Evaluation of Acoustics in the built Environment, Mapping and Estimation of noise in the Stamping Sector of a Metallurgical Industry

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***Abstract*— *In this work a study of the acoustic problem in a metalworking industry of the Industrial Pole of Manaus, Brazil is carried out. The aspects related to the industrial environment such as the constructive aspects and the machineries in an area of stamping were analyzed. A mapping of the entire area of interest was carried out and the noise measurement points were selected at three different times, morning, afternoon and night. The results of the statistical analysis performed using statgraphics software demonstrate that there are no statistically significant differences between the noise levels achieved in different work shifts and that this condition is met for the case where the machines are working or not. The study considered to determine the areas that have the greatest noise affectation, proving that the average value achieved does not differ statistically between the different internal areas of the stamping process. All the information obtained serves as a guide for the company to establish the control measures, it is estimated that there will be a reduction of the levels of Sound Pressure Levels (SPL) emitted by machinery from the printing industry to the environment, guaranteeing a better quality of life for workers during the industrial working day.*

Keywords*— *Assessment in Acoustics in the Built Environment, Occupational noise, Stamping industry, Metallurgical industry.

I. INTRODUCTION

The industrial environment provides several problems related to acoustics and its construction. Observing the aspects of comfort, it is seen that the architectural projects assign greater relevance to the thermal, ergonomic and lighting aspects, to the detriment of the aspects directed to the acoustic treatment [1, 2]. This can be attributed to the fact that the assessment of the level of sound by the human ear is different from the evaluation of the distance by the eyes or the weight by the arm [3]. In this way, the negative acoustic interferences of the environment are not always easily perceived by the user.

Within the industry landscape, the issue of acoustic comfort usually does not receive the relevant concern it deserves. To control exposure to high levels of SPL, Individual Prevention Teams are traditionally used – IPE (Individual Protection Equipment), which act as palliatives, causing little intervention in the sources of noise emission (machinery), and minimal or no concern with the built environment, which justifies the relevance of studying the propagation of sound in indoor environments, since the machinery, the largest source of noise, is also a key component of factory productivity. Concerns about solutions to problems related to the comfort of industrial buildings have been increasing in Brazil [4].

The discussion of control of the problem of occupational noise also addresses factors that may be responsible for the worsening of the real condition, such as the use of constructive materials unfit for sound absorption and the lack of acoustic comfort guidelines that make it difficult to control SPL in the environment [5].

In order to better characterize and create effective proposals for the noise problem in the industrial environment, we intend to create an integration relationship between two physical space evaluation tools: the formal and systematic process of Post-Occupancy Assessment – POS and the physical space management process, seeking the real scenario of the environmental

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conditioners through a management system that allows the detailing of the investigations [6].

For the Brazilian Association of Technical Standards - ABNT (1987), the concept of noise is the mixture of tones whose frequencies differ from each other, due to the value inferior to the discrimination (in frequency) of the ear.

There is also classification according to the variation of noise according to the standard IS02204/1979, also in the standard NBR 10152 [7].

• Continuous - noise with variations of negligible levels (up to ± 3dB) during the observation period;

• Intermittent - noise whose level continuously varies from an appreciable value (greater ± 3dB) during the observation period;

• Impact or impulse noise - that which presents in acoustic energy peaks lasting less than one second. The waveform of this type of noise is often described by amplitude and duration, the amplitude being measured at the maximum peak, and the duration is the time the wave takes to drop 20 dB from its normal level.

He asserts that the main reactions and behavior of the wave are: transmission, absorption, reflection and diffraction. These reactions depend on the characteristics of the material that compose the incident obstacle of the spherical wave [8], according to figure 1.

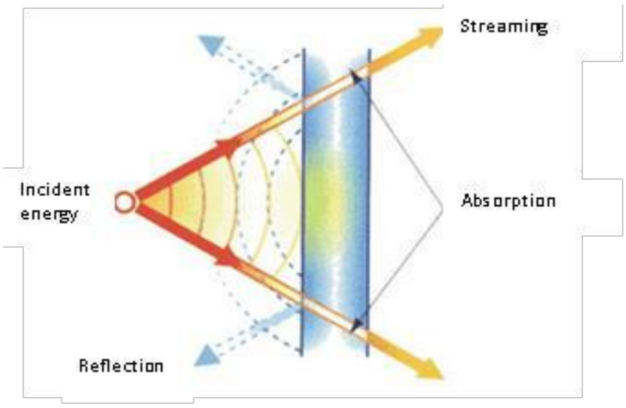

Fig.1: Scheme of the behavior of the wave incidence. Source: [8].

1.1 Industrial noise

The issue of industrial noise is directly related to the use of machines that are the tools of production, [8] describes the origin of industrial noise as the vibrations of the equipment in operation, which excite several parts of the equipment itself or parts attached to it.

For the characterization of the acoustic condition of an environment to be studied, it is necessary to understand that the architecture and the sound are inseparable, since the space by itself already presents certain loudness.

For [8] industrial noise originates from machines operating in industry and, as it should not be, comes from the vibration of bodies, surfaces and machines, which are caused by the movement of moving parts of machines, utensils and any objects that are excited by such vibrations.

According to [9], the mere existence of closures in an enclosure gives rise to reflected sounds and implies the emergence of 'reverberating intensity'. From the acoustic point of view, it will always be desirable to sound and reverberation. The basic points to be considered in this regard are the acoustic characteristics of building materials.

They argue that the result of these collections can be transposed to a graphical representation called acoustic map, which are charts that represent the noise actually existing in a given area, and can be obtained through measurement and / or through computational instruments [9]. The map allows to visually identify the critical areas of an environment, determining the priority points for the intervention, characterizing all physical space according to the sound levels.

The general noise regulation and the definition of the ceiling of SPL that are acceptable according to the activities carried out are defined by some institutions that specify the limits [7].

Therefore, the objective of this work was to evaluate the non-machinery and non-ambient noise levels (stamping sector) of a metallurgical industry, to diagnose the problems of the built environment and to identify areas with greater SPL.

1.2 Sound spectrum

The sonorous spectrum is an approach little explored in general terms of the concern with the selection of hearing protectors, the characteristic that distinguishes between serious sounds and acute sounds is called height, which is a function of frequency [10].

The set of infrasounds, audible sounds and ultrasound is called the sound spectrum. Infrasounds have a frequency less than 20 Hz. Audible sounds for humans have a frequency of 20 Hz to 20000 Hz. Ultrasound have a frequency above 20000 Hz. waves of lower frequency and of greater length while ultrasound have higher frequency and lower length [11].

II. MATERIALS AND METHODS

The methods for the results to be obtained in the intervention project in the stamping PLOTAM da Amazônia LTDA were organized as follows:

2.1 Survey of physical aspects:

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It was developed through photographic record, in loco measurements, quantification of the area occupied by material, reporting on the physical aspects of the production line.

a) External composition:

The building presents a diversified characterization of building materials. The front, bottom and sides of the industrial building is constructed of concrete masonry and complemented with galvanized plates, according to Figure 2.

Fig.2: Zinc Plates and Concrete Masonry.

b) ***Detailing of materials:***

1→Galvanized sheets 2→Masonry wall (concrete block).

c) Internal composition:

The internal composition of the industrial building does not differ from the external characteristics of the absorption coefficient because it has the predominant material, both in the structure of the building and in the covering and in all the machinery of the production, according to Figures 3 and 4.

Fig.3: Metal structures and roofing with zinc and polycarbonate tiles.

d) Details of materials:

1→Zinc sheets 2→Masonry wall (concrete block).

Fig.4: Organization of internal space.

e) Materials:

- Galvanized sheets
- Masonry wall (concrete block)
- Metal structure
- Metal elements

f) Survey of Sound Pressure Levels - SPL:

It was used the GERGES methodology [12] and NHO [13], with the brand decibel meter: INSTRUTHERM Model: DEC-416, calibrated by INSTRUTHERM CAL 1000; the measurement data was collected on the four sides of each machine, according to Figure 5.

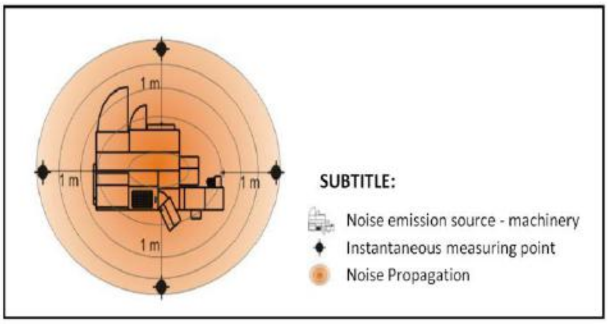

Fig.5: Instant measurement collection.

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A total of 45 sources were mapped (Figure 6) and 180 measurements were performed at three different times, being 9:30 p.m., 3:30 p.m. and 8:30 p.m. This step determined the priority sources of SPL emission within the production line and checking which schedule is noisier.

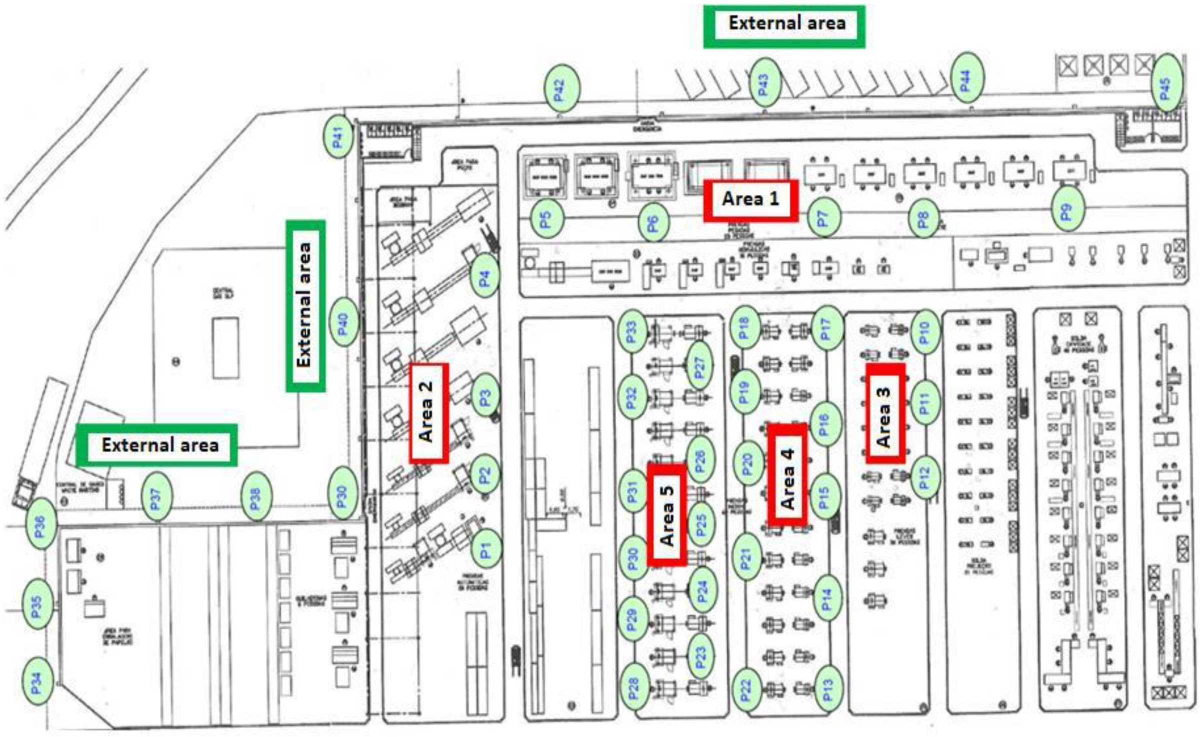

Fig.6: Stamping Sector - Font Map.

g) Statistical analysis of data.

Where:

Sample 1: MED 1 Measurements at 9:30 with machines running.

Sample 2: MED 1 No Measurements at 9:30 am the machine is not running.

Sample 3: MED 2 Measurements at 15:30 with machines running.

Sample 4: MED 2 No Measurements at 3:30 p.m. not working.

Sample 5: MED 3 Measurements at 8:30 PM with machines running.

Sample 6: MED 3 No Measurements at 8:30 PM on machines not working.

The software Statgraphics Plus v. 5.1 was used in Spanish to analyze the noise measurement data from the PLOTAM production process in Amazonia, in three different working hours and with or without operating conditions of the process machines.

We used the option of comparing multiple data samples and obtained numerical and graphical options, such as; Tabular Options: Procedure Summary

Statistical summary; ANOVA Table (Analysis of Variation); Table of Averages; Multiple Row Contrast (LSD); Contrast of variation; Tests of Kruskal-Wallis and Friedman [14];

Graphic Options: Scatter plot; Chart of Averages; Box and Mustache Graphics; Residue in front of the Exhibition; Waste versus Predito; Residual against the observed Average Analysis Chart (ANOM).

The process was divided into 5 work areas A1 through A5; and compared the noise levels between the areas for the same working hours.

Where, according to the attached plan of procedure:

Area 1: p1-p4

Area 2: p5-p9

Area 3: p10-p12

Area 4: p17-p22

Area 5: p23-p33

Ext. Area: p34-p45.

III. RESULTS AND DISCUSSION

3.1 Survey of physical aspects:

As the presses machines presented SPL in a range of 85.3 - 94.1dB were identified as due to the electric motor being coupled directly to the metallic body of the machine's sealing and control which, when vibrating, causes resonance to further aggravate the noise initially generated by the motor, according to Figure 7. This condition is repeated in several machines within the production line

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Fig.7: Partial view of the motors and general of the metal body of the presses.

The presses presented SPL in a range of 88.2 - 89.1dB, although they did not have continuous use. When connected, they generate high SPL due mainly to impact noise and, because it is an old machine, vibrates and transmits this vibration to the floor and adjacent equipment.

One aspect observed was the impossibility of total insulation of the motors of the presses due to their physical composition and to the interference in the operability of the production, which further aggravates the acoustic conditions of the environment as a whole.

Although all the presses already have vibration dampers, some of these need to be replaced because they do not present any more functionality in the operation, as shown in Figure 8.

Fig.8: Vibration damper with low efficiency.

The compressed air nozzles used for the cleaning of the metal chips, both of the parts and of the workers themselves, have a very variable time of use, but required several times during the working day, have SPL in the house of 110dB at each moment of use and in certain points this is used continuously, according to Figure 9.

Fig.9: Air nozzle without proper nozzle.

Fig.10: Storage boxes without lining.

It was observed that the carriages of transport of pieces, storage boxes and tables of support to the process do not have lining in its interior. (Figure 10).

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3.2 Calculation of Reverberation Time

Survey of physical aspects of the production line, such as building design, construction characteristics, photographic record, graphic representations of the building configuration, application of the Sabine formula for the frequencies of 125Hz, 500Hz and 2000Hz.

The Reverberation Time Calculation was designed for the company's production line environment in the frequencies 125Hz, 500Hz and 2000Hz. Using the absorption coefficients of the existing materials in the physical configuration of the building from the NBR–10152 [15] e [16], the Real Reverberation Time (TRR) can be found through the Sabine Formula, according to Annex 1, and the correction is made for the frequency of 125Hz, also according to the recommendation of the NBR –12179 [17].

The existing building materials in the evaluated environment have predominantly reflective characteristics to the sound, such as metal plates and structures, masonry walls, zinc tiles, among others. All the metallic machinery and the ambient volume of 18,000 m^3 are significant for the propagation of noise, making the difference from the ideal to the real, as can be observed in the results shown in Table 1 between the comparison of the calculated TOR and the recommended TOR in the NBR-10152 standard.

Os materiais construtivos existentes no ambiente avaliado possuem características predominantemente reflexivas ao som, como chapas e estruturas metálicas, paredes de alvenaria, telhas de zinco, entre outros. Todo o maquinário metálico e o volume do ambiente de 18.000m^3 são significativos para a propagação do ruído, fazendo a diferença do ideal para o real, como pode-se observar nos resultados demonstrados na Tabela 1 entre a comparação do TR calculado e o TOR recomendado na norma NBR-10152 [15].

Table 1: Comparison between Calculation of TR found and TOR recommended.

Frequency	125Hz	500Hz	2.000Hz
TR Calculated (s)	5,77	5,72	7,1
TOR Recommended (s)	2,45	1,69	1,69

The result showed a very marked difference between the TR found and the TOR recommended by the standard. There was no concern regarding the acoustic quality of the industrial environment, both as regards the architectural design and the choice of the elements that compose the noisy environments.

The high noise is due to machines, equipment and tools existing in the production line, built of predominantly metallic components, generating noise due to their own conditions, and also due to the advanced life of the equipment.

INTERNAL MEASURES IN THE PROCESS OF INDUSTRY

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3.1 Statistical analysis of data.

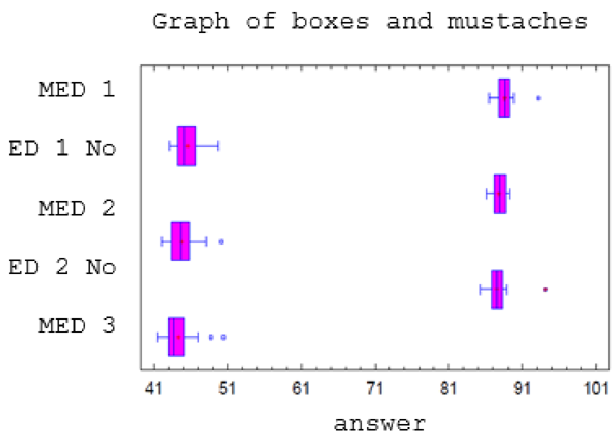

Fig.11: Graph of boxes and mustaches.

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In Multiple Queue Tests, Least Significant Differences (LSD) are used to determine the means that are significantly different from each other, as shown in Table 2.

Contrast Múltiple de Rango					
Method: 95,0 percentage LSD					
Frequency.			Average	Homogeneous group	
MED 3	No	33	44,2697	X	
MED 2	No	33	44.7606	X	
MED 1	No	33	45,5727	X	
MED 3		33	87,5485	X	
MED 2		33	87,8212	XX	
MED 1		33	88,5242	X	
Contrast				Differences	+/- Limits
MED 1 - MED 1 Não				*42,9515	0,75346
MED 1 - MED 2				0,70303	0,75346
MED 1 - MED 2 Não				*43,7636	0,75346
MED 1 - MED 3				*0,975758	0,75346
MED 1 - MED 3 Não				*44,2545	0,75346
MED 1 Não - MED 2				*- 42,2485	0,75346
MED 1 Não - MED 2 Não				*0,812121	0,75346
MED 1 Não - MED 3				* - 41,9758	0,75346
MED 1 Não - MED 3 Não				*1,30303	0,75346
MED 2 - MED 2 Não				*43,0606	0,75346
MED 2 - MED 3				0,272727	0,75346
MED 2 - MED 3 Não				*43,5515	0,75346
MED 2 Não - MED 3				* - 42,7879	0,75346
MED 2 Não - MED 3 Não				0,490909	0,75346
MED 3 - MED 3 Não				*43,2788	0,75346

* indicates a significant difference.

The asterism that is next to the 12 pairs indicates that they show statistically significant differences at a 95.0% confidence level. At the top of the page, 4 homogeneous groups are identified according to the alignment of the sign X in the column. within each column, levels that have sign X form a group of means between which there are no statistically significant differences.

As can be seen in the table, there are significant differences between the noise levels measured in the process when the machines are running or not, for any working time (column pairs of values: MED 1-MED 1 No; MED 2- MED 2 No, MED 3-MED 3 No).

The differences between noise levels for running machines are not significant between morning and afternoon measurements (MED 1-MED 2) and between afternoon and evening (MED 2-MED 3). The differences are significant but in a low fly between the measurements performed in the morning and at night (MED 1-MED 3). There are also no significant differences between mean levels of noise between the afternoon and evening hours (MED 2-MED 3).

That is, average noise levels at any time are around 88 dB, which is high according to Standard NR 15.

The comparison of two samples of noise measurement values at the same time but with the machines running and not running (Example MED1-MED1 No) reflects the following:

Sample 1: MED 1

Sample 2: MED 1 No

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Contrast Múltiple of Range					
Method: 95,0 percentage LSD					
Frequency			Average	Homogeneous groups	
MED 3	Não	33	45,5727	X	
MED 1	Não	33	45,5242	X	
Contrast				Differential	+/- Limits
MED 1 - MED 1 Não				*42,9515	0,73583

The asteristic that is next to one of the pairs indicates that it shows a statistically significant difference at a 95.0% confidence level.

That is, there are significant significant differences in noise levels when the machines are running or not. The graph of Figure 12 shows the mean values achieved and typical intervals of the measurement values with respect to the average morning noise levels.

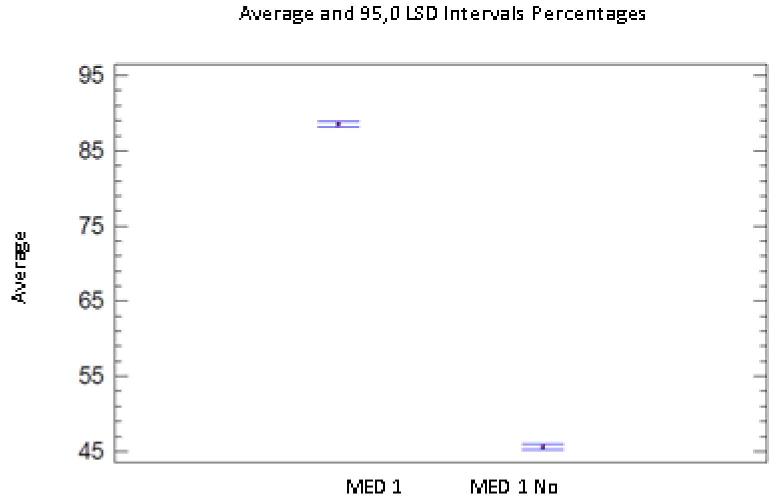

Fig.12: Averages and percentages of LSD intervals

Comparison between work areas for the same working time with machines running. For the morning time (MED1).

STATISTICAL SUMMARY

	Frequency	Average	Variance	Typical deviation	Minimum
Area 1M1	4	88,725	2,86917	1,69386	86,7
Area 2M1	5	88,82	2,357	1,53525	87,6
Area 3M1	3	88,2667	10,2933	3,20832	85,2
Area 4M1	6	89,1667	2,82667	1,68127	87,3
Area 5M1	11	88,3091	0,560909	0,748939	87,2
Total	29	88,6276	2,2085	1,4861	85,2
	Maximum	Range	Typical asymmetry	Typified Curtosis	
Area 1M1	90,7	4,0	-0,0621196	-0,185936	
Area 2M1	91,3	3,7	1,27327	0,605122	
Area 3M1	91,6	6,4	0,26265		
Area 4M1	91,5	4,2	0,228867	-0,683066	
Area 5M1	89,8	2,6	0,672859	0,202606	
Total	91,6	6,4	0,737913	0,30049	

The average noise values are above Standard NR 15 in all work areas and the measured minimum values also exceed the value of 85.

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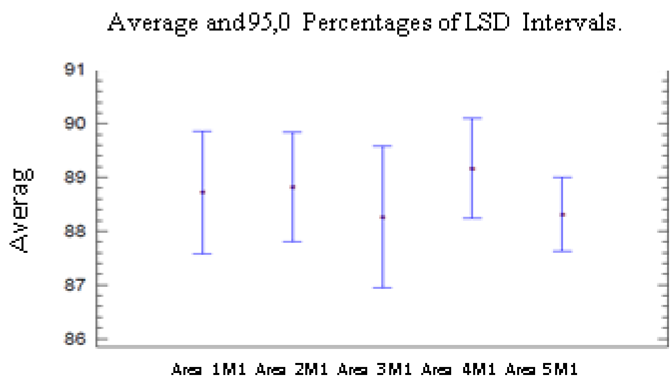

Fig.13: Average and percentages of LSD intervals.

Contrast Múltiple de Range					
Method: 95,0 percentage LSD					
Frequency			Average	Homogeneous groups	
MED 3M1		3	88,2667	X	
MED 2M1		11	88,3091	X	
MED 1M1		4	88,725	X	
MED 3M1		5	88,82	X	
MED 2M1		6	89,1667	X	
Contraste				Differential	+/- Limits
Area 1M1 – Area 2M1				-0,095	2,15906
Area 1M1 – Area 3M1				0,458333	2,4582
Area 1M1 – Area 4M1				-0,441667	2,07756
Area 1M1 – Area 5M1				0,415909	1,87922
Area 2M1 – Area 3M1				0,553333	2,35049
Area 2M1 – Area 4M1				-0,346667	1,94892
Area 2M1 – Area 5M1				0,510909	1,73595
Area 3M1 – Area 4M1				-0,9	2.27585
Area 3M1 – Area 5M1				-0,0424242	2,09636
Area 4M1 – Area 5M1				0,857576	1,63347

* indicates a significant difference.

As can be seen, there are no significant differences between the noise levels in the different work areas for the measurements performed in the morning hours.

Noise levels were compared in the same area for different working times and machines operating or not.

For example, in Area 3:

Contrast Múltiple of Range					
Method: 95,0 percentage LSD					
Frequency			Average	Homogeneous Groups	
Area3 M3		3	88,5333	X	
Area3 M2		3	88,0667	X	
Area3 M1		3	88,2667	X	
Contraste				Differential	+/- Limits
Area 3M1 – Area 3M2				0,2	3,98246
Area 3M1 – Area 3M3				0,733333	3,98246
Area 3M2 – Area 3M3				0,533333	3,98246

* indica uma diferença significativa.

EXTERNAL NOISE MEASUREMENTS IN THE IFER PROCESS:

External noise levels are compared with machines running at three different working times.

STATISTICAL SUMMARY

	Frequency	Average	Variance	Typical deviation	Minimum
Ext MED1	7	82,5714	42,3557	6,50813	68,7
Ext MED2	7	84,0143	8,5681	2,92713	78,6
Ext MED3	7	73,3143	28,8014	3,20832	66,8
Total	21	79,9667	47,5153	5,3667	66,8
	Maximum	Range	Typical asymmetry	Typified Curtosis	
Ext MED1	88,2	19,5	-2,1799	2,48351	
Ext MED2	87,2	8,6	-1,2013	0,503909	
Ext MED3	79,8	13,0	-0,0494558	-1,19699	
Total	88,2	21,4	-1,52957	-,0586752	

Contrast Múltiple of Range					
Method: 95,0 percetage LSD					
Frequency			Average	Homogeneous Groups	
Ext MED1		7	73,3143	X	
Ext MED2		7	82,5714	X	
Ext MED3		7	84,0143	X	
Contraste				Differential	+/- Limits
Ext MED1 – Ext MED2				-1,44286	5,78914
Ext MED1 – Ext MED3				*9,25714	5,78914
Ext MED2 – Ext MED3				*10,7	5,78914

* indicates a significant difference.

That is, there are significant differences, as reflected in the previous table, between the average levels of exterior noise between the morning and evening hours (MED1-MED 3)
and those of the afternoon and evening (MED2-MED 3), influenced by internal noise levels. Between morning and afternoon there are significant but minimal differences (-1.44286).

Outdoor measurements with or without running machines for different working hours.

STATISTICAL SUMMARY

	Frequency	Average	Variance	Typical deviation	Minimum
Ext MED1	7	82,5714	42,3557	6,50813	68,7
Ext MED1 Não	7	46,3571	4,83286	2,19838	43,1
Total	14	64,4643	374,869	19,3615	43,1
	Maximum	Range	Typical asymmetry	Typified Curtosis	
Ext MED1	88,2	19,5	-2,1799	2,48351	
Ext MED1 Não	50,2	7,1	0,566466	0,710728	
Total	88,2	45,1	0,186408	-,0586752	

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Contrast Múltiple of Range					
Method: 95,0 percentage LSD					
Frequency			Average	Homogeneous Groups	
Ext MED1 Não		7	46,3571	X	
Ext MED1		7	82,5714	X	
Contraste				Differential	+/- Limits
Ext MED1 – Ext MED1 Não				*36,2143	5,65705

* indicates a significant difference.

For the rest of the working hours the graphic results are shown (in all cases there are marked significant differences):

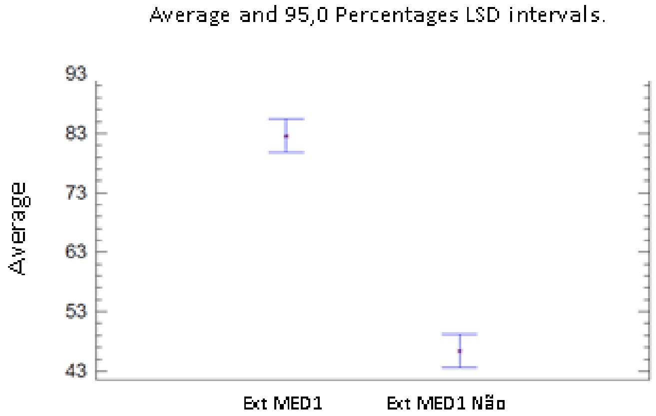

Fig.13: Average and percentages of LSD intervals.

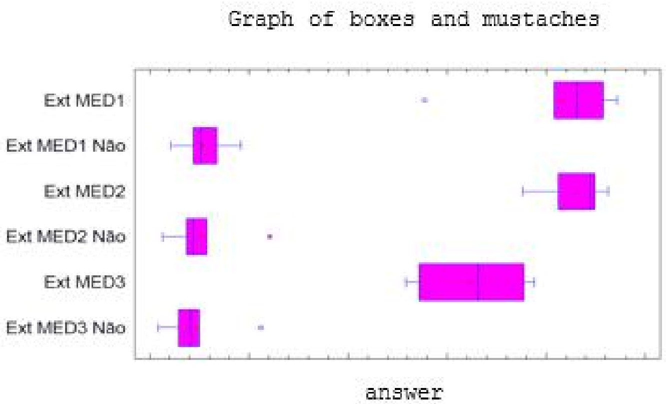

Fig.14: Mean and percentages of LSD intervals.

To sum up, for all external measurements with or without the operation of the machines in the interior, it is observed that there are significant differences between the average levels of noise outside when the machines are working or not and for the different working hours. The mean values of noise at night are lower, possibly affected because the non-inherent contribution to the process is lower.

It is also observed that in the evening hours the average noise levels are lower, with or without the machines running.

V. CONCLUSION

The noise present in the work environment studied is above the level of action and therefore requires the adoption of preventive measures. The relationship between man and the environment involves physical and functional aspects that contribute to a symbiotic harmonization. In industrial environments, quality of life is a fundamental item and directly influences the productivity of the individual. Thus, the performance of the environment from the physical point of view should favor the metabolism of the individual in order to provide adequate conditions to their physical requirements and, from a functional point of view, should contribute to the activities being developed with quality and efficiency. Environmental comfort provides this, and each of its aspects - thermal lighting and acoustics - must be in line to achieve the appropriate environmental quality. The

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acoustic comfort, object of this work, is one of the most important and relevant aspects in the quality of life of users, as well as for industrial productivity. It was concluded that the architectural features do not contribute positively to acoustic comfort; the noise sources generate high SPL that are aggravated by the high reverberation time coming from the physical characteristics of the environment. Therefore, there is a need for acoustic treatment and insulation at some critical points. It was also identified the need to deepen the SPL survey, with differentiation of frequencies, the functionality of the environment, the necessary conversation between workers and dosimetry. The statistical treatment reflected that there are no significant differences between the averages of the measured noise values at different working hours. In addition, it is found that the average levels achieved do not differ from one area to another within the stamping sector.

It is suggested ways of reducing machine noise, such as total or partial enclosure that completely covers down noise sources. The noise control by enclosure is a practical and feasible solution for noise reduction of a machine that is already installed and in operation, but each case must be studied looking for the best alternative, as suggested for the transport cart, boxes storage tables, support tables, electric motors and compressed air nozzles.

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