Serbian guidelines, if the measured L_{eq} levels for 8-h time weighted average noise exposure are above 85 dB(A), frequency analysis at 1/3 octave

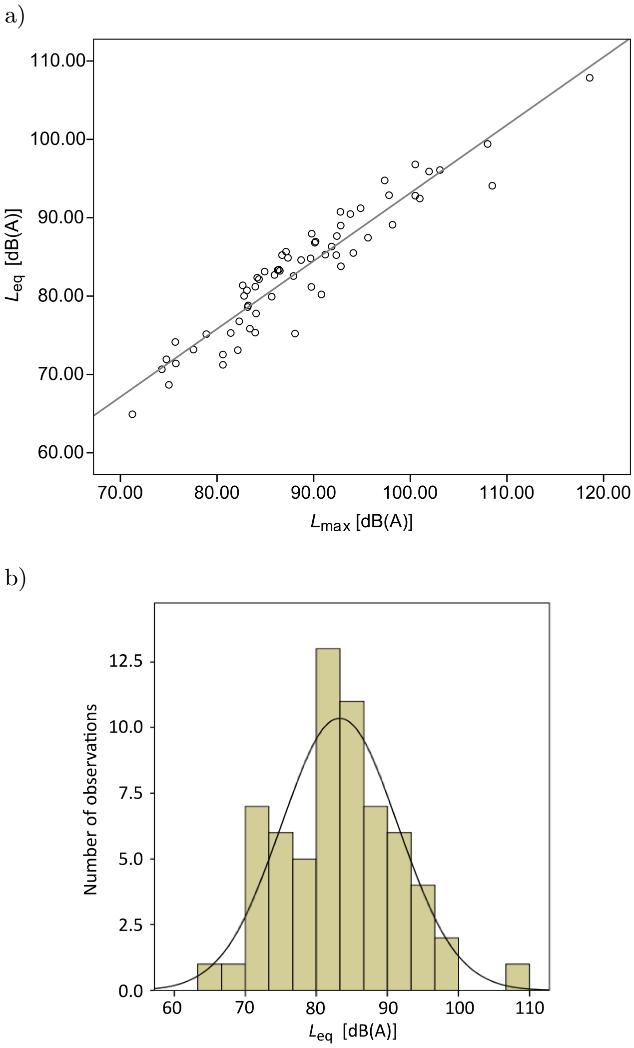

Fig. 2. a) Linear correlation between L_{eq} and L_{max} measurements; b) normal distribution of averaged L_{eq} values.

band for each workstation should be done. The frequency spectra are then compared with the N-curve. The value of N-curve must be less by 5 dB(A) than the permitted noise level for that workstation. A similar principle was applied in this paper to examine whether there is a critical frequency at which the maximum noise levels occur for certain types of machines, and to determine which frequencies are most offensive to the listener.

Given that the experimental values of L_{eq} were measured in the 1/3 octave, which provides an in-depth outlook on noise levels across the frequency composition, N-80 curve at 1/1 octave band is interpolated. The level of 1/1 octave band can be converted to three 1/3 octave bands by substracting $10\log_{10}(3) = 4.771$ dB from the 1/1 octave band level (Blevins, 2015). Figure 3 represents 1/1 N-80 curve with interpolated N-80 curve at 1/3 octave band.

Figure 4 represents the dB(A) means of L_{eq} (SPL) at 1/3 octave band for each type of machine which exceeds the acceptable values given by N-80 curve with marked maximum values of L_{eq} at specified frequencies.

Approximately 30% of the total number of tested machines exceeds the threshold level. In addition, for most machines octave bands with an elevated value of L_{eq} are very wide, with maximum levels at high frequencies with the most dominant noise at 5000 Hz, whereas for the wood, metal and energy industries the most dominant noise was observed at mid frequencies (500–2000 Hz). Since hearing damage from excessive noise primarily occurs at high frequencies (3, 4, and 6 kHz) and then spreads to lower frequencies, working capacity and social adequacy of workers is limited (Gidikova *et al.*, 2007). In addition, knowing that double increase of the sound pressure increases the level of noise for 3 dB(A), it can be rightly concluded that the situation gets worse with an increasing number of machines. Nevertheless, in a typical working environment in most cases a listener will not be able to detect the difference in a sound level which is less than 3 dB(A) (Harris, Piersol, 1968). As can be seen from Fig. 4, the highest values for means of

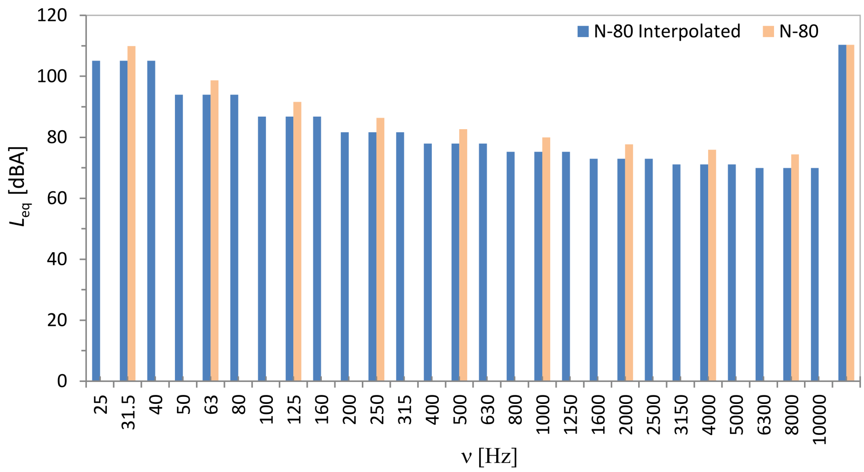

Fig. 3. Line plot of 1/3 octave band interpolation for N-80 curve.

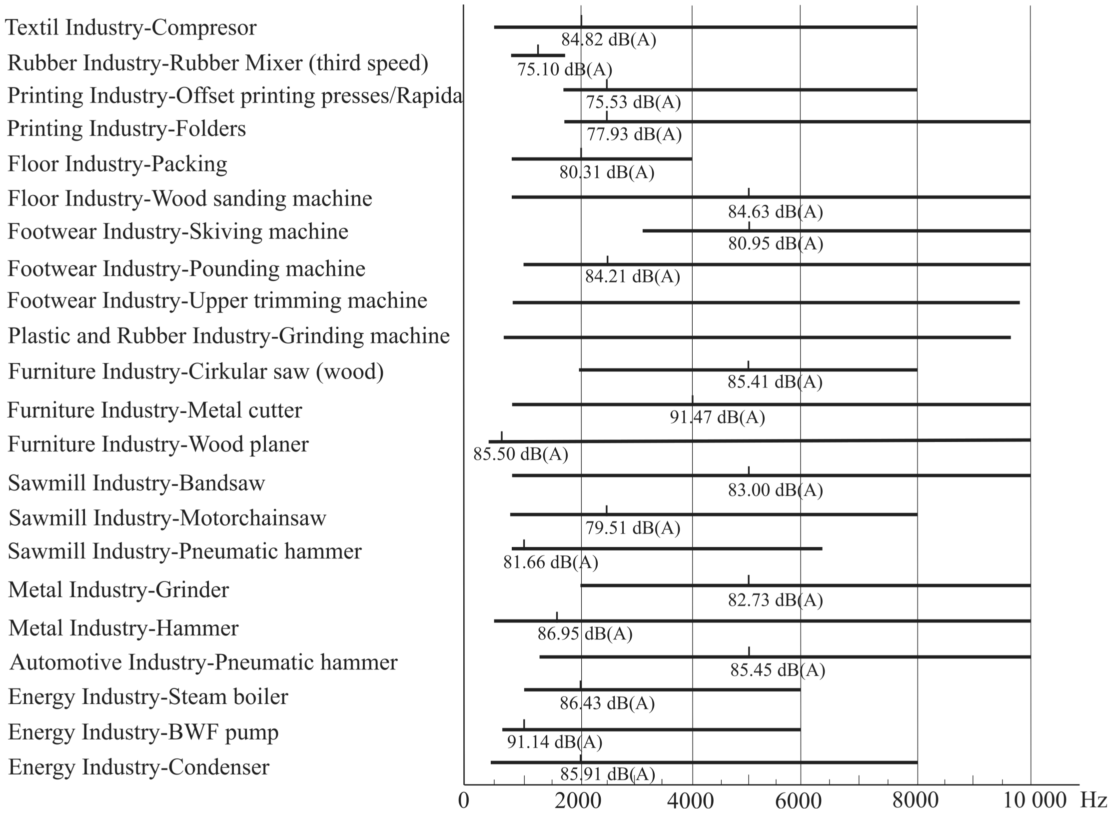

Fig. 4. Means of L_{eq} levels for machines that exceeded N-80 curve levels.

L_{eq} levels are for the machines that process wood and metal; milling cutters, circulars, wood planers, metal cutters, and for devices which are used to energy production; steam boiler, BWF pump, condenser. In order to see at which frequencies the maximum noise level occurs, the dB(A) means of L_{eq} at 1/3 octave bands for the abovementioned machines in comparison with interpolated NR-80 curve at 1/3 octave band are presented in Figs 5 and 6.

Very high levels of L_{eq} can be observed throughout the whole frequency range for wood and metal processing machines. They are considerably greater than N-80 levels at 4000 Hz and 8000 Hz for metal cutters (Fig. 5).

For the wood planer and hammer (metal processing) the maximum of L_{eq} values are at lower frequencies (630 and 1600 Hz, respectively) whereas for metal cutter and wood sanding machine these values are at higher frequencies (4000 and 5000 Hz, respectively). In any case, Figs 5 and 6 represent specific cases where the measured L_{eq} values are above the N-80 curve throughout the whole frequency range. Spectral con-

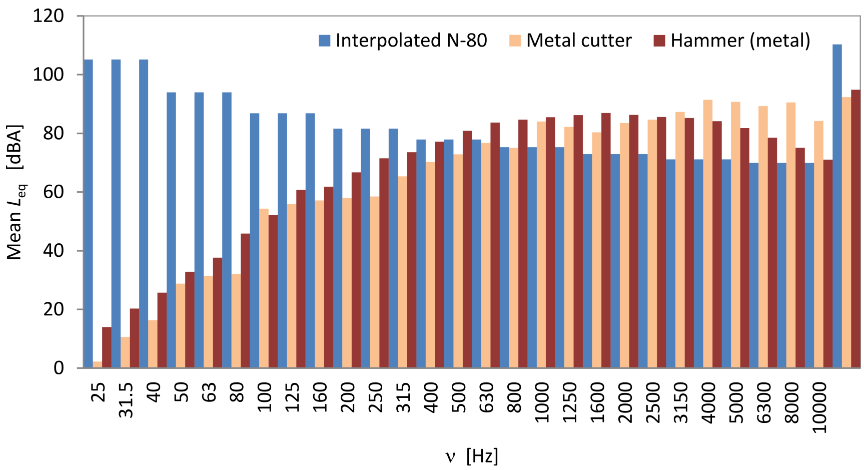

Fig. 5. Means of L_{eq} at 1/3 octave bands for metal processing in comparison with the interpolated N-80 curve.

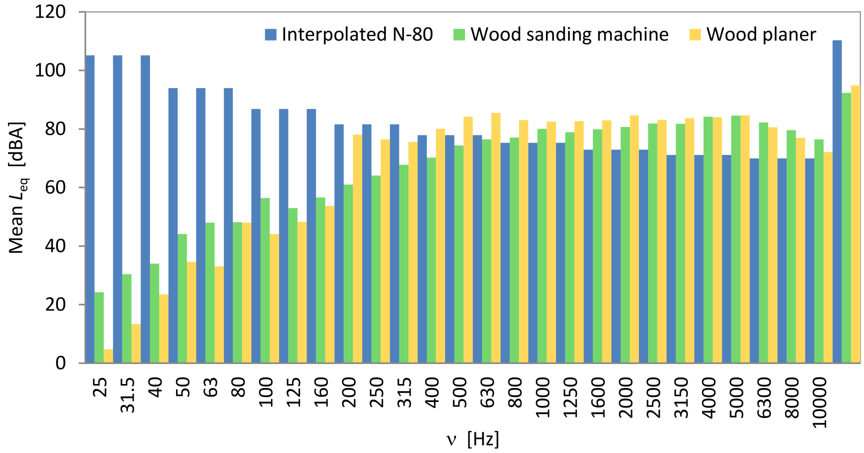

Fig. 6. Means of L_{eq} at 1/3 octave bands for wood processing in comparison with the interpolated N-80 curve.

tent of noise is very important to consider as personal protective equipment is often designed in accordance with the noise spectrum.

3.2. Noise protection

Sound level meters are instruments which measure sound pressure levels in dB and phon is the unit which is connected with dB by the psychophysical response of the ear. For the sound frequency of 1 kHz the readings in dB and in phon are the same. However, for all other frequencies the phon scale is based on subjective judgements of loudness equality for complex sounds or for tones of differing frequency (Pease, 1974). In order to convert dB into phons a graphic of equal loudness curves which were determined experimentally is needed. Consequently, sound pressure level measured by the instruments in dB is weighted by the A curve. In effect, the A-weighting is based on the 40 phon Fletcher-Munson curves which represented an early determination of the equal-loudness contour for human hearing (Fletcher, Munson, 1933). Essentially the level of sound pressure measured in dB(A) represents roughly the level of sound pressure in phons (Table 2) (Harris, Piersol, 1968). This observation suggests that the conversion is based on subjective individual perception of sound which is very important in considerations of normative values of noise in a working environment. Many studies have shown that the use of the A-weighting curve underestimates the role low frequency noise plays in loudness, annoyance, and speech intelligibility and that measuring A-weighted sound pressure level is not necessarily indicative of the loudness of noises (Pierre, Maguire, 2004). However, as can be seen from Fig. 4, a significant number of machines generate higher levels of noise at mid to low frequencies. Surely, a redesigned A-weighted filter would provide industry, acoustic, practitioners and the public with better equipment capable of providing more realistic measurements (McMinn, 2013).

Table 2. A-weighting corrections for octave band data.

Octave band centre frequency [Hz]	Relative A-weighted response [dB(A)]
31.5	–39.5
63	–26.0
125	–16.0
250	–8.5
500	–3.0
1000	0
2000	+1.0
4000	+1.0
8000	–1.0
16000	–6.5

The physiology of the human ear significantly contributes to relevance of high frequencies. Every ear (auditory) canal is of a different length and if we consider the mechanical aspect of sound spreading, we can see that it actually represents a tube closed at one end (by the eardrum membrane). In this environment a standing mechanical wave can be formed and a resonant increase of the sound of a certain frequency can happen. For most people the ear canal is 25–30 mm long, so the human ear is the most sensitive to frequencies within 3000–5000 Hz, with the peak of sensitivity at 3500–4000 Hz. Principally, people with a shorter ear canal are more sensitive to frequencies above 4000 Hz (OpenStax College, 2012). Certainly, most of the machines generate the highest values of noise precisely in this frequency range, as can be seen from Fig. 4. The question is how to properly solve the problem of noise in industrial production processes and if that is actually possible.

Generally speaking, the noise generated in the operation of certain machines depends on a number of factors, but for the most part on the type of process, operation mode (speed) and different types of raw materials that are being processed. Accordingly, this research shows that the production year of the machines does not have a significant impact on the noise they produce. The machines that generally create higher noise are pneumatic power tools, compressors, pumps, metal forming, wood forming machines, turbo generators. A global index of acoustic quality would be a useful tool for acoustic assessment of machinery (Pleban, 2010). In the foreign-invested factories the machines that produce increased noise levels are soundproofed by modular acoustic panels or placed in separate rooms. These factories also have protocols for workers and visitors concerning protective measures that have to be taken to prevent overexposure to noise. Noise control and the effective strategy are very important considering that some findings raise concerns about the effectiveness of hearing protection as a substitute for noise control (Groenewold *et al.*, 2014). Widely available pieces of protection equipment are earplugs which are user-friendly and do not require individual optimisation, and earmuffs. However, workers rarely use protective equipment. Some authors (Reddy *et al.*, 2012) point out that there is a belief among workers that noise is an acceptable and unavoidable part of the job. According to authors Tantranont and Codchanak (2017), studies in developed countries determined that noise-exposed workers used hearing protection devices only 14% to 49% of the time they were required to. The most common reasons cited by workers for not wearing hearing protectors include feelings of insecurity, discomfort and impracticality, especially in cases when they needed to take them off frequently, as well as interference with communication and job performance (Samelli *et al.*, 2018). On the other hand, some results confirm the lack of efficiency of earplugs at low and medium frequencies (Kusy, Chatillon, 2012). It is generally accepted that the sound attenuation from combinations of earplugs and earmuffs is higher than the highest of the individual attenuations of each of the protectors (Behar, 1991). However, Abel and Armstrong (1992) investigation shows significant gain in wearing double protection for frequencies below 2000 Hz. Recent studies have shown that the simultaneous use of earmuffs and other personal protective equipment affect the sound pressure level under the earmuffs, most often causing it to increase (Kozłowski, Młyński, 2019). Basically, the choice of hearing protectors depends on numerous factors regarding different situations. Use of earmuffs or other personal protective equipment has not been observed in this investigation.

The fact that education plays an important role in workers' protection from excessive noise exposure is often ignored. The results of research concerning proper insertion of earplugs into ear canals indicate that training in earplug insertion is important for good attenuation and for bringing poor attenuation to a minimum (Toivonen *et al.*, 2002). Many studies show that perceived hearing status and interpersonal influences are significantly related to the use of hearing protectors (Tantranont, Codchanak, 2017; McCullagh *et al.*, 2002; Hong *et al.*, 2005).

Apart from sound insulation of the machines, other technical solutions for the attenuation of sound in this investigation have not been found. There is a strategy that can be followed to achieve a healthy and safe workplace, such as the use of acoustic (meta) materials, acoustic insulation of floors and ceilings (sound-absorbing ceiling baffles, decorative acoustical panels), or absorptive silencers, but their installation mostly depends on company policy. Each solution needs substantial finances, but with careful planning noise exposure can be avoided or reduced to a minimum. And finally, we would like to point out that implementation of alerting devices such as an emergency button for warning lights and sound signals, would make a significant contribution to worker protection.

4. Conclusion

Preliminary research of noise pressure levels in industrial facilities in Novi Sad shows that 30% of investigated machines produce noise above set threshold level of 85 dB(A). For the most part, the elevated noise is generated during the manufacturing process of raw materials such as wood and metal. One third of octave analysis indicates that high noise values occur in wide octave frequency range, with mean maximum equivalent SPL at mid and low band frequencies (0–2000 Hz) as well as at high band frequencies (4000–5000 Hz). These findings might contribute to better assessment of A-weighted sound level pressure measurements in low and mid frequency bands, which should be reviewed by the competent authorities and acoustic community in order to achieve more realistic and useful measurements for reducing the risk of exposure. Established correlation between equivalent, minimal and maximal noise values might point out further statistical analyses in order to find possible correlation between L_{eq} values measured during one cycle of machine work processes and daily dose $L_{\mathrm{ex,8h}}$.

Nevertheless, one of the major observations is that most workers do not use provided protective equipment. It is very important to raise workers and employers awareness of hazardous noise levels and ways to prevent not only hearing loss but prospective adverse impacts on health and wellbeing. This can be achieved through different training courses and education programs. Accordingly, their awareness of the need to preserve individual health will change if the relevant information is provided in an appropriate manner. It is also important to provide more protective equipment suitable for particular workers.

Another relevant recommendation concerns the installation of the required light and sound signalisation for noise. In most cases it will lead to greater security of the workers when they use protective equipment. The installation of emergency buttons should also be considered. They should be installed near every workstation where excessive noise is generated so that the workers can activate them in case of injury. It is also important to exert influence on the decision makers with the aim to achieve good acoustic design of a workplace with control at source being the most preferable form of noise control. Despite the inevitable increase in the expenses, preservation of a good working environment will indirectly impact productivity and production.

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