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Assessment of Indoor and Outdoor Noise Pollution at a University Hospital Based on Acoustic Measurements and Noise Mapping

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Abstract

This paper describes an analysis of the sound pressure levels at the exterior façade and inside the Hospital de Clínicas of the Federal University of Paraná. Measurements were taken at a total of 45 points, 24 at the exterior facade and 21 points inside the hospital on all the floors of the main building and in the maternity building. These 45 measurements were used to calculate the acoustic map of the hospital, which is located on General Carneiro Street, in the city of Curitiba, state of Paraná, Brazil. A comparison of the measured outdoor sound pressure levels against those established by Curitiba Municipal Law No. 10625 revealed that they all exceeded the daytime limit of 55 dB(A) permitted for areas around hospitals. The indoor sound pressure measurements and the noise levels for acoustic comfort established by the Brazilian technical standard ABNT NBR 10152 were compared, indicating that all the measured points, including those in the neonatal intensive care unit, exceeded the established limit of 35 dB(A) to 45 dB(A).

Keywords

Noise Pollution, University Hospital of The Federal University of Paraná, Sound Measurements, Sound Pressure Levels, Noise Mapping

1. Introduction

The University Hospital (**Hospital de Clínicas**) of the Federal University of Paraná (UFPR), which is 55 years old, is the largest hospital in the state of Paraná, Brazil. It is also the fifth largest university hospital in Brazil and is a reference in various health services, which are offered free of charge to the population, especially to the most needy.

This university hospital currently comprises 60,473,000 square meters of built area, with 261 consulting rooms and 643 beds distributed among 59 specialties, and has a staff of 3113.

The World Health Organization [1] considers noise a public health problem, which involves not only those who receive the sound levels but also its means of propagation and emission source. Noise, can be classified as a type of toxic pollution [2] [3].

Several studies have correlated noise pollution with health problems, the most common of which are irritability, poor concentration, insomnia and headache [1] [4] [5] [6] [7].

In hospitals, technological advances in medicine have resulted in potentially harmful sound pressure levels [8] [9] [10]. Moreover, many hospitals are located in areas exposed to outdoor noise sources such as high volumes of traffic. However, there is strong evidence that hospital equipment and medical staff talking loudly to each other may cause most of the noise inside hospitals [11] [12] [13] [14] [15].

In fact, in order to increase efficiency and safety, more physiological parameters are monitored and more medical devices are employed in clinical routines. Common examples of noise generators include vacuum cleaners, cardioscopes, oximeters, ventilators, oxygen and compressed air outlets, computers, printers, phones, moving furniture, and health professionals talking to each other and to patients [16] [17] [18].

Noise affects the psychological state of patients, causing sleep disturbance, disorientation and anxiety [16] [19]. A pleasant environment can benefit patients and hospital staff, creating less fatigue and psychological stress, and thus helping patients recover more quickly.

Since 1974, the United States Environmental Protection Agency [20] has recommended that noise levels in hospitals should not exceed 45 dB(A) in the daytime and 35 dB(A) at night. In Brazil, standard NBR 10152 of ABNT [21], the Brazilian Association of Technical Standards, recommends 35 to 45 dB(A) as acceptable levels for hospital environments, considering the lower level the one for comfort and the upper one acceptable for the functioning of these environments.

Noise and its effects on health and the curing of illnesses have been a concern for many years [2] [9]. Therefore, it is essential that this problem be quantified so that mitigation measures can be implemented [22] [23].

The purpose of this study was to evaluate and quantify the sound pressure levels around and inside the University Hospital of the Federal University of Paraná. A noise map of the facade of the hospital was calculated for the outside area in front of the main hospital entrance, where traffic flow is heavy. The sound levels in different areas inside the hospital were also evaluated. These areas involved all the floors of the maternity building, including the neonatal intensive care unit, and several areas inside the hospital's main building.

2. Materials and Methods

Since 1974, the United States Environmental Protection Agency [20] has established

that noise levels in hospitals should not exceed 45 dB(A) in the daytime and 35 dB(A) at night.

Standard NBR 10152 of the Brazilian Association of Technical Standards [21] suggests 35 to 45 dB(A) as acceptable levels for different hospital settings, the former being the desirable level and the latter the acceptable limit for the functioning of these environments. The American Academy of Pediatrics [24] states that the sound levels in neonatal intensive care units should not exceed 45 dB(A). The World Health Organization [1] recommends an equivalent sound pressure level, Leq, of 30 dB(A) and a maximum level, Lmax, of 40 dB(A) for indoor hospital environments. In hospital environments, since there are patients in the recovery phase, the level should not exceed 35 dB(A). At night, these sound pressure levels should be reduced by about 5 to 10 dB(A) [1].

In Brazil, the rules for environmental noise pollution assessments are specified by standard NBR 10151 "Noise Assessment in Populated Areas, Seeking the Comfort of the Community." **Table 1** describes the sound levels established by the Brazilian technical standard NBR 10151 [25], according to the type of area.

The purpose of the NBR 10152 standard—"Noise levels for acoustic comfort" is to define noise level limits in closed environments such as schools, hospitals, etc. The values adopted by NBR 10152:87 for the evaluation of acoustic comfort in different environments are listed in **Table 2**. In the column on the right in this table, the lower equivalent sound pressure level Leq is considered the level of "acoustic comfort", while the upper sound level is considered the "acceptable sound level" for the function of the indoor environments evaluated". Indoor environments with higher noise levels that those listed here are considered "uncomfortable". The norm NBR 10152 also emphasizes that indoor environments with sound pressure levels higher than those in **Table 2** do not necessarily mean sound levels that cause health damage.

Curitiba Municipal Law No. 10625 [26] establishes regulations on urban noise, public protection and welfare. The law defines three time periods, namely: 1) Daytime—from 07h01 to 19h00; 2) Evening-from 19:01 to 22:00; 3) Nighttime—from 22:01 to 07:00. The city of Curitiba is divided into several zones: a special commercial sector, a historical sector, a special educational zone, an industrial zone, a residential zone, mixed-use zone, and others.

Table 1. Limit noise levels according to standard NBR10151:2000.

Types of regions	Daytime noise levels limits dB(A)
Country houses and farms	40
Strictly urban residential, hospital or school areas	50
Mixed, predominantly residential areas	55
Mixed area of commercial establishments and offices	60
Mixed area predominantly for recreational use	65
Predominantly industrial area	70

Table 2. Noise levels according to NBR 10152:1987.

Locations	Leq dB(A)
Hospitals	
Private rooms, hospital wards, nurseries, surgical	**35 - 45**
Centers, laboratories	40 - 50
Areas for public use	45 - 55
Services	
Schools	
Libraries, music rooms, drawing rooms	35 - 45
Classrooms and laboratories	40 - 50
Circulation areas	45 - 55
Hotels	
Guest rooms	35 - 45
Restaurants, living rooms	40 - 50
Front office, reception desk, circulation areas	45 - 55
Homes	35 - 45
Bedrooms	40 - 50
Living rooms	
Auditoriums	
Concert halls, theaters	30 - 40
Conference rooms, cinemas, multipurpose rooms	35 - 45
Restaurants	40 - 50
Offices	
Meeting rooms	30 - 40
Managers' offices	35 - 45
Computer rooms	45 - 65
Office machinery rooms	50 - 60
Places of worship	40 - 50

Table 3 lists the permissible noise limits for different zones of use in the city of Curitiba. For a better understanding, the zones are divided into regions equivalent to those of NBR 10151 divided into regions equivalent to those of NBR 10151.

Some of the zones of use established by the aforementioned municipal law, corresponding to the regions defined by the NBR 10151 standard, are listed below.

1) Region 1: RZ-CO—Residential Zone of Controlled Occupation; RZ-SF—Residential Zone of Santa Felicidade; RZ-U—Residential Zone of Umbará; RZ-P—Residential Zone of Passaúna. Region 1 also includes: schools, kindergartens, libraries, clinics, nursing homes and hospitals (Hospitals are considered special zones of silence).

2) Region 2: RZ-1—Residential Zone 1; RZ-2—Residential Zone 2; RZ-3—Residential Zone 3; RZ-AG—Residential Zone Alto da Glória; RZ-B—Residential Zone Batel; RZ-M—Residential Zone Mercês.

3) Region 4: RZ-4—Residential Zone 4; CZ—Central Zone; TZ-BR-116—Transition Zone BR—116; UM-Z—Mixed Use Zone; SZ-S—Special Zone for Sports; HS—Historical Sector; SS-SF—Special Commercial Sector of Santa Felicidade; SS-LE—Special Sector of Linhão do Emprego 10; APA-SS—Service Sector.

4) Regions 5 and 6: SS-1—Service Sector 1; SS-2—Service Sector 2; IZ—Industrial Zone; APA-SSU—Sector for Sports Use.

A 300 meter stretch was used for the outdoor measurements of the main facade of

Table 3. Permissible noise limits for the different zones of use, according to NBR 10151.

Zones of use	Daytime hours 7:01-19:00	Evening hours 19:01-22:00	Nighttime hours 22:01-7:00
Regions 1 and 2	55 dB(A)	50 dB(A)	45 dB(A)
Region 3	60 dB(A)	55 dB(A)	50 dB(A)
Region 4	65 dB(A)	60 dB(A)	55 dB(A)
Regions 5 and 6	70 dB(A)	60 dB(A)	60 dB(A)

the hospital. These measurements were distributed at 10 meter intervals, making a total of 30 measured points, as shown in Figure 1. The measurement time, which followed recommendations found in literature, was set at 10 minutes per point [7] [27] [28]. Simultaneous to these measurements, vehicle counts were made (light vehicles, motorcycles, heavy vehicles—buses and trucks) during the daytime on weekdays. The data thus collected were: number of light and heavy vehicles and measurements of equivalent sound levels, Leq, expressed in dB(A), as specified by the Brazilian standard NBR 10151. These noise measurements were taken using BK-2237 and BK-2238 sound level meters. The noise maps were calculated using B&K Predictor 7810 software.

Acoustic mapping enables the assessment of the entire area affected by noise in front of the main facade, providing a detailed view of noise pollution [29] [30] [31]. In this study, the acoustic map was calculated using Predictor 7810 software. The site's contour line data that were inserted into the model were provided by the Institute for Research and Urban Planning of Curitiba. After including altimetry data in the model, orthophotographs were inserted in order to digitize the buildings and enter their respective heights. The standard used was 3 meters per floor in each building of the University Hospital.

Noise measurements were taken on all floors of the central building and the hospital's maternity building, making a total of 21 measured points. The measured locations were the hallways or sectors on each floor, where measurements were previously authorized. The indoor noise measurements were taken on weekdays, during the daytime.

3. Results and Discussion

Figure 1 shows the measuring points along the frontal façades of the buildings of the University Hospital. Measurements were performed at 30 points, as shown in Table 4.

During the measurements taken along the façade of the hospital, the average vehicle count per hour was 12 motorcycles, 213 light vehicles and 12 heavy vehicles. The average speed of motorcycles and light vehicles was 40 km/h and that of heavy vehicles was 30 km/h. The inclusion of these data in the Predictor software enabled the calculation of the outdoor acoustic conditions of the University Hospital.

Figure 2 shows the color scale with the corresponding variation in sound pressure levels used in the acoustic maps, while Figure 3 and Figure 4 depict the 2D and 3D acoustic maps of the University Hospital.

As can be seen from the acoustic maps in Figure 3 and Figure 4, the noise levels

Figure 1. Noise measurement points along the frontal façades of the buildings of the University Hospital of the Federal University of Paraná—UFPR.

Table 4. Measurements of outdoor sound pressure levels.

Points	L_{eq} - dB(A)	Points	L_{eq} - dB(A)
1	67.2	16	64.5
2	63.7	17	64
3	62.9	18	60.5
4	63.1	19	59.4
5	63.2	20	60.6
6	62.3	21	61.9
7	63.2	22	62.8
8	62.2	23	63.4
9	61	24	61.7
10	60	25	62.3
11	61.8	26	62.5
12	58.4	27	63.5
13	57	28	64.7
14	60	29	66.5
15	63	30	66.7

calculated for the frontal façade of the hospital show values of 70 to 75 dB(A) in the middle of the street, decreasing to 65 to 70 dB(A) as they approach the facade. The noise levels that reach the facade of the hospital are mostly in the range of 55 to 60 dB(A), reaching 60 to 65 dB(A) in the most central part of the frontal facade of the hospital.

Figure 2. Color scale of the acoustic maps.

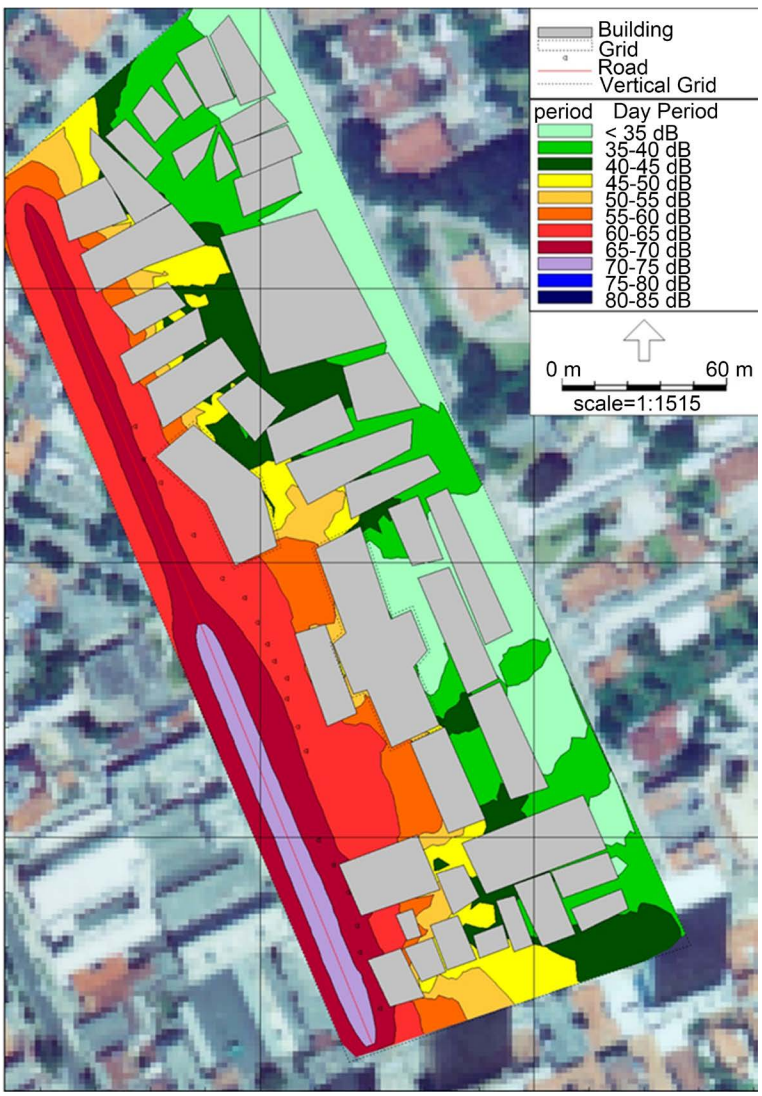

Figure 3. Noise mapping of the frontal facade of the main building of the University Hospital of UFPR, located on General Carneiro Street, Curitiba, Paraná, Brazil.

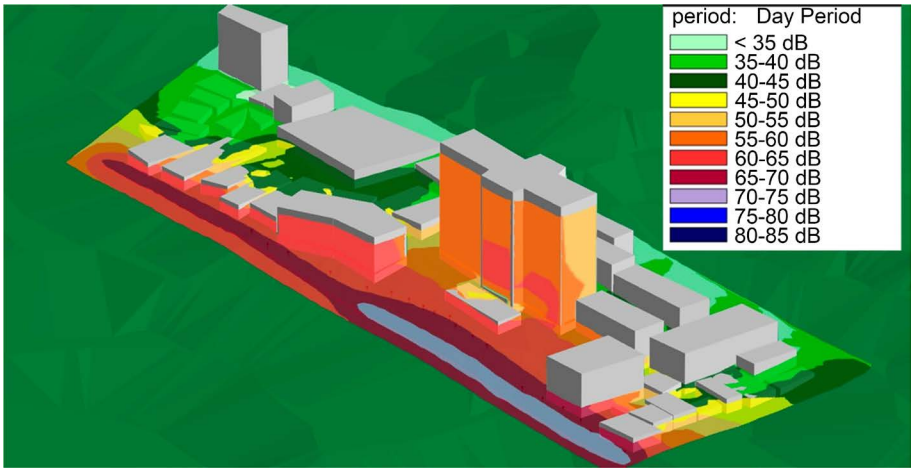

Figure 4. Three-dimensional noise mapping of the frontal façades of the buildings of the University Hospital of the Federal University of Paraná—UFPR.

The acoustic maps clearly show the existence of noise pollution mainly due to the traffic of light and heavy vehicles. The heavy vehicles counted during the sound pressure measurements were predominantly buses. These buses transport patients from several locations in the city and state to the University Hospital. Any reduction in the noise levels that reach the frontal facade of the hospital, and therefore the patient rooms and other hospital facilities facing the street along the front of the hospital, would require an immediate reduction in the vehicle flow, especially of buses, in front of the hospital. This would be difficult to achieve, since many patients who arrive at the hospital are unable to walk and have to be dropped off right at the main entrance of the hospital.

It would also be difficult to reorganize the traffic as a whole that passes in front of the central facade of the hospital, because the hospital is located in a central area of the city. Vehicle traffic in this area is intense, including along the streets adjacent to and behind the hospital.

A possible acoustic engineering solution would be to improve the sound insulation of the windows of the main facade. However, this solution would require a considerable outlay of financial resources, which the hospital does not have. Therefore, in the short term, there can be no foreseeable improvement of the current situation of noise pollution revealed by the sound pressure level measurements and confirmed by the acoustic maps.

The façade of Hospital de Clínicas consists of the following materials: 1) Masonry walls; 2) Plain glass/light metal shutter sliding window. The materials thicknesses are: 1) Plain glass—6 mm; 2) Light metal shutter—3 mm; 3) Walls—200 mm.

Oliveira Filho and Zannin [32] measured acoustic insulation in several types of façades, being one of the types similar to that found in Hospital de Clínicas. They measured acoustic insulation in three different situations: Situation 1—Only the glass door closed (metal shutters open); Situation 2—Only the metal shutters closed (glass door open); Situation 3—Metal shutters and glass door both closed. The measured val-

ues for the weighted standardized level difference were as follows: Situation 1:17 dB; Situation 2:9 dB; and Situation 3:19 dB [32]. The area measured for plain glass/light metal shutter sliding door was: 3.18 m^2.

The area of each window of the Hospital facade is smaller than the area considered in the measurements of Oliveira Filho and Zannin [32]. With this, one can expect a greater sound insulation, but still smaller than that established by the Brazilian standard of acoustic performance in buildings NBR 15575-4 [33], where the acoustic insulation for a bedroom, located on the façade, should be 25 dB. In Portugal for the bedroom, the sound insulation should be 28 dB [32]. The Brazilian standard does not make special mention for the acoustic insulation for bedroom in Hospitals.

Hospitals are considered special zones of silence. Around these areas, within a radius of 200 meters, the sound level should be in the daytime period of 55 dB(A) and nighttime of 45 dB (A), according to the silence law No. 10.625 of the city of Curitiba [34].

In Figure 5, note that the measured sound pressure levels exceed the acceptable limit of 55 dB(A) established by Curitiba Municipal Law in all the 30 outdoor points measured along the facade of the hospital for the daytime. By observing the values of the measured sound levels, it is possible that the acoustic insulation of 25 dB established by the standard NBR 15575-4 is not enough to provide comfort to the patients of the Hospital. Considering the special case of a-Hospital-one can point to a weighted standardized level difference of at least 30 dB, or even larger, around 35 dB.

Table 5 shows the results of the sound pressure level measurements taken inside the hospital. These measurements were taken at 21 points located in the maternity building and the main building of the University Hospital of UFPR. Sound pressure levels were measured on all the floors of the two buildings.

Figure 6 compares the measured indoor equivalent sound pressure levels Leq with the limit established as "acceptable" by NBR 10152:87, which is Leq = 45 dB(A). According to

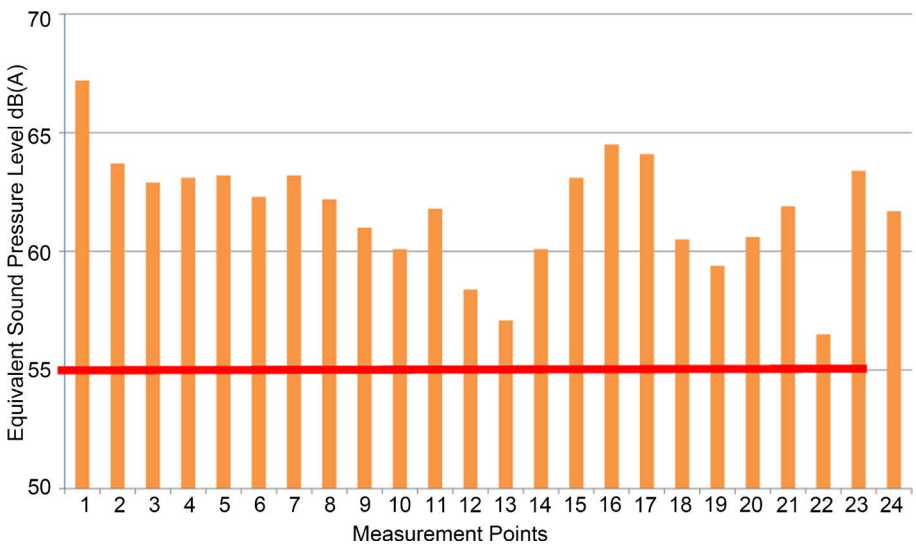

Figure 5. Comparison of measured outdoor sound pressure levels with those permitted by the municipal law.

Table 5. Indoor sound pressure levels measured inside the University Hospital of UFPR.

Points	Leq - dB(A)
1) 5th floor—Maternity building Gynecology	62.3
2) 4th floor—Maternity building Auditorium—medical courses	63
3) 3rd floor—Maternity building Neonatal ICU	57
4) 2nd floor—Maternity building Patient wards	60.8
5) 2nd floor—Main building Examination rooms	66
6) 2nd floor—Main building Outpatient clinic	62.4
7) 3rd floor—Main building Digestive endoscopy	66.8
8) 4th floor—Main building Hospitalization unit	61.5
9) 6th floor—Main building Traumatology	60.8
10 7th floor—Main building Department of Surgery	66.4
11) 8th floor—Main building General surgery	63.3
12) 9th floor—Main building Urology	64.2
13) 10th floor—Main building Medical clinic men's health	59.6
14) 11th floor—Main building Medical clinic women's health	66.2
15) 12th floor—Main building Nephrology	64.3
16) 13th floor—Main building Ear, nose and throat	60.7
17) 14th floor—Main building Pediatrics	64.2
18) 4th floor—Main building Private patient room with open window	65.5
19) 4th floor—Main building Private patient room with closed window	60
20) 4th floor—Main building Patient room with open window—facade	55.7
21) 4th floor—Main building Patient room with closed window—facade	54.8

this standard, 35 dB(A) is the limit value for "acoustic comfort" (see Table 2).

As can be seen in Figure 6, the sound pressure level at each of the 21 points measured indoors is well above the limit considered "acceptable" by NBR 10152, which regulates noise levels inside buildings. Hence, this characterizes indoor noise pollution of the evaluated environments.

Point 3 corresponds to the 3rd floor of the hospital's Maternity building, which contains the Neonatal Intensive Care Unit. The measured sound pressure level of 57 dB(A) is one of the lowest among the total of 21 points measured indoors, but it is still well

above the limit of 45 dB(A) for the functioning of this environment.

Figure 7 depicts one of the many "Keep Silence" notices posted on every floor of the University Hospital of the Federal University of Paraná. Therefore, it is clear that the awareness of everyone involved, from clinical staff to students and visitors, must be raised regarding the serious problem of noise inside a hospital environment.

4. Conclusions

Based on the outdoor and indoor measurements of sound pressure levels, along with the acoustic mapping of the facade of the University Hospital of the Federal University of Paraná, and the comparison of these measurements with the sound level limits specified by the Brazilian standards for evaluating the indoor and outdoor noise levels of buildings, it can be concluded that this hospital is acoustically polluted.

This noncompliance is directly linked to the intense vehicle traffic on General

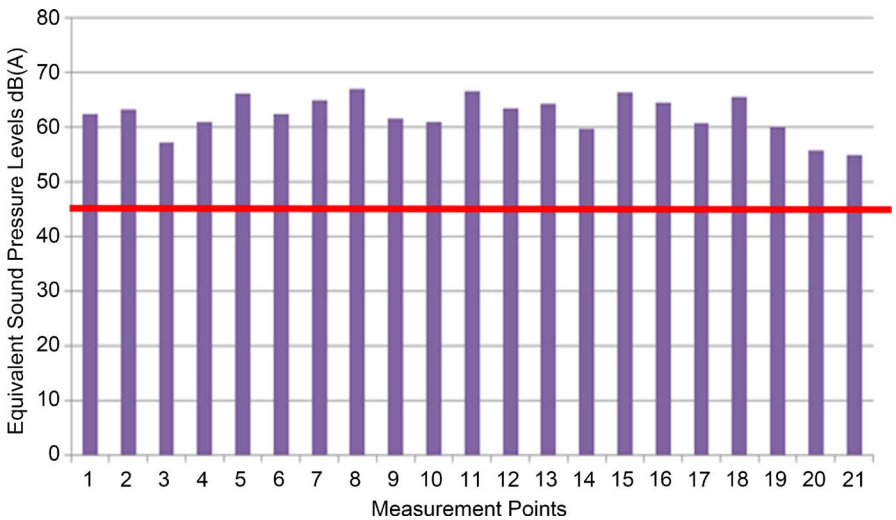

Figure 6. Comparison of measured indoor sound pressure levels with the limits established by standard NBR 10152:87.

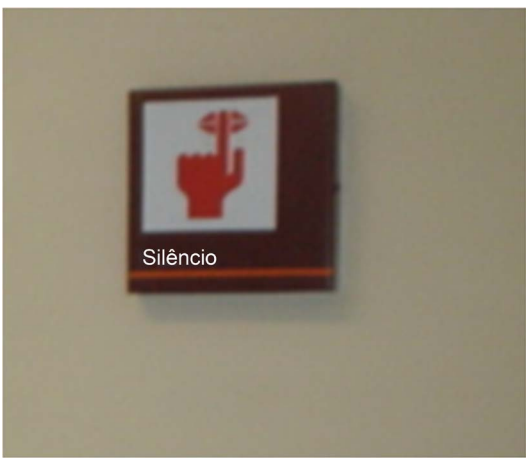

Figure 7. Keep Silence (Silêncio) notice in the Hospital.

Carneiro and Conselheiro Araújo streets, along with the heavy traffic of buses that arrive at the hospital each day, bringing patients from other cities. All these buses park in front of the hospital, where their preferential parking spots are located.

One way of trying to reduce the noise that reaches the front façade of "**Hospital de Clínicas**" would be to improve the acoustic insulation of the façade. For this it would be necessary to change all the current windows. On the other hand, the Hospital does not have the financial resources to implement a new acoustic insulation.

The sound pressure levels measured indoors exceed the limit suggested by the Brazilian standard NBR 10152, which sets noise level limits for indoor environments, according to their function.

The high indoor sound pressure levels were found to be the result of hundreds of people circulating in the hospital every day and of hospital staff and students talking in the hallways and in restricted areas. It should be noted that the "Hospital de Clínicas" is a university hospital that belongs to the Federal University of Paraná; therefore, medical students of this university frequent this hospital starting in their third year to attend classes or perform mandatory internships. Thus, the frequent conversations and students coming to and leaving output classes generate intense and permanent noise in the hospital's outpatient clinics, intensive care units, surgical center, consulting rooms and corridors.

The numerous "**Keep Silence**" notices posted on all the floors and corridors of the hospital are ineffective, given that they are disregarded by students and staff. Therefore, measures must be adopted to raise the awareness of students and health professionals who work in the hospital regarding the hazards of noise. It should not be forgotten that noise can increase medical mistakes and cause intense stress in the staff, as well as hinder the recovery of patients [16] [19].

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