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# Evaluation of Psychoacoustic Annoyance and Perception of Noise Annoyance Inside University Facilities

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The levels of noise produced in university facilities by students, increases the noise annoyance. The quality of life and the academic performance of university students could be influenced by this factor. Unfortunately, as far as methodology is concerned, there are no regulations or standards that allow for the correct evaluation of noise annoyance at educative facilities. In this work a method for the evaluation of noise annoyance and an indicator of noise annoyance are presented. In order to obtain a numerical value, a percentage index, and a verbal index that represents the noise annoyance in a specific area at university facilities, psychoacoustic annoyance (PA) and evaluation of perception of noise annoyance has been related. Resulting from this correlation an indicator of noise annoyance was proposed. The results were associated with this indicator. The method and the proposed indicator allow for deeper evaluation of noise annoyance and facilitate the development of appropriate actions against noise.

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## 1. INTRODUCTION

The impact of noise on the quality of life of people is a topic of interest of many researchers. The works on this topic mainly focused on studying noise annoyance produced by urban sources and its influence on quality of life, and the physical and psychological health of the general population.<sup>1-5</sup> However, noise annoyance inside educational facilities at the university level is a topic that has not been deeply studied. Topics such as background noise levels in classrooms, speech intelligibility, isolation, and acoustic conditioning specially inside classrooms are the main study areas.<sup>6-9</sup> There are several factors that influence the increase of noise in these places. Inside university facilities, the students themselves are the main source of noise. Throughout the day, students are involved in many activities inside the university facilities. At the university, usually, there are places with a large mass of students. This is why noise increases significantly and, consequently, the noise annoyance as well.<sup>10</sup> This problem is worst mainly in places with inexistent acoustic treatment like common halls and hallways. Typically, noise annoyance is a parameter evaluated with objective and subjective methods, but currently, there are no regulations to evaluate this parameter. This is the reason why different methods to determine annoyance are used

in many studies.<sup>1,2,4,11-20</sup> However, the method described by Fastl and Zwicker<sup>21</sup> is used in many studies. This method is based on the calculation of psychoacoustic parameters such as loudness, roughness, sharpness, and fluctuation strength. These four parameters result in another parameter that evaluates the annoyance known as psychoacoustic annoyance (PA). On the other hand, another typical method is based on listening tests in combination with the application of questionnaires.<sup>22-25</sup> Different kinds of questionnaires and different scales of evaluation were used in the existing studies.<sup>1,3,5,26</sup> However, to standardize the evaluation of the response to noise, the International Commission of the Biological Effects of Noise (ICBEN) established a method based on a survey that was developed in different languages.<sup>27</sup> This survey is the result of the collaboration of different researchers from around the world and consists of two questions; each one of them has different scales (a 5-point verbal scale and an 11-points numerical scale), which will be explained later. Because of the importance of the effects of noise on health, quality of life, and school performance of university students, the noise sources and acoustic conditions in areas where students usually develop their daily activities should be studied. In addition, it is essential to develop the mechanisms that study and develop strategies and regulations applicable to students, an important population group.

This could help protect students from the effects of noise on their physical and psychological health, and consequently improve their school performance. In this work, a methodological proposal to evaluate noise annoyance at university facilities is presented. The results were correlated and represented in a graphic colour scale.

## 2. METHOD

This work involved a study of the noise conditions in university facilities. The methodology proposed requires an acoustic analysis using data obtained from the recordings of specific sound environments. This was done using the method of evaluation of the PA proposed by Fastl and Zwicker.<sup>20</sup> Second, an assessment directly derived from the perception of noise of students was carried out. This was developed through the combination of the application of a listening test and a noise annoyance questionnaire based on the standardized general-purpose noise reaction questions for community noise surveys proposed by ICBEN.<sup>26</sup> To obtain two related noise indexes, the results of the two methods mentioned previously were correlated. These indexes, called "percentage noise annoyance index" (PNAI) and "verbal noise annoyance index" (VNAI), indicate a conclusive percentage value and a verbal value incorporated and represented in a graphic colorcolour scale that helps to identify the level of noise annoyance in a specific place.

### 2.1. Participants

A total of 33 students (17 male and 16 female) between 19 and 34 years old participated in the experiment. Twelve of the participants were degree students, 9 were master students, and 12 were doctorate students. Before the trial, the current state of participants' auditory health was evaluated according to the International Organization for Standardization Acoustics.<sup>28</sup> The participants did not exceed 20 dB in the frequency range of 125–8 kHz.

### 2.2. Selection and Recording of Sound Environments

The audio recordings completed at the places where students usually conduct their study activities have been used for this experiment. These locations include: a classroom during an exam, a classroom during a normal lesson, a hallway adapted for studying, a library, a computer room, and a common hall also adapted for studying. The sound environments were recorded using a Zoom H4n Handy Recorder previously calibrated in controlled acoustic conditions (anechoic chamber). The file format used was a WAV file at 16-bit, 44.1 kHz, and the length of each sound environment recorded was two minutes long. The output level also was calibrated in an anechoic chamber using the Bruel and Kjr head and torso simulator (HATS) Type 4128D and Pulse platform. The audios were reproduced using Pro Tools D9 software for Mac, a sound card Mackie Onyx Satellite, and headphones (model AKG K142 HD). The listening tests were carried out inside an audiometric chamber. The total time spent on each test lasted 12 minutes.

### 2.3. Evaluation of PA

The recordings and their subsequent analysis were performed using the psychoacoustic analyser Brel and Kjr Sound Quality type 7698. Psychoacoustic metrics, such as loudness ( $N$ ), specific loudness ( $N_0$ ), sharpness ( $S$ ), roughness ( $R$ ), and

**Table 1.** Verbal answer and numeric scale for the annoyance question (5-point scale).

Verbal answer recommended	Numeric scale
a) Not at all	0
b) Slightly	21.93
c) Moderately	47.34
d) Very	73.39
e) Extremely	97.72

uctuation strength ( $FS$ ), were obtained. These parameters are related to describe quantitatively the PA from the information obtained in the laboratory, the method proposed by Fastl and Zwicker.<sup>21</sup> The PA value is obtained using the following equation:

$$PA = N_5(1 + \sqrt{W_S^2 + W_{FR}^2}). \quad (1)$$

Where  $N_5$  is the percentile 5 of loudness,  $W_S$  is the component where sharpness ( $S$ ) is included,

$$\begin{cases} \text{if } S > 1.75 & W_S = 0.25(S - 1.75) \log N_5 + 10; \\ \text{if } S \leq 1.75 & W_S = 0 \end{cases}; \quad (2)$$

$W_{FR}$  is the modulation component where fluctuation strength ( $FS$ ) and roughness ( $R$ ) are included.

$$W_{FR} = \frac{2.18}{N_5^{0.1}}(0.4(FS) - 0.6R). \quad (3)$$

### 2.4. Perception of Noise Annoyance

The method to evaluate the perception of noise annoyance is normally through listening tests and surveys. This questionnaire consisted of two questions related to noise annoyance based on the questions recommended by ICBEN.<sup>26</sup> Likewise, two answer scales are proposed for these two questions: a 5-point verbal scale and 0–10 numeric scale (11-point scale). These scales have been used because a slight difference of perception between a numerical scale and a verbal scale could exist. The participants were questioned about the noise conditions inside the facilities recorded previously. The questionnaire was applied to the students while they were listening to the recording inside an audiometric room and they did the test only once. They were asked to take enough time to listen to the recordings before starting to answer the questions to have a better sensation of the sounds presented. For the 5-point verbal scale (see Table 1), the question was, "In this recording, how much does the environmental sound bother, disturb, or annoy you: extremely, very, moderately, slightly, or not at all?"; Numerical values have been assigned to each specific score in the 5-point verbal scale, proposed in the standardized general-purpose noise reaction questions for community noise surveys for Spanish language given by ICBEN<sup>27</sup> (Table 1).

The question for the 11-point scale (see Fig. 1) was, "Next is a zero-to-ten opinion scale for how much the environmental sound heard in the recording bothers, disturbs, or annoys you. If you are not at all annoyed, choose zero; if you are extremely annoyed, choose ten; if you are somewhere in between, choose a number between zero and ten."

### 2.5. Numerical, Percentage, and Verbal Noise Annoyances Indexes

To have a variable that allows the classification of sound environment according to the level of annoyance, two correlated

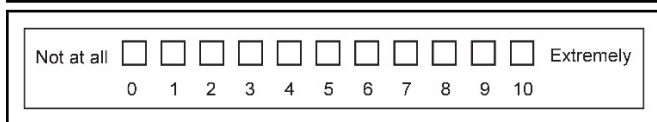


Figure 1. Numeric answer scale for the annoyance question (11-point scale).

Table 2. Relationship between numerical index (NNAI), percentage index (PNAI) and verbal index (VNAI).

Numerical Index — NNAI	Percentage Index — PNAI	Verbal index — VNAI
0–3.60	0%–3.6%	Not at all
3.61–23.55	3.61%–23.55%	Slightly
23.56–58.62	23.56%–58.62%	Moderately
58.63–89.77	58.63%–89.77%	Very
89.78–100	89.78%–100%	Extremely

variables have been proposed: one percentage index and one verbal index. Resulting from the mean of the results between the evaluation of the PA and the evaluation of perception of noise annoyance, a numerical index is obtained and called numerical noise annoyance index (NNAI). Because NNAI is numerical data represented on a scale of 0 to 100 points, it is possible to transpose and express it directly in percentage terms. Thus it is possible to obtain an index which is called percentage noise annoyance index (PNAI). Furthermore, a verbal index called verbal noise annoyance index (VNAI) is directly related to the numerical ranges given on the scale of reaction to noise proposed by ICBEN<sup>22</sup> and according to the numerical value obtained from the mean of the results between the evaluation of psychoacoustic annoyance (PA) and that of the perception of noise annoyance (Table 2).

### 3. RESULTS

#### 3.1. Evaluation of PA

The evaluation of the PA was performed according to the method described previously in section 2.3. This research is not focused on the particular study of each one of the psychoacoustic parameters because the main variable to be studied is the PA formulated by Fastl and Zwicker.<sup>21</sup> However, as described previously, to obtain this variable, it is necessary to obtain known psychoacoustic parameters such as loudness ( $N$ ), specic loudness ( $N'$ ), sharpness ( $S$ ), roughness, and uctuation strength ( $F/S$ ). To obtain these parameters, the six sound clips were recorded with HATS. The recordings and the subsequent analysis of the clips were performed using the psychoacoustic analyser Brel and Kjaer Sound Quality Type 7698. Table 3 summarizes the results of this analysis for all clips recorded, and Fig. 2 shows the one-third octave spectrum of all environments as reported by Tristán et al.<sup>29</sup> The equivalent total level ( $L_{Aeq,T}$ ) of these sound environments oscillates from 68.1 and 83.5 dBA. For loudness, it is possible to observe that the minimum and maximum values correspond to the classroom during an exam (16.55 sones) and the common hall (46.75 sones), respectively. For sharpness, the minimum level was observed in the common hall (1.31 acum), and the maximum level was seen in the classroom during an exam (1.65 acum). In the case of roughness, it has been possible to observe the minimum and maximum values in the computer room (1.57 asper) and the classroom during an exam (1.70 asper), respectively. The minimum value of uctuation strength was registered in the common hall (1.28 vacil), whereas the computer room is the place with the maximum value (2.07 vacil). Finally, the minimum

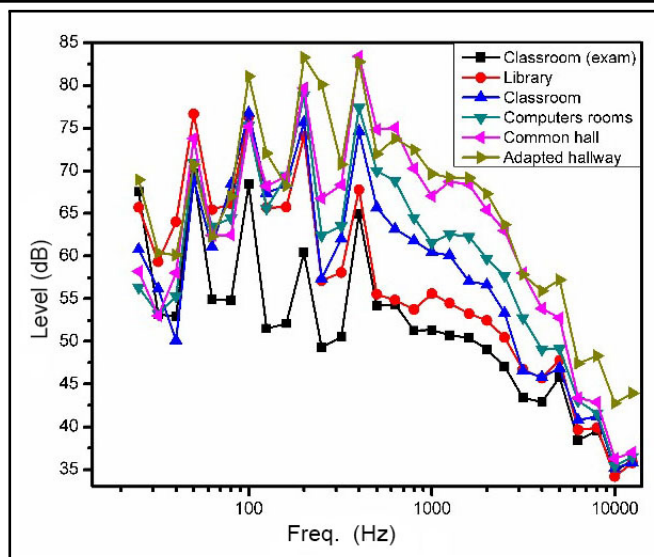


Figure 2. One-third octave band spectra of each sound environment.

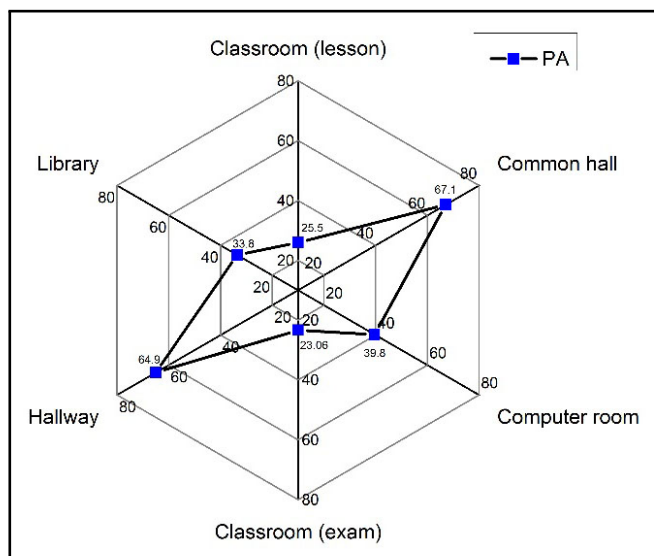


Figure 3. Psychoacoustic annoyance value for each sound environment.

and maximum values of specic loudness ( $N$ ) correspond to the classroom during an exam (0.75 sones/Bark) and the hallway (2.25 sones/Bark), respectively.

Thus, in evaluating and performing according to the method described in III, the results show that the sound environment with a higher value of PA corresponds to the hallway (PA = 64.99) and the common hall (PA = 67.09). On the other hand, the lowest values of PA correspond to the classroom during a lesson (PA = 25.96) and the classroom during an exam (PA = 23.34). The computer room obtained a PA value of 39.6, and the library, with a PA value of 33.5, is also an environment with low PA (Fig. 3).

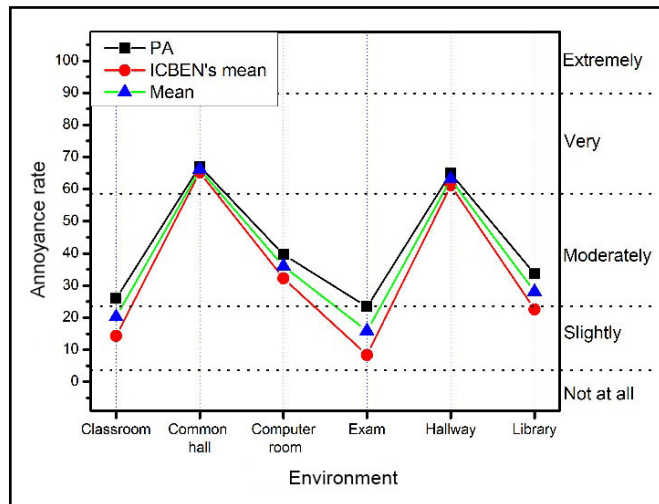
#### 3.2. Evaluation of the Perception of Noise Annoyance

##### 3.2.1. Relation Between ICBEN 5-Point verbal scale and 11-Point Numerical Scale.

The results show that participants perceive that the common hall (63.04 points) and the hallway (57.56 points) are the most annoying places. Conversely, the classroom during an exam (5.31 points) and the classroom during a normal lesson

**Table 3.** Summary of results of the evaluation of psychoacoustic annoyance.

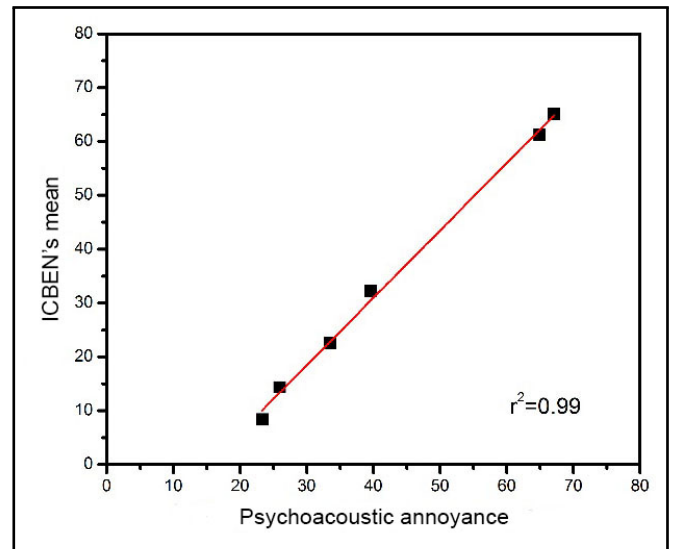
Environment	SPL (dB)	L (sones)	S (acum)	R (asper)	F.S. (vacil)	N' (sones/Bark)	N5 (sones)	PA
Common hall	68.1	46.75	1.31	1.58	1.28	2.01	38.55	67.09
Computer room	76.5	31.15	1.32	1.47	2.07	1.41	20.40	39.60
Classroom (lesson)	76.0	23.50	1.36	1.58	2.01	1.19	12.49	25.96
Library	72.6	19.20	1.39	1.59	1.62	0.92	16.21	33.57
Hallway	81.7	43.28	1.39	1.64	1.96	2.25	35.10	64.99
Classroom (Exam)	83.5	16.55	1.65	1.70	2.06	0.75	10.11	23.34



**Figure 4.** Comparison between results of the evaluation of perception of noise.

(14.06 points) are the less annoying places. Table 4 summarizes the results of the question related to the ICBEN 5-point verbal scale. On the other hand, according to the results for the ICBEN 11-point numerical scale, the classroom during an exam is the place with the lowest annoyance (4.54 points). On the other hand, the common hall is the place that participants perceive as the most annoying place of all the environments (67.27 points). A summary of the descriptive statistics is shown in Table 4.

Thus, to determine if obtained results between both 5- and 11-point scales (referred to as ICEBEN 5 and ICBEN 11, respectively) are directly related, a statistical analysis was performed. According to the Kolmogorov-Smirnov test, the differences between both 5- and 11-point scales of all sound environments (except for the classroom during an exam) present a normal distribution; therefore, a t-test for related samples was carried out. For the classroom during an exam, a repeated-measures ANOVA with a Greenhouse-Geisser correction was used. The related measures t-test revealed that in the case of the classroom, no significant differences ( $t(32) = 0.166, p = 0.869$ ) between ICBEN 5 (14.0612.31) and ICBEN 11 (14.5511.75) were found. Likewise, for the common hall, no significant differences ( $t(32)=1.753, p=0.089$ ) between ICBEN 5 (14.0612.31) and ICBEN 11 (14.5511.75) were found. Furthermore, no significant differences ( $t(32) = 0.696, p = 0.491$ ) for the computer rooms between ICBEN 5 (31.1712.41) and ICBEN 11 (33.3310.80) were found. The mean of the differences of the classroom during an exam between the two tests, ICBEN 5 (5.319.54) and ICBEN 11 (4.545.64), were not significantly different ( $t(32) = 0.558, p = 0.581$ ). Differences in the hallway between ICBEN 5 (57.5622.95) and ICBEN 11 (64.8527.17) also were not significant ( $t(32) = 0.147, p = 0.147$ ). In the case of the library, it also was possible to observe no significant differences ( $t(32) = 0.435, p = 0.667$ ) between ICBEN 5 (27.7323.48) and ICBEN 11 (23.3317.79). Finally, for the classroom during an exam, the repeated-measures ANOVA test



**Figure 5.** Correlation between evaluation of perception of noise annoyance (ICBEN's mean) and Psychoacoustic Annoyance (PA).

shows no significant differences ( $F(1,32) = 0.311, p = 0.581$ ). Furthermore, the comparison and the mean value between both 5- and 11-point scales of each environment are shown in Table 4.

### 3.3. Numerical, Percentage, and Verbal Noise Annoyances Indexes

A numerical variable was obtained from the comparison of the means carried out between the results derived from the mean of both 5- and 11-point annoyance scales and evaluation of the PA. This variable has been called numerical noise annoyance index (NNAI). A graphical comparison of both variables is shown in Fig. 4. Likewise, Table 5 summarizes the results obtained from each sound environment and the allocation of the verbal noise annoyance index (VNAI), which directly depends on the numerical noise annoyance index (NNAI) obtained. Also, the percentage noise annoyance index (PNAI) is shown. In addition, has been changed to verify that the numerical noise annoyance index (NNAI) is a significant value, a Pearson correlation was used to check whether a significant correlation exists between both annoyance scale variables. The Pearson's r correlation shows a clear positive correlation between both variables:  $r = 0.999, p < 0.01$  (Fig. 5).

### 4. INDICATOR OF NOISE ANNOYANCE LEVEL

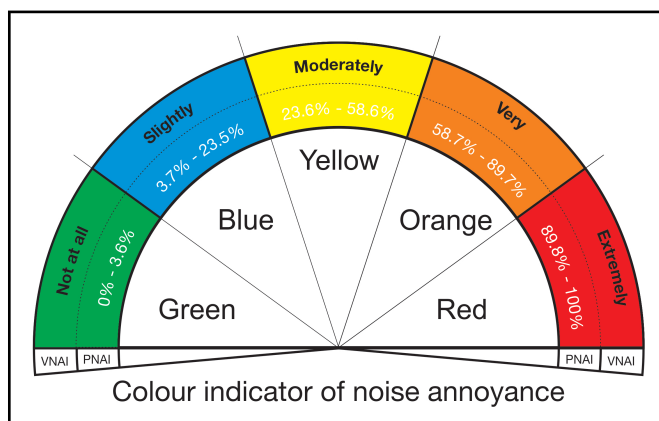
An indicator of the level of noise annoyance represented in a colour scale is proposed. This scale of annoyance is graphically represented in an indicator, where the colour levels according to the percentage index and verbal index is combined (Fig. 6). This indicator has five levels of colours (green, blue, yellow, orange, and red) that are used and related to the

**Table 4.** Summary of descriptive statistics of the evaluation of the perception of noise annoyance.

Sound environment	5-points verbal scale				Mean	11-points numerical scale			
	Min.	Max.	S.D.	Mean		Mean	S.D.	Max.	Min.
Classroom	.00	47.34	12.31	14.06	<b>14.30</b>	14.54	11.75	40	.00
Common hall	21.93	97.72	16.88	63.04	<b>65.16</b>	67.27	21.10	100	20
Computer room	21.93	47.34	12.41	31.17	<b>32.25</b>	33.33	10.80	60	20
Classroom (exam)	.00	21.93	9.543	5.31	<b>4.93</b>	4.54	5.64	20	.00
Hallway	21.93	97.72	22.95	57.56	<b>61.20</b>	64.84	27.17	100	.00
Library	.00	73.39	23.48	21.73	<b>22.53</b>	23.33	17.79	70	.00

**Table 5.** Summary of results for each sound environment obtained from the evaluation.

Sound environment	PA	ICBENs mean	Difference	Mean (NNAI)	PNAI	VNAI
Classroom	25.96	14.30	-11.6600	20.13	20.1%	Slightly
Common hall	67.09	65.16	-1.929993	66.12	66.1%	Very
Computer room	39.60	32.25	-7.329998	35.92	35.9%	Moderately
Classroom (exam)	23.34	8.31	-16.6900	15.82	15.8%	Slightly
Hallway	64.99	61.21	-3.77999	63.10	63.1%	Very
Library	33.57	22.53	-11.0400	28.05	28.0%	Moderately



**Figure 6.** Proposed color indicator of level of noise annoyance.

percentage noise annoyance index (PNAI) which is derived for the numerical noise annoyance index (NNAI) and also with the verbal noise annoyance index (VNAI) (see section 3). Considering the importance of unifying criteria for the evaluation of noise annoyance, the ranks of this colour scale are based on the 5-point scale described previously (Table 1) in reaction modifier given by ICBEN.<sup>21</sup>

### 5. CONCLUSIONS

In this work, a method to evaluate noise annoyance in university facilities has been proposed. This method was based on the comparison and correlation of two known methods to evaluate noise annoyance, the PA,<sup>15</sup> and the evaluation of perception of noise annoyance through listening tests, on the basis of the method described by ICBEN.<sup>21</sup> The results from the evaluation of perception of noise annoyance show that between the answers of both rating scales (5-point and 11-point), there were no statistically significant differences; this means that there is an important relation between the answers of both scales. Thus, derived from the mean of both tests, it has been viable to determine a numerical value that represents noise annoyance in a specific place. Furthermore, the recordings of six sound environments inside university facilities were studied. Psychoacoustic parameters were obtained, and it was possible to determine a specific value for the PA. A numerical variable, named numerical noise annoyance index (NNAI), was obtained from the comparison of the means between the results derived from both 5- and 11-point annoyance scales and the PA. This variable gives us a numerical value to represent the level of noise

annoyance in a specific sound environment. During this study, it has been possible to observe that classrooms and libraries are not the only places used for study activities. Many other places, such as hallways, halls, and gardens, are employed as study places in an improvised way and used for study activities and for socialization with other students. The results of this study show that these places are the most annoying. The data collected from this study provides important information about the conditions where students develop their study activities. It makes the development of the most adequate strategies against noise easier. It is well known that acoustic conditioning is the most expensive action. Consequently, finding cheap and reliable alternatives is necessary. Thus, a color indicator of noise annoyance has been proposed. The variables from this methodology have been summarized. This indicator serves as a tool to facilitate the classification of a particular sound environment according to their level of noise annoyance and also for designing strategies against noise. The method and the color indicator proposed in this work will allow a deeper evaluation of noise annoyance and also facilitate the development of strategies and appropriate actions against noise.

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