

# Evaluation of the Acoustic Comfort in University Classrooms, Based on the Brazilian Technical Standard NBR 10152—Use of Noise Mapping and Acoustic Barriers to Counter Noise on a University Campus

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## Abstract

An evaluation was made of the acoustic quality of classrooms on two campuses of the Federal University of Paraná. Despite the heavy vehicle traffic flow on the streets in and around the campuses, the noise maps of the Polytechnic Center campus indicated that the noise that reaches the facades of the buildings vary from 55 to 60 dB(A), putting this campus within the limit of 60 dB(A) established by municipal law for Special Educational Zones (SEZ). In contrast, noise pollution at the Jardim Botânico campus has reached serious proportions, with noise maps indicating that its buildings are directly affected by noise levels of 65 to 70 dB(A). A simulation of the construction of two acoustic barriers showed their effectiveness in reducing noise levels to 55 and 60 dB(A). However, the downside is that acoustic barriers are expensive to build and cause visual pollution.

## Keywords

Environmental Noise, Noise Pollution, University Campus, Acoustic Barrier

## 1. Introduction

According to the World Health Organization, a large part of the world's population is affected by noise pollution, which is second only to air and water pollution (WHO, 2017). Goines and Hagler (2007) call noise pollution a modern scourge. In addition to the auditory effects of noise pollution, non-auditory effects include annoyance, cognitive impairment, sleep disorders and cardiovas-

cular problems (Basner *et al.*, 2014). Among the many human activities that require a high level of acoustic comfort are teaching and learning. According to Zannin and Loro (2007), for decades there has been a need for good acoustic quality in classrooms and the subject is of interest to engineers, architects, speech therapists and pedagogues, as it involves aspects of the design of educational buildings and their users: students and teachers. The acoustic quality of an environment is related to the internal characteristics of rooms, such as absorption materials and their placement. Classroom learning typically involves intensive communication through speech between teachers and students and among students themselves. The effectiveness of this communication, and hence, of the learning environment is mediated by the acoustic conditions in classrooms. Good classroom acoustics facilitates learning, enabling it to be easier, deeper, more sustained and less stressful. Excessive noise and reverberation in classrooms are obstacles to learning, insofar as they degrade or inhibit speech communication (Lubman & Sutherland, 2001).

This work was guided by three main objectives: 1) Analysis of the equivalent sound pressure levels ( $L_{eq}$ ) measured in the classrooms of the Polytechnic Center and Jardim Botânico campuses of the Federal University of Paraná. 2) Comparison of the measured equivalent sound pressure level ( $L_{eq}$ ) and that recommended by ABNT, the Brazilian Association of Technical Standards, NBR 10152—Noise levels for acoustic comfort. 3) Determination of the Noise Curve (NC) of each classroom, classifying it based on its measured equivalent sound level, as well as its subjective classification. This subjective classification may describe the classroom as very quiet, quiet, moderately noisy, noisy, very noisy and extremely noisy, according to Cavanaugh *et al.* (2010). The calculations for noise mapping of the front façades of buildings on the two campuses are also shown. A scenario was simulated using two acoustic barriers to reduce the sound levels on the façades of the central building of the Jardim Botânico campus, where noise pollution is more critical. Such barriers have proven to be effective in combating noise pollution. However, the main problem is that they cause visual pollution, not to mention that their construction is expensive.

## 2. Methodology

Equivalent sound pressure levels,  $L_{eq}$ , were measured following the guidelines of the Brazilian standard NBR 10152 on noise levels for acoustic comfort. The evaluated classrooms were furnished but unoccupied, and the only people in the rooms were the operator of the sound pressure level meter and his assistant. A representative block of buildings was chosen on each campus. The block chosen at the Polytechnic Center was the Science and Technology buildings, where eight measurements were taken. The main block of buildings chosen on the Jardim Botânico campus was the one located next to the main entrance on Professor Lothário Meissner Avenue, where five measurements were taken. The duration of all the measurements was 10 minutes (Fiedeler & Zannin, 2015; Bunn & Zan-

nin, 2016; Paiva *et al.*, 2019). The equipment used was a B&K 2270 sound level meter/analyzer. NBR 10152 presents a method to evaluate the noise criterion, NC, curve. This is a noise evaluation curve represented by a number determined by measuring the sound pressure levels in octave band frequencies. The NC rating of the assessed environment is then established by placing these levels on a graph and comparing the results with the standard NC curves. However, the Brüel & Kjaer 2270 analyzer itself already calculates the NC curve for the measurement. This is a highly innovative and very useful feature, since it provides fast and accurate measurements of NC curves. Therefore, in this study, the NC curve was calculated by the device itself, although it was also checked by the conventional method in order to ensure compatible results. Note that it is often difficult to reach a consensus about the exact rating of the NC curve using the conventional method. Hence, the use of this sophisticated device increases the reliability and accuracy of the data. The data were then tabulated and compared to the Leq values in dB(A) and the NC recommended by the NBR 10152 standard, as indicated in **Table 1**. This table presents the limit ratings for both the equivalent sound level Leq in dB(A) and the NC curves, according to the Brazilian Standard for Acoustic Comfort. The lower value corresponds to acoustic comfort, while the higher one indicates the acceptable limit according to the type of space.

### 3. Results and Discussion

This section describes the results of the measurements taken at the Polytechnic Center of the Federal University of Paraná—UFPR. Using a B&K 2270 analyzer, Leq measurements were taken in the following spaces of the Science and Technology buildings: in classrooms PG 03, PG 11, and PF 06, as well as on the first, second and ground floor of the Library, in Study Room 2.8 of the library, and in the Study Hall facing the library, as illustrated in **Figure 1**.



**Figure 1.** Location of the classrooms where Leq measurements were taken in the Science and Technology buildings of the Federal University of do Paraná. Meaning: PG 03 = Classroom 03/PG 11 = Classroom 11/PF 06 = Classroom 06/S.E. 2.8 = Study Room 2.8/Library 1<sup>st</sup> floor/Library 2<sup>nd</sup> floor; Library ground floor/S.H. = Study Hall. Coordinates: 25°27'13"S 49°13'57"W. Source: Google Earth.

**Table 1.** The various functions of spaces, according to NBR 10152, with limit Leq values in dB(A) and limits for NC curves.

Types of spaces	dB(A)	NC
Hospitals		
Private rooms, Wards, Nurseries, Operating rooms	35 - 45	30 - 40
Laboratories, Areas for public use	40 - 50	35 - 45
Service areas	45 - 55	40 - 50
Schools		
Libraries, Music rooms, Drawing rooms	35 - 45	30 - 40
Classrooms, Laboratories	40 - 50	35 - 45
Circulation spaces	45 - 55	40 - 50
Hotels		
Rooms	35 - 45	30 - 40
Restaurants, Sitting rooms	40 - 50	35 - 45
Front door, Reception desk, Circulation spaces	45 - 55	40 - 50
Private Homes		
Bedrooms	35 - 45	30 - 40
Living rooms	40 - 50	35 - 45
Auditoriums		
Concert rooms, Theaters	30 - 40	25 - 30
Conference rooms, Cinemas, Multipurpose rooms	35 - 45	30 - 35
Restaurants	40 - 50	35 - 45
Offices		
Meeting rooms	30 - 40	25 - 35
Management rooms, design and administration rooms	35 - 45	30 - 40
Computer rooms	45 - 65	40 - 60
Copy rooms	50 - 60	45 - 55
Churches and Places of Worship (meditative worship)	40 - 50	35 - 45
Sports Venues		
Enclosed pavilions for shows and sports activities	45 - 60	40 - 55

The duration of the measurement at each point was 10 minutes. Graphs were created using Brüel & Kjær's BZ-5503 Measurement Partner Suite, and are shown in **Figures 2-9**. The equivalent sound pressure level, Leq, measured in classroom PG 03 was 37 dB(A). **Figure 2** also illustrates the NC 30 curve. As can be seen in the graph, the NC 30 curve touches the frequency spectrum at 4000 Hz.

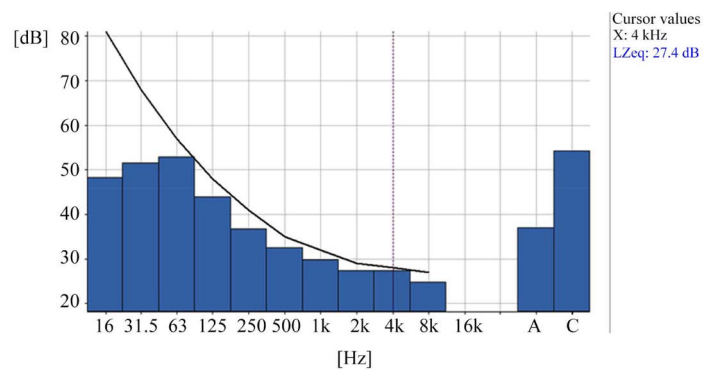
**Table 2** lists all the locations of internal measurements, the equivalent sound pressure levels and NC curve ratings, and the subjective acoustic assessment of the environment according to [Cavanaugh et al. \(2010\)](#).

The LAeq measured in classroom PG 11 was 44.7 dB(A), while the NC curve was 40. The curve was found to touch the spectrum at the frequency of 4000 Hz, a frequency band that presented an LZeq of 37.8 dB. In classroom PF 06, the measured Leq was 49 dB(A). This time, the NC curve that touched the frequency spectrum was NC 45, at a frequency of 500 Hz, where the LZeq was 48.9 dB.

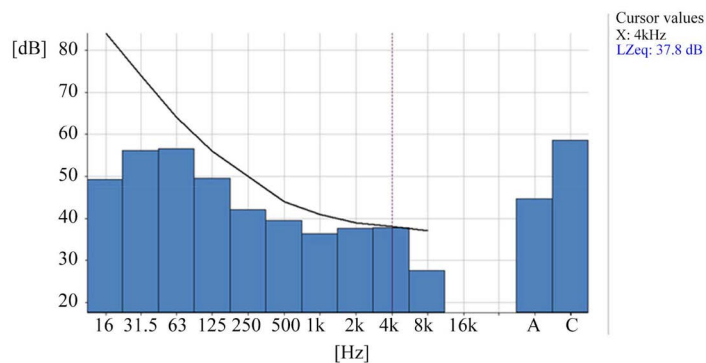
The measurements in the library of the Science and Technology department at the Polytechnic Center of UFPR were taken on a day when the employees were on strike, so it was closed to the public. The Leq measured on the first floor of the library was 37.3 dB(A), while the NC rating was 31, reaching the frequency spectrum at 125 Hz with LZeq of 48.2 dB. On the second floor of the library, the measured Leq was 37.2 dB(A), while the NC rating was 30 at 250 Hz, and the LZeq was 40.6.

**Table 2.** LAeq and NC ratings measured as specified by the Brazilian technical standard NBR 10152, and subjective assessment according to [Cavanaugh et al. \(2010\)](#).

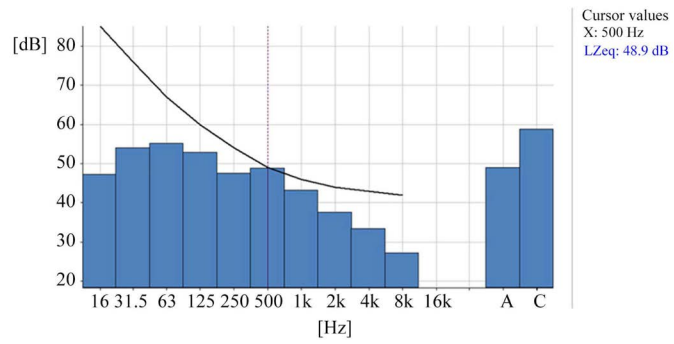
Spaces	Leq dB(A)	NC	Recommended dB(A)	Recommended NC	Subjective assessment
Classroom PG 03	37	30	40 - 50	35 - 45	Quiet
Classroom PG 11	44.7	40	40 - 50	35 - 45	Moderate
Classroom PF 06	49	45	40 - 50	35 - 45	Moderate
Library—1 <sup>st</sup> floor	37.3	31	35 - 45	30 - 40	Quiet
Library—2 <sup>nd</sup> floor	37.3	30	35 - 45	30 - 40	Quiet
Library—Study Room 2.8	34.8	28	35 - 45	30 - 40	Quiet
Library—Ground floor	36.8	31	35 - 45	30 - 40	Quiet
Student Study Hall	64.8	62	45 - 55	40 - 50	Extremely noisy



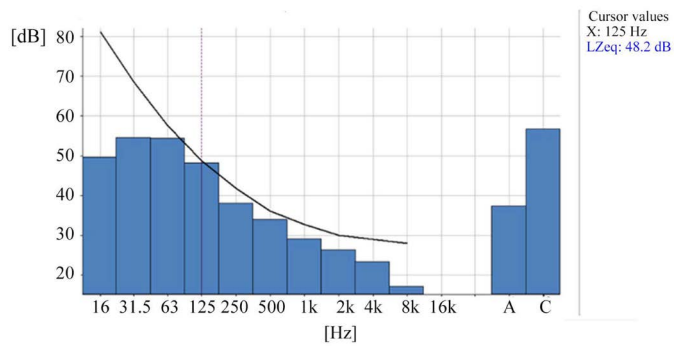
**Figure 2.** NC curve measured in classroom PG 03.



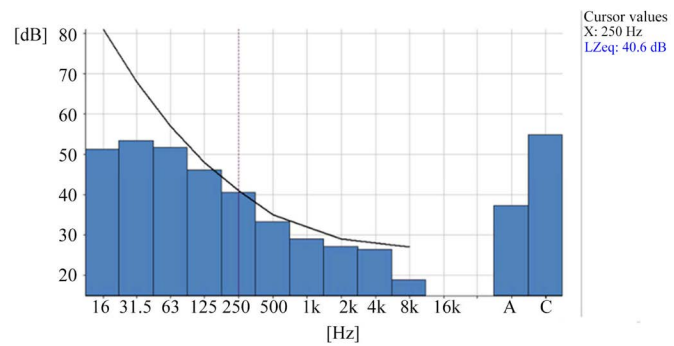
**Figure 3.** NC curve measured in classroom PG 11 at the Polytechnic Center.



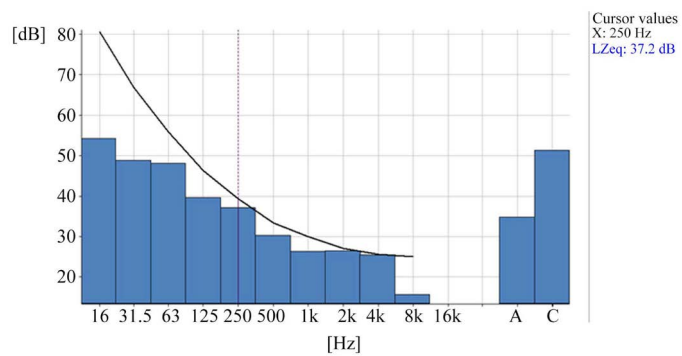
**Figure 4.** NC curve measured in classroom PF 06, at the Polytechnic Center.



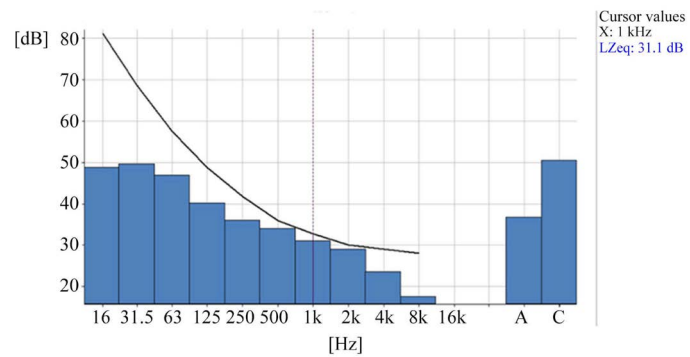
**Figure 5.** NC curve measured on the first floor of the Central Library at the Polytechnic Center.



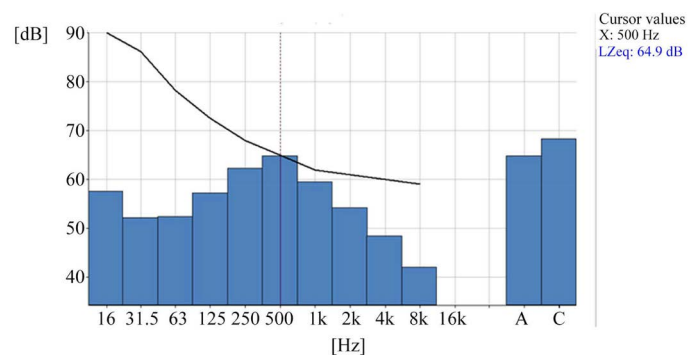
**Figure 6.** NC curve measured on the second floor of the Central Library at the Polytechnic Center.



**Figure 7.** NC curve of Study Room 2.8 in the Central Library.



**Figure 8.** NC curve on the ground floor of the Central Library at the Polytechnic Center.



**Figure 9.** NC curve of the student study hall at the Polytechnic Center.

The Leq measured in study room 2.8 of the library was 34.8 dB(A), while the NC was 28, as indicated in **Figure 7**.

As can be seen, the curve touches the spectrum at 250 Hz, 2000 Hz and 4000 Hz. These frequency bands presented LZeq values of 37.2 dB, 26.4 dB and 25.5 dB, respectively. Note, however, that the NBR 10152 standard presents NC curves in intervals of 5. In this case, for example, the accuracy of NC 28 can only be ascertained with the help of the BK 2270 analyzer.

The LAeq measured on the ground floor of the Library was 36.8 dB(A), while the NC curve was 31. The frequency of 1000 Hz that presented LZeq of 31.1 dB touched the NC 31 curve. In the Study Hall, the LAeq was 64.9 dB(A), and the NC curve was 62. At 500 Hz, the frequency spectrum showed a value of LZeq 64.9, thus touching the NC 62 curve, as depicted in **Figure 9**.

All the spaces had Leq values within or below the recommended range except the Study Hall, whose measured Leq was 64.8 dB(A), while the recommended maximum limit is 55 dB(A) (**Table 2**). The NC rating of the Study Hall was 62, thus also exceeding the limit specified by NBR 10152, which recommends up to NC 50. Lastly, the subjective classification according to *Cavanaugh et al. (2010)* indicated this space was extremely noisy.

It should be noted that, for this analysis, the student Study Hall was considered a “circulation area,” while the other spaces were considered library and

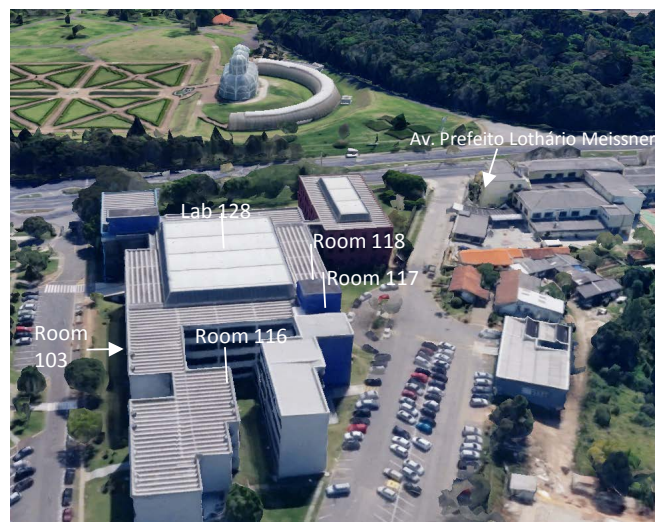
classrooms. Although there are several study tables, this is a circulation area because it is close to one of the main entrances to the block and is also a meeting place. It is common to see people working together, discussing ideas and talking loudly, which explains the measured Leq levels. Be that as it may, the data collected here and analyzed indicated that this space is too noisy to be used for studying. Some noise control measure would have to be implemented to meet original purpose for which it was designed. A reformulation of the layout and/or raising the awareness of its occupants is alternatives that could be implemented. Another alternative to lower the noise levels in the room would be to line its walls and ceiling with acoustic absorbing material.

The NC ratings of classrooms PG 03, PG 11 and PF 06 were 30, 40, and 45, respectively, all of them below or within the recommended limit of NC45. As for the subjective evaluation, classrooms PG11 and PF 06 were classified as moderate and PG 03 as quiet.

On the ground floor, first floor, second floor and study room 2.8 of the library, the NC ratings were 31, 31, 30 and 28, respectively. As for the perception of sound, the four spaces were classified as quiet.

The measurements taken on the Jardim Botânico campus of UFPR are presented next. The spaces measured indoors on this campus were classrooms 103, 116, 117, 118 and computer lab 128. **Figure 10** illustrates the location of these rooms on the campus. These rooms were chosen so that that at least one room was measured on each side of the main building, where most of the classrooms are located. The diagonal areas of the building facing Avenida Mayor Lothário Meissner were not measured because they are staff offices.

**Table 3** indicates the locations of indoor measurements taken on Jardim Botânico campus, along with their equivalent sound pressure levels, NC curves, and subjective assessment of acoustic quality, based on [Cavanaugh et al. \(2010\)](#).



**Figure 10.** Location of the classrooms measured on the Jardim Botânico campus. Meaning: room = classroom/Lab = Computer lab). Coordinates: 25°26'43"S 49°14'16"W. Source: Google Earth.

**Table 3.** LAeq and NC values measured as specified by the NBR 10152 standard, and subjective assessment according to [Cavanaugh et al. \(2010\)](#).

Rooms	Leq dB(A)	NC	Recommended dB(A)	Recommended NC	Subjective assessment
103	51.2	44	40 - 50	35 - 45	Moderate
116	42.8	37	40 - 50	35 - 45	Quiet
117	42.8	37	40 - 50	35 - 45	Quiet
118	46.1	41	40 - 50	35 - 45	Quiet
Lab 128	47.6	45	50 - 50	35 - 45	Moderate

**Figures 11-15** illustrate the NC curves of the locations described in **Table 3**.

**Figure 16** illustrates the outdoor measurements taken on the campus of the Polytechnic Center, indicating the equivalent sound pressure level at each of the 40 points measured there. A horizontal red line cuts through the graph at 60 dB(A), which is the maximum limit according to municipal law for the Special Educational Zone (SEZ) where the university campus is located.

The upper line that cuts through the graph in **Figure 16** represents the permissible noise limit specified by Curitiba Municipal Law 10,625 for Special Educational Zones—SEZ, while the lower line corresponds to the limit for SEZ established by Brazil's NBR 10151 standard for acoustic comfort of the community.

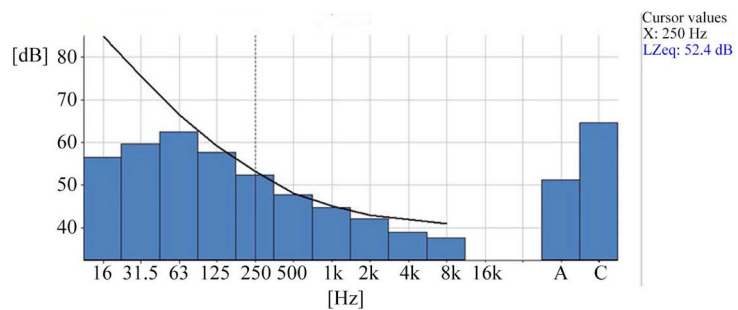
**Figure 17** shows a daytime noise map of the facades of the buildings on the Polytechnic Center. On this map, note that the facades closest to the streets and avenues on and around the Polytechnic Center campus are the ones affected by high noise levels, originating from both inside and outside the campus. The predominant colors indicate noise levels of 65 - 70 dB(A) and 55 - 60 dB(A), while lower noise levels of 50 to 55 dB(A) predominate further inside the campus. This finding indicates that noise levels on most of the Polytechnic Center campus falls within the limits established for educational zones by the Brazilian standard that regulates Community Noise.

**Figure 18** depicts a noise map of the façades of the buildings on Jardim Botânico campus.

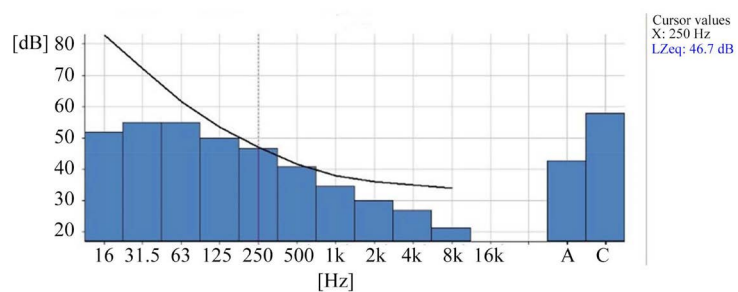
As can be seen in **Figure 18**, the facades of the central building of the Jardim Botânico campus are subjected to high sound levels, particularly the entire front façade, where noise levels of 65 to 70 dB(A) were recorded. High sound levels in the range of 60 to 65 dB(A) also reached the side façade of the building. This classifies the Jardim Botânico campus as noise polluted, since the sound levels reaching the façades exceed the limit for Special Educational Zones—SEZ established by Curitiba Municipal Law 10625, which is 60 dB(A). These levels also exceed the noise limit of Leq 55 dB(A) specified by the Brazilian NBR 10151 standard for quiet zones around schools and hospitals.

In an attempt to solve the problem, the placement of noise barriers along the front of the Jardim Botânico campus was simulated, as depicted in **Figure 19**.

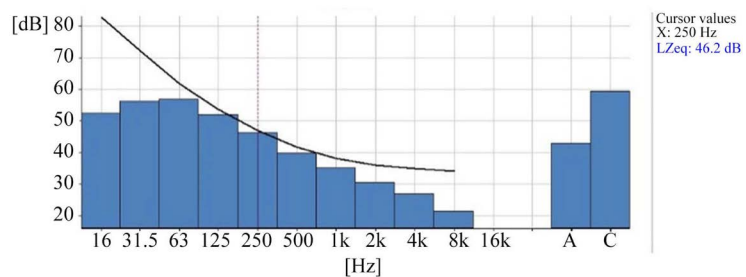
**Figure 20** shows simulated noise maps of the situation with and without noise barriers, revealing a perceptible reduction in noise through the use of noise barriers, lowering it to levels of 55 to 60 dB(A) along the facade of the central building. This enables Jardim Botânico campus to comply with the requirements of Curitiba Municipal Law 10625, which establishes an outdoor limit Leq of 60 dB(A) for educational zones. However, the situation is still critical, since there are still places along the central facade where noise levels vary from 65 to 70 dB(A). The traffic of both heavy vehicles and passenger cars that passes in front of the central facade of this campus is very intense. Much of the noise originates from vehicles circulating on campus, as well as from the intense vehicle traffic at the main entrance of the Jardim Botânico campus. Reducing the vehicle flow is practically impossible, given that the avenue along the front of the central facade connects the city of Curitiba to the coast of the state of Paraná. Therefore, the traffic here is very heavy and the vehicle flow is intense and constant throughout the day.



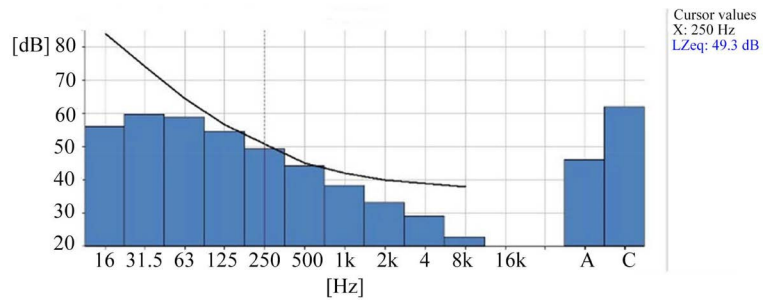
**Figure 11.** NC curve of Classroom 103 on the Jardim Botânico campus.



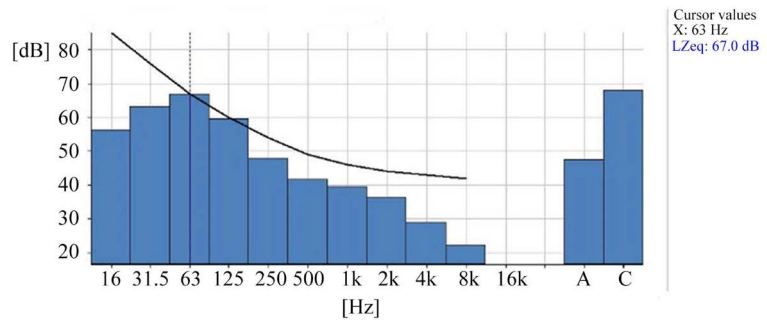
**Figure 12.** NC curve of Classroom 116 on the Jardim Botânico campus.



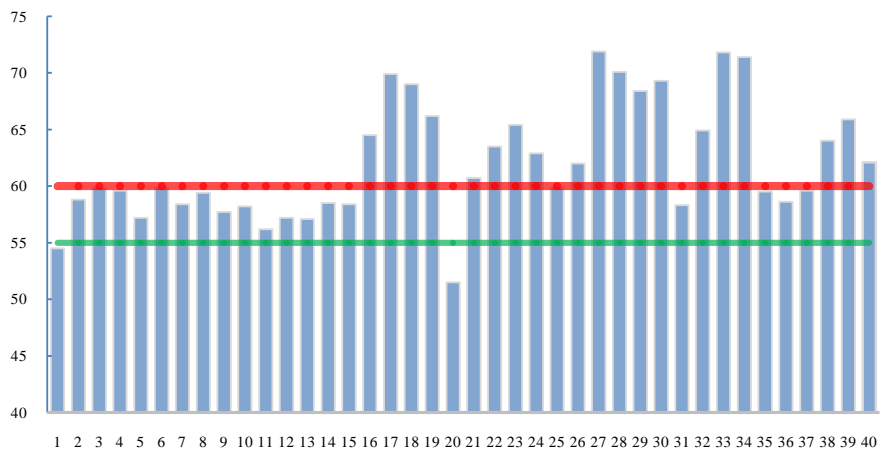
**Figure 13.** NC curve of Classroom 117 on the Jardim Botânico campus.



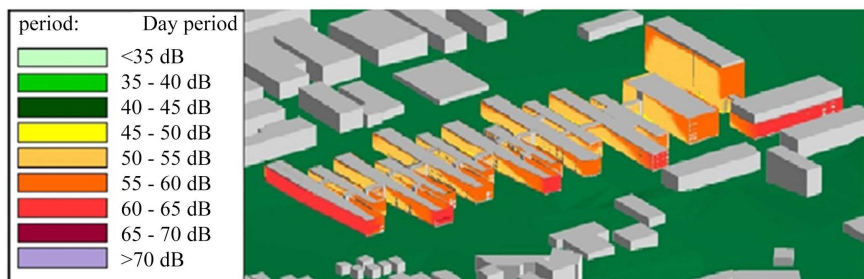
**Figure 14.** NC curve of Classroom 118 on the Jardim Botânico campus.



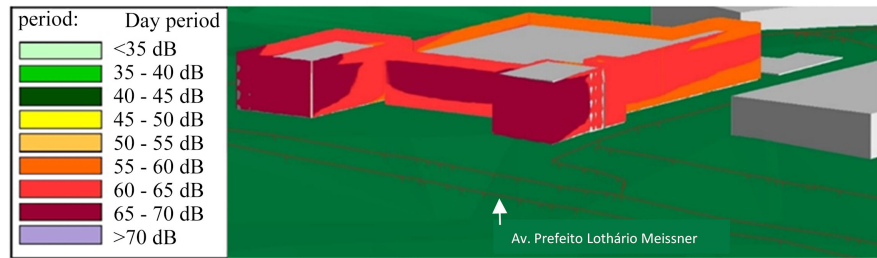
**Figure 15.** NC curve of Lab Classroom 128 on the Jardim Botânico campus.



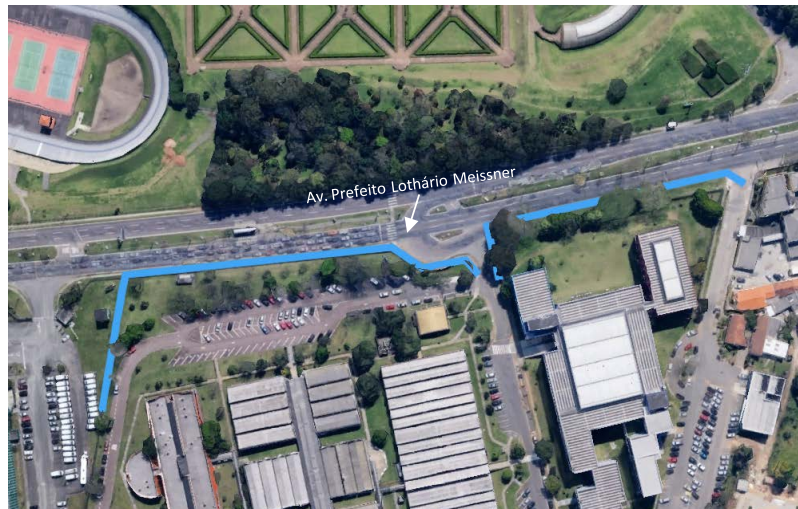
**Figure 16.** Equivalent sound pressure levels measured at each point in the Polytechnic Center, making a total of 40 measured points. The green line in turn represents the limit established for Silent Zones.



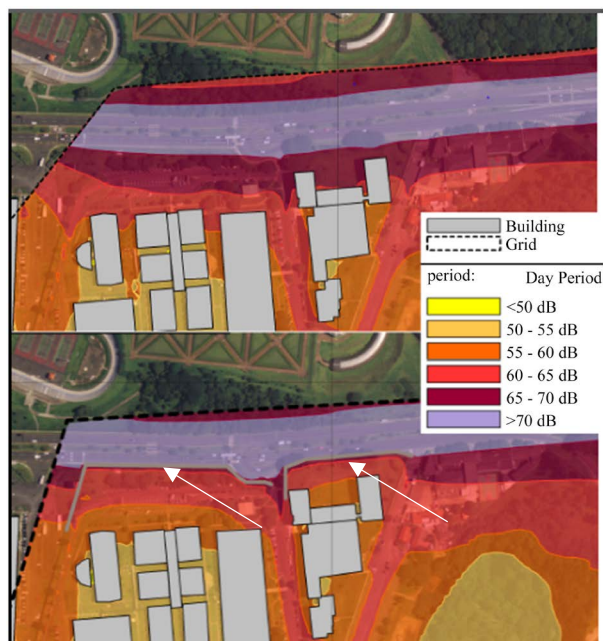
**Figure 17.** Noise maps of the façades of the buildings on the Polytechnic Center campus.



**Figure 18.** Noise maps of the façades on the Jardim Botânico campus.



**Figure 19.** Simulation of noise control by means of noise barriers on the Jardim Botânico campus. The two noise barriers are shown in blue. Source: Google Earth.



**Figure 20.** Simulated noise barriers along the front façade of the Jardim Botânico campus, resulting in significantly reduced noise immisions (façades of the central blocks of buildings). White arrows are indicating the presence of noise barriers according **Figure 19**.

## 4. Conclusion

This work involved an evaluation of the noise levels on the Polytechnic Center and Jardim Botânico campuses of the Federal University of Paraná. The findings indicate that most of the classrooms of the Polytechnic Center offer acoustic comfort, qualifying them as “quiet” according to Cavanaugh et al. (2010). The noise maps of the buildings at the Polytechnic Center indicate a predominance of noise levels of 55 to 60 dB(A), i.e., within the limit of 60 dB(A) established by Curitiba Municipal Law 10625 for Special Educational Zones—SEZ.

On the other hand, noise levels of 65 to 70 dB (A) reach the front façades of the buildings on the Jardim Botânico campus, placing it in a situation of serious noise pollution. The noise limit established by municipal law for SEZ is 60 dB(A). To reduce these levels, simulated noise barriers were placed in front of the buildings. These simulated noise barriers proved to be highly effective, reducing the noise levels depicted in Figure 20 to 55 to 60 dB(A). However, despite the effectiveness of the simulated noise barriers in reducing noise levels on the Jardim Botânico campus, the construction of such barriers would not only involve high investment costs but also cause undesirable visual pollution.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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