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Noise monitoring in urban canyon in Maringá city

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ABSTRACT

The urban noise problems aggravate when roads and buildings configurate urban canyons, especially due to quasi-reverberation phenomenon. This study objective was to propose mitigating measures for urban canyon situations. To know sound behavior in these places, it was carried out sound pressure levels monitoring in an urban canyon, in 4 characteristic rush hours, to evaluate the variation of sound levels during the day. On morning rush hour, the monitoring was done on 10 floors of a building to evaluate sound levels variation with increasing altitude, along the façade. The noisiest periods of the day are late afternoon (18:00 - $L_{A,eq}$=73.8 dB) and early in the morning (08:00 - $L_{A,eq}$=72.8 dB). There was a predominance of low frequencies at all periods and floors measured. Sound levels do not decrease with increasing height uniformly, being the third floor the noisiest ($L_{A,eq}$=69.3 dB). The mezzanine causes an acoustic shadow on the leisure storey, therefore the noise levels on this floor are the lowest ($L_{A,eq}$=62.4 dB). The monitoring results, both on the floor and in height, exceeded the acceptable levels of Brazilian technical standards by 8 dB to 24 dB, depending on the situation. Measures have been proposed to mitigate noise pollution.

Keywords: Traffic noise, Noise monitoring, Mitigating Measures

1. INTRODUCTION

According to World Health Organization (WHO), knowledge of the health damage caused by noise are increasing as well as authorities concern. Previously surveys, in six countries, had pointed to noise pollution as the third largest factor in the environmental burden of disease, expressed in disability-adjusted life years (DALYs). Later, WHO have shown burden of disease from environmental noise as the second highest, losing only for air pollution. WHO estimates that a quarter of European Union population is exposed to noise levels that causes a wide range of health effects, directly related to sound or not, from some simple to serious problems, including reduction in life expectancy. Cities are essentially noise producers, however, the largest source of urban noise is traffic, mostly road traffic (1, 2, 3, 4, 5).

To minimize problems caused by noise and prevent people from being exposed to levels above adequate parameters, organizations and governments create guides, standards and laws. In Brazil, the national standards that gives parameters to guarantee acoustic comfort are ABTN NBR 10151 (6), ABNT NBR 10152 (7) and ABNT NBR 15575 (8). Brazilian legal references are *Lei de Crimes Ambientais*, *Lei* nº 9.605/98 (9), *Resoluções do CONAMA* nº 001and 002 (10, 11).

In dealing with urban canyons, noise problems became even worse. According to Oke (12) an urban canyon is consisted of the walls and the ground, that is usually a street, between two adjacent buildings and references (13, 14) said that the geometry of the canyon is related to the height and thickness of the buildings. The buildings alignment can vary along the canyon. An urban canyon can be identified by Equation 1, that gives the “aspect ratio” (AR) and is the relation of the height of the buildings and the width of the street.

$$AR = (H_1 + H_2)/2W \leq 1 \qquad (1)$$

Where H_1 and H_2 are the buildings heights that contour the canyon and W is the street width.

The measured sound level at urban canyons is composed of the direct sound and quasi-reverberation, a non-diffused reverberation, that consists of flutter echoes between the façades of the buildings that delineate the canyon (14).

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This search objective, then, was to monitor the sound at ground level and in a building façade, located on an urban canyon of Maringá city, confirm that the sound levels were not in accordance with the standards and laws, so that mitigating measures could be proposed.

2. Method

According to the objectives this research is exploratory, and the technical procedures used are experimental (15).

2.1 Experimental site

For the accomplishment of this study, was chosen an urban canyon located in the Maringá City, being this part of the Special Zone 1, defined on the *Lei Complementar* (LC) 331/99 (16), that was replaced and supplemented by LC 888/11 (17), and specified by LC 416/01 (18). The special zone is part of the *Zona 1* neighborhood and is called *Novo Centro*. It is divided into three glebes (A, B, C) and the urban canyon is located on *Advogado Horácio Raccanelo Filho* Avenue, in Glebe A. Although today this region is in the central part of the municipality, there passed a line of merchant train, in the streets level, and the place was abandoned for a while, after the train loading locations were transferred outside the city. The zone was revitalized after the 2000s, along with the lowering of the railway line, and that is the reason why it is named as the "new downtown". As it is part of the center, the LC stipulated that use and occupation of soil should be composed by multifamily housing, commerce and central and vicinal services, excluding gas stations.

Due to the geometric, use and occupation characteristics determined on (18) and implemented on *Novo Centro*, the *Advogado Horácio Raccanelo Filho* Avenue configures an urban canyon, and therefore it was chosen to be the experimental site. The law stipulates that the Glebe A must be occupied with a basement consisting of two floors, ground floor and mezzanine, intended for use of commerce and services, and with a vertical block, residential or for use of commerce and services. This obligation of a vertical block gave rise to the urban canyon. The constructed area of the basement must be at least 50% of the total land area, distributed throughout the front width of the lot, with openings for garages, parking lots and galleries transverse to the building alignment permissible. Pillars are allowed in the building alignment, with the external face concordant with the alignment and maximum dimensions of 80 centimeters in parallel to the alignment and 50 centimeters transversely to it. The height of the lining of the gallery formed by the basement should be at least 3.50 meters and at most 5.50 meters. The maximum height of the base must be 10 meters, considering the height between the sill of the building and the upper face of the flat roof, guardrail frame or roof. All lots of the *Novo Centro* must obey the frontal recoil of the ground floor, of 3 meters, which should continue the walk, free of steps, unevenness and longitudinal or transverse ramps. The utilization coefficient of *Novo Centro* is 6, the biggest in the city. The occupancy rate is 50% for the towers and 90% for the other floors. The aspect ratio calculated for the measurements point in the avenue is 1.40, what characterizes the urban canyon, that can be seen at Figure 1a.

Other building characteristic of the site is the galleries formed at the ground floor by the mezzanine, a different situation that is interesting to evaluate and analyze how sound behaves on this circumstance. A profile of the site is shown in Figure 1b, where it can be seen that the avenue has two avenue tracks and a parking lane for each direction, the cycle lane at the center, sidewalks and the galleries.

The measurements had two phases, the first was the monitoring of traffic noise daily variation, described at 2.2 and the second was the monitoring of traffic noise variation along the building façade, presented at 2.3.

2.2 Monitoring of traffic noise daily variation

The objective of this phase was to evaluate the daily variation of traffic noise and to verify at what time the sound levels were stronger. As urban canyon situations are critical for sound propagation, the measurements of traffic noise variation along the day were made under this condition. It was chosen only one point of the avenue to do this, in front of the building where the measurements of the second phase of the study would be made. This spot is shown in Figure 2.

Four measurements, lasting one hour each, were taken at the hush hours. The stipulated timetables for measurement were from 7:15 a.m. to 8:15 a.m., from 11:30 a.m. to 0:30 p.m., from 1:00 p.m. to 2:00 p.m. and from 5:30 p.m. to 6:30 p.m. To ensure the validity of the results, the day of measurements was a typical traffic day, a Wednesday, July 4, 2018. The equipment was positioned on the sidewalk, 1 meter from the curb, at 1.20 meters from the ground.

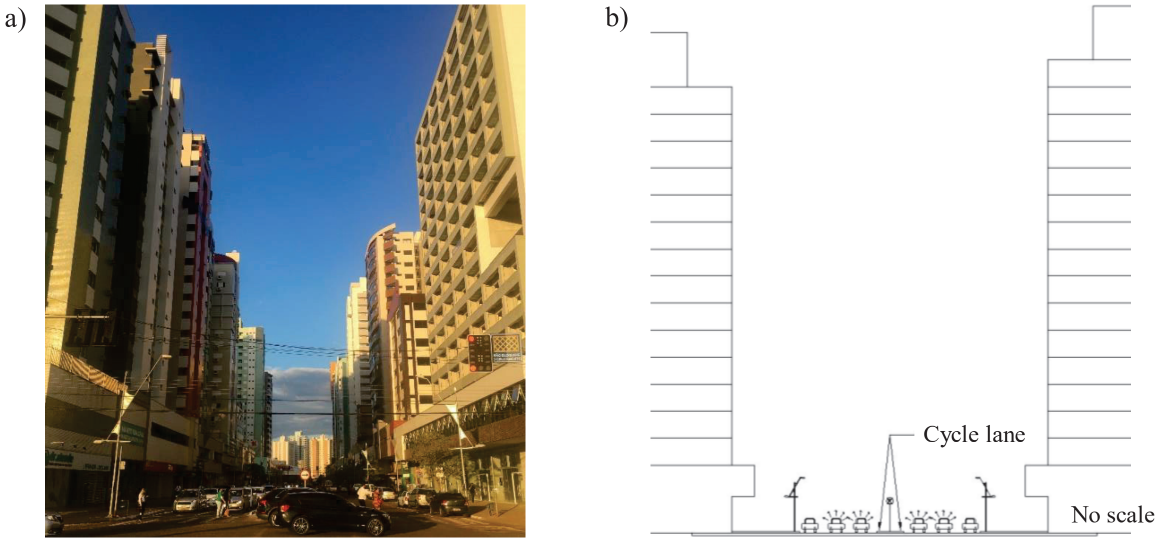

Figure 1 – a) Urban canyon formed at the *Advogado Horácio Racanello Filho* Avenue; b) Geometric scheme of the experimental site

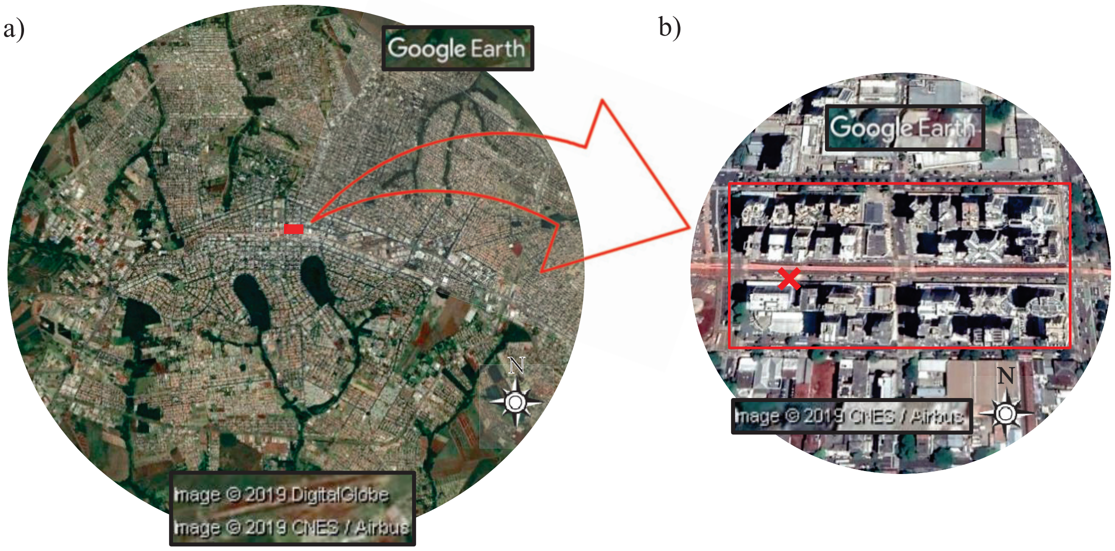

Figure 2 – a) Maringá city map; b) Urban canyon and measurement point (19)

Map data: Google, DigitalGlobe and CNES/Airbus

The sound level meter used was the Solo SLM 01dB, that gives sound spectrum, $L_{eq,A}$, L_{10}, L_{50} and L_{90} parameters, which are sensitive to the random characteristics of traffic noise. The sound level meter was configured to collect data every second. It was fixes to a tripod. At minute 00, 30 and 60 of each measurement, the temperature and the air relative humidity were measured. To gauge temperature and humidity it was used a CEM DT-321 temperature and humidity meter.

2.3 Monitoring of traffic noise variation along the building façade

The noise monitoring along the building's façade was done in a dwelling that was being built. The building has 14 typical floors and is located in a street corner, at the end of the urban canyon, however, because it extends into the block and the monitoring was carried out on the balconies more internal to the canyon, the measurements were carried out without considering the effects of end of canyon. As the first floor protrude forward from the building alignment, it was decided to make the measurement on the ground floor (on sidewalk), on the leisure, first, second, third, fourth, seventh, tenth and thirteenth floors. For the ground floor measurements, the tripod was used to support the equipment. For other floors, the sound meter level was coupled to a bracket to fit balcony structures so that the sonometer was two meters outside the building.

The sonometer was the same as that used on the first phase, but the measurements on each floor lasted only 2 minutes, since 9 measurements would have to be made at the same hush hour (one-hour period) of the same day, making a longer monitoring impractical. The sound meter level collected data every second. It had been observed in the first phase of the study that sound levels from 5:30 p.m. to 6:30 p.m. were the largest, so it would have been appropriated to measure the levels in the façade in this period. However, the office hour of the dwelling where monitoring was taken ends 5:30 p.m., making impossible to make the measurements at that time. Therefore, the period chosen for the second phase of measurements had the second highest sound levels, from 07:15 to 08:15. The measurements were made on a typical traffic day, July 7, 2018. While all the measurements on the façade were being carried out, the temperature and relative humidity of the air were measured. Figure 5a shows the photo of the measurement on the leisure floor, Figure 5b shows the photo of the measurement on the tenth floor and Figure 5c shows the layout of the building with the measuring floors and the height of each floor from the ground.

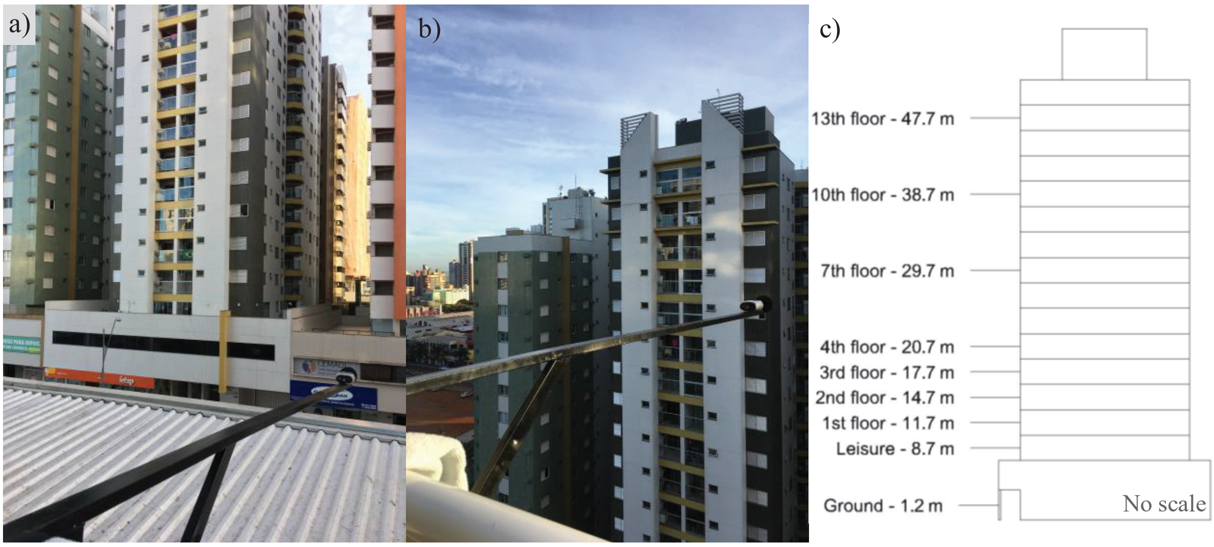

Figure 3 – a) Measurement at leisure floor; b) Measurement at 10th floor; c) Geometric scheme of the measured building

In the next section the results will be presented.

3. RESULTS AND DISCUSSION

With sound pressure levels (SPL) for frequencies and hours (first phase results), it was plotted a graphic of frequency by SPL, for the 4 periods of monitoring. That is presented at Figure 4. As expected for a traffic noise evaluation, noise was higher at the lower frequencies. At this phase, in the morning the temperatures were around 17 ºC, at the time of other measurements, around 27 ºC. The sky was clear.

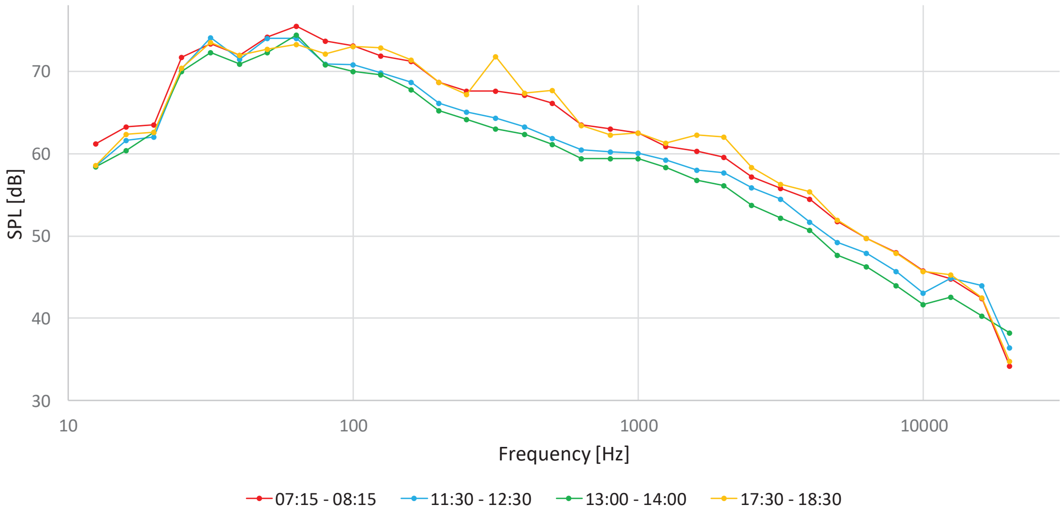

Figure 4 – graphic of frequency [Hz] X SPL [dB], for the 4 periods of monitoring

The Lilliefors method was used to verify the normality of the data. For the measurements of the first monitoring period, only the time of 7:15 was not normal, since the other schedules, because they have the maximum distance smaller than the critical one, were proven as normal. For the measurements of the second phase, which had less data, of the 9, only 2 were normal.

The monitoring at each floor lasted two minutes (second phase). The data collected with these measurement times are representative because is higher than the minimum monitoring time for the local traffic volumes at this period. Author (20) developed a parameter for minimum monitoring time according to the traffic volume. Based on that parameters and the volume for the period of almost 3000 equivalent vehicles per hour, it was noticed that less than 1 minute of monitoring would be required, validating the data obtained from the 2-minute measurements.

At this stage, temperatures varied around 10° C and the sky was clear. Graphics of frequency by SPL of each floor were plotted in Figure 5. As it was expected for traffic noise, the strongest levels were at the lower frequencies for all storeys.

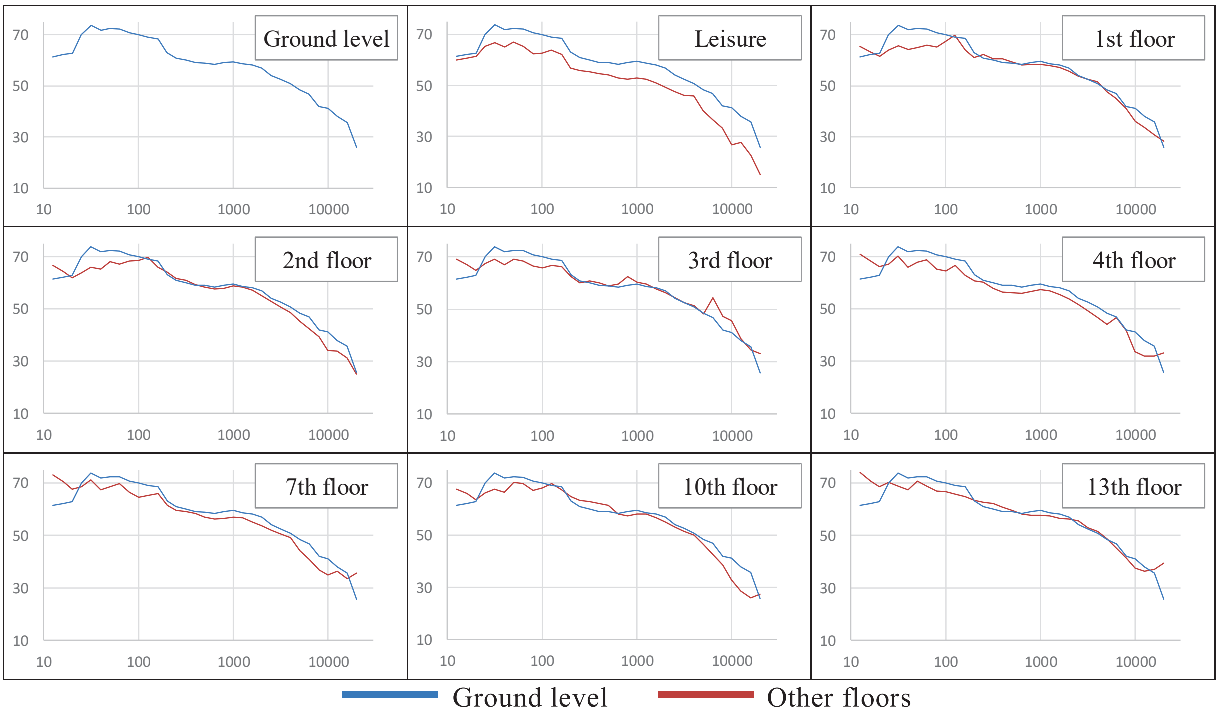

Figure 5 – graphics of frequency [Hz] X SPL [dB] for all measured floors

From analyses of the graphics and calculations, it is possible to observe regions of suppression and superposition of waves in some frequencies, for certain floors, for example, a suppression on the 20-25 Hz region, on the 7th floor, and a superposition on the 50-63 Hz region, on the 10th floor. This is due to the difference in wavelengths of each frequency and the distance from the sound source to the building façade. Beyond the site geometry influence in the results, depending on the frequency and height in the building, there may be zones where the waves are in phase, what is the superposition of them, increasing the sound pressure levels. In other regions, there may be a difference of half wavelength between the direct and reflected waves that arrives at the façade, which means there is suppression of them, reducing the SPL.

Measurements were carried out from bottom to top on the façade. However, the leisure storey, which should have been the third measured if followed this logic, was the last one. To verify if the inversion of the upward order had interfered in the sound behavior profile of the building façade, the data of the first hour of the phase one of measurements (7:15 a.m. to 8:15 a.m.) were separated into 4 periods of 15 minutes. The leisure floor was measured at the fourth period. From the 15-minute intervals SPL tables, L_{90}, L_{50} and L_{10} values were extracted. With this procedure it was observed that L_{90} and L_{50} at the last of the four periods were the worst and L_{10} was the second higher value. Even though the last period presented bad results, the SPL on the leisure storey were the lowest. With this analysis, can be inferred that the low sound pressure levels measured at leisure floor were caused by the building and site geometries. This behavior was already expected since de mezzanine protrude forward from the building alignment producing a region of acoustic shadow, in which the leisure floor is inserted.

This significant noise reduction in almost all frequencies can also be seen both in Figure 6a, that represents the graph of SPL by building height for octave band frequencies, and in Figure 6b, that is the graph of SPL by building height in terms of measured $L_{A,eq}$ and ideal $L_{A,eq}$. This ideal theorical behavior of SPL correspond to that expected for an open and unobstructed field, disregarding any sound reflections and attenuations. Sound behavior on the building differs from the theorical due to the building format, the geometry of the region and the reverberant urban canyon effect. The theorical sound SPL can be calculated by Equation 2. The ideal $L_{A,eq}$ plotted in Figure 6b was calculated from this equation and represented the expected SPL for the floors levels where the levels were measured, for a 87dB-power linear source in the free field situation.

$$L_P \approx L_I = 10\log\left(\frac{W'}{2\pi 10^{-12}}\right) = L_{W'} - 10\log r - 8 \qquad (2)$$

Where: L_P is the SP [dB]; L_I is the sound intensity level [dB]; W′ is the linear sound power [W/m]; r is the distance from source to receptor point; and $L_{W'}$ is the linear sound power level [dB/m].

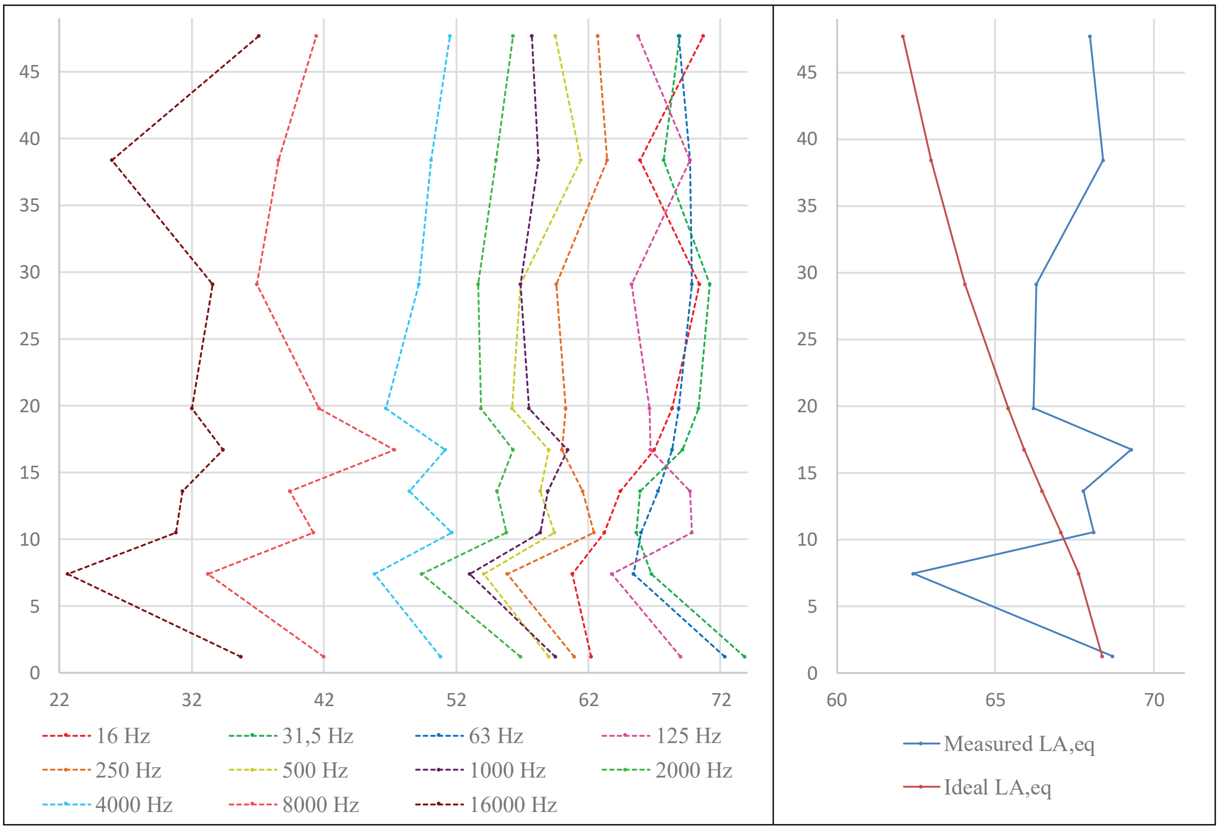

Figure 6 – a) graphic of SPL [dB] X building height [m] by frequency; b) Graphic of measured and ideal $L_{A,eq}$ [dB] X building height [m]

It was noted that the site and building geometries strongly influenced the measured SPL in the façade. Because of that, it is understood that the results could vary if the measurements had been taken in another building of the avenue. This is because sound obey optical properties, characteristic that becomes more significant in cases of urban canyons, due to quasi-reverberation. So, the sound behavior is expected to change if the site and building geometries change. To estimate how this behavior would be, Kang *et al.* (21) elaborated an equation (Equation 3) to describe sound distribution considering the geometric study of the square, for diffusely reflecting boundaries, what eliminates the need for multiple monitoring. Equation 3 is for point sources, but a line source can be simplified as a combination of multiples sources.

$$L = L_W + 10\log\left[\frac{Q}{4\pi r^2} + \frac{3H}{W+L}\frac{4}{\left(\frac{S\alpha_T}{(1-\alpha_T)}\right)}\right] \qquad (3)$$

Where Q is the source directivity factor, r is the source-receiver distance [m], L is the square length [m], W is the square width [m], H is the square height [m], S is the total surface area (including an imaginary square ceiling) [m^2] and α_T is given by Equation 4.

$$\alpha_T = \bar{\alpha} + 4mV/S \qquad (3)$$

Where $\bar{\alpha}$ is the average absorption coefficient (including an imaginary square ceiling), m is the air absorption factor and V is the volume (V= LWH) [m^3]. This analysis was not considered on this paper, but it could be applied to compare the theorical results with the measured ones.

With the data, it was observed that in every situation analyzed the SPL exceeded the noise limits for daytime period established by LC 218/98 of Maringá city (22) and ABNT NBR 10151 (2000) of 55 dB, A-weighted. In the balconies case, results of 8 to 14 dB above the limit was found. For the ground floor, the situation was even more critical, with equivalent levels of 14 to 23 dB above the ideal. Because of this, it is recommended that attitudes are taken to reduce noise levels and regularize the situation.

According to a study elaborated by Kook *et al.* (23), traffic noise can be divided mostly into three elements: aerodynamic, from the engine and from the friction of the tires with the pavement. For the studied case, as the maximum speed permitted in the avenue is 50 km/h, the friction component is predominant, surpassing the aerodynamic component by approximately 10 dB and being higher than the engine component by approximately 5 dB. The aerodynamic component can be practically ignored, but the engine part must be considered.

In dealing with the engines, technology already permits production of vehicles that emit a sound power so low that it can be despised for this speed range, specially for light vehicles. The improvement in the engine performance is the solution for that component, however, it only works if the cars used by the population have silent equipment. This can be guaranteed by legal devices. In case of cars and motorcycles, the city may impose stiffer automotive noise emission limits and improve control devices. Thinking beyond noise problems and aiming to make the city more sustainable it may be forbitten or overtaxed the use of cars that are not electrical, since they are more silent. In dealing with big vehicles, restriction on non-electric vehicles may also be implanted, both for trucks and busses. In addition, trucks may suffer movement restrictions in the city.

Knowing the main noise-causing parcel (friction of the tires), the efforts to mitigate noise problems can be focused on it. One measure capable of reducing this component is the reduction of the speed limit to 40 km/m, an easy and fast change to implement, however its efficiency depends on the drivers respect for the new limit. Drivers disrespect for limits can be faced with speed cameras on the road. Road safety would also be improved with this solution. Another way to treat friction portion is changing the pavement of the road to one that produces less noise with the friction of the tires or that is more absorbent and is less reflective, reducing emission of the noise generated during the passage of the vehicles to the atmosphere. In cases where it is not possible to change the entire pavement, it is interesting that it is recapped with an acoustically more appropriate material. A material that could be tested is pavement with crumb rubber modified binders (CRMB), as reference (24) that achieved 1.8 dB SPL reduction with 20% of additive.

To reduce reverberation effects due to urban canyon configuration both at the top of buildings and for pedestrians at street level building façade treatment is an option. The coating materials can be changed to more absorbent or diffusive ones. A good artifice is installation of green walls, which provides more benefits for citizens then only on noise matters.

Another way to solve noise issues and, at the same time, to be compatible with sustainable principles and the concept of a city for people is changing totally the way that people move around the city center, banishing all private vehicles at downtown to prioritize bicycles and collective transport. In this case, busses could still be used or could be replaced by light rail or even metro.

4. CONCLUSIONS

The objectives of this research of monitoring traffic noise at ground level and in the building façade to understand sound behavior in an avenue of Maringá City to confirm that the levels were not in agreement with the standard so mitigating measures should be proposed were achieved. It was suggested measures to act directly on the two main components of the biggest noise-causing agent in the city, the traffic. There were from simple and fast implementation suggested actions to other more complex structural and conceptual ones.

It was noticed that, in any situation measured, sound pressure levels were much higher than the permitted by the national standard and the municipal law. This happened even at the leisure floor, that is located on an acoustic shadow provided by the mezzanine, what caused an important reduction of noise levels, however, the equivalent noise level still exceeded the allowed one by more than 7 dB.

For future researches, it is of great importance to test the solutions proposed, by applicating then e monitoring the sound levels at the same way that they were in this research, to attest its effectiveness and to verify which mitigating measure provides the greatest noise attenuation in urban canyon situations and at ground level, to find solutions that are appropriate for other situations. At first, measures can be applied separately and then they can be combined. The changing of the energy matrix of heavy vehicles or the changing of the vehicles themselves can be verified by prohibiting them to circulate at the avenue for a study period. After that, all vehicle may be prevented from driving on the avenue to evaluate SPL if no vehicle passed through there. Absorbent materials might be installed on the building façades to see if the reverberant issues cause by urban canyon configuration would be solved. Then, the avenue speed limit may be reduced. Lastly an acoustically efficient pavement can be applied at the experimental blocks of the avenue. After testing the solutions separately, they can be tested in combination to se how they interact with each other.

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