Influence of the Openings Size on Acoustic Quality of Naturally Ventilated Classrooms

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Summary
The classrooms acoustics can directly interfere in the teaching and learning process. Some building components can influence under such conditions. In hot-humid climate, the openings (windows) are used for the primary purpose of providing natural ventilation. Conflict between the need for environmental comfort can be checked when such components also allow the entry of external noise, causing a decrease in sound insulation. In isolation and ventilation aspects it is necessary to approach the openings in the inner sound quality interference. In this context, the present study aims to evaluate the influence of the openings size in the acoustic quality of naturally ventilated classrooms in the municipal public schools in Maceió-AL, in the northeast of Brazil. The methodology consisted of parametric analysis, based on results of the acoustic quality parameters: Reverberation Time (RT), Clarity (C_{50}), Speech Transmission Index (STI) and Percentage Articulation Loss of Consonants (% ALCons) obtained via the computer simulation program. The results showed that increasing the opening area leads to significant improvements in the acoustic parameters. Knowledge about the effect of the openings in the internal acoustic quality architectural design can assist in the decision-making process on the part of the architects.

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1. Introduction

In classroom environments, oral communication corresponds to the main mechanism of transmission of knowledge, so that learning is directly related to the understanding of the words and speech intelligibility. The acoustic quality of an environment depends on several aspects, such as the geometric shape, the sound absorption of internal materials, sound sources, as well as its surroundings and effects of the openings in the environment. Some studies have reported the influence of environmental architectural features with the results in acoustic parameters [1].

Due to the need for compliance with environmental comfort requirements in the context of school architecture, it appears that in tropical regions such as Brazil, the conflict between the design recommendations based on comfort are constant. The openings are significant elements of such a conflict, because, while there is a need of entry of natural ventilation in order to meet the requirements of thermal comfort, it is also observed that the openings make the rooms subject to environmental noise, which can cause damage to speech intelligibility. The openings are usually identified as points of greater permeability of sound, subject matter being in work directed to the theme of sound insulation of buildings.

In order to minimize the problem of the dichotomy between the thermal and acoustic aspects, it is worth mentioning the work of Araújo [3] and Oiticica [11], with the development of architectural components, hollow elements (cobogós) and windows ventilated sills, respectively; that simultaneously allow the passage of natural ventilation and sound insulation.

The acoustics of rooms dedicated to the study of indoors. However, open spaces, with the existence of openings are often designed due to the necessity of the use of natural ventilation as a strategy for passive thermal cooling, as is the case of Maceió, Alagoas, located in Northeastern Brazil, and the need to ensure the favorable acoustic conditions development of activities in the environment, according to its use. Therefore, it is necessary to approach the openings of the interference in the determination of acoustic quality, the effect of view of the behavior of the sound openings environments and hence its implications in relation to the sound quality parameters.

Most of the literature [8] [5] [10] considers the window as a perfect acoustic absorber, since the total amount of sound that addresses the opening is transmitted to the outside the building. Thus, the absorption coefficient (α) of the opening corresponds to 1 (one) for all frequencies, so that 100% of the incident sound energy is absorbed in this component, which in turn can contribute to the attainment of lower results Reverberation Time.

Because the windows are the main opening elements employed in these environments, this study was based on the variation of the openings size, because it is an important aspect that can be decided by the architect, and consequently can affect the quality acoustics. This study aims to evaluate the influence of the openings size on acoustic quality of naturally ventilated classrooms in the municipal public schools in Maceió, Brazil.

2. Method

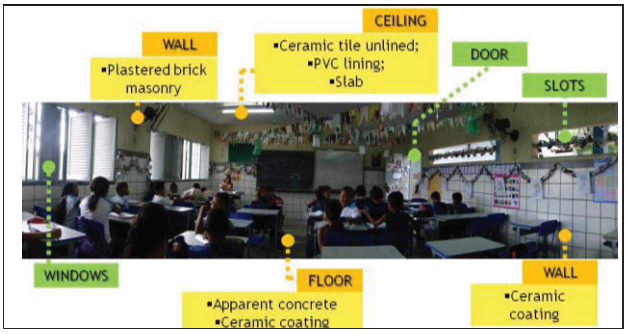
This work consists of a parametric analysis of the influence of the openings size on acoustic quality of classrooms, with the help of computer simulation. The applied method was divided into three steps, described below.

2.1. Data collection

Were consulted 56 architectural projects available in digital files, which equates to about 60% of the population of school buildings registered by INEP [7]. The data relating to the dimensions of 502 classrooms were raised beyond the opening area percentage with respect to the floor area and then carried out a statistical analysis based on the frequency of occurrence.

The physical-constructive characterization were based on the work on public school site architecture and *in loco* visits. Figure 1 summarizes the architectural materials and components of a classroom, which can be considered as representative.

Figure 1. Typical classroom municipal network of Maceió-AL education.



2.2. Characterization of models

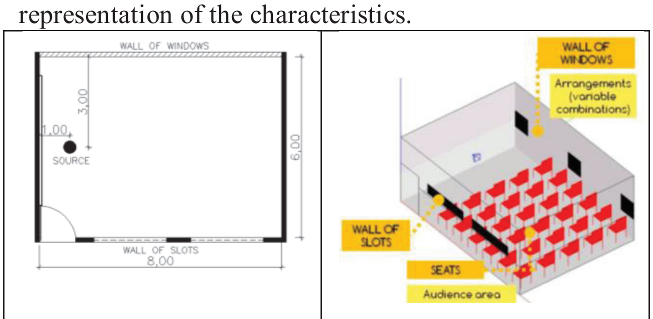
The dimensions of the classroom model, 6m (width), 8m (length) and 3m (ceilings height) were defined according to the most recurrent room, identified in the statistical analysis. Sound absorption coefficients (α) of the finishing materials are presented in Table I.

Table I. Sound absorption coefficients (α) of the component materials of the classroom model. Adapted from Bistafa [4].

MATERIALS		Frequency (Hz)					
		125	250	500	100	2000	4000
WALL	Plain plaster on masonry bricks or blocks	0,03	0,03	0,04	0,04	0,04	0,04
	Ceramic coating	0,01	0,01	0,01	0,01	0,02	0,02
FLOOR	Apparent and polished concrete	0,01	0,01	0,01	0,02	0,02	0,02
CEILING	Plaster	0,02	0,02	0,03	0,04	0,04	0,03
DOOR	Door wood painted	0,24	0,19	0,14	0,08	0,13	0,10
OPENING		0,01	0,01	0,01	0,01	0,01	0,01

In addition to size, other characteristics relating to the geometry still remain, such as the wall containing the slots and the door. The only suffering partition changes in the models it is the wall containing the windows opposite the wall having the slots (Figure 2).

Figure 2. Classroom Model: (a) floor plan (dimensions in meters). (b) Model in Ease 4.3, with the representation of the characteristics.



(a) (b)

In order to verify the effect of the openings size on acoustic quality of classroom, the models were based on the percentage values of openness in relation to room floor area, shown in Table II. Each of the percentage values of openness in relation to room floor area corresponding to the sum of the pane and slots (Table II). Thus, for example, 10% opening relative to the floor area is 5% in relation to the slots floor area windows and 5% in relation to the floor area.

Table II. Percentage of openness with respect to floor area considered in the simulation models.

OPEN PERCENTAGE	10%	15%	20%	25%	30%	35%	40%
Representation in view of the wall of windows							
Total area opening (slots+windows)	4,8m²	7,2m²	9,6m²	12m²	14,4m²	16,8m²	19,2m²
Window opening area	2,4m²	4,8m²	7,2m²	9,6m²	12m²	14,4m²	18,8m²

2.3. Acoustic computer simulation

The results of acoustic parameters were obtained by computer simulation, using the program Ease 4.3.

The sound source used it is one of the default settings of the male human voice available in the program, willing to 1.7m above the floor, which corresponds to the height of an adult. The background noise adopted was 50 dB(A), estimated for the empty room. The form of simulation was used to map with reflections for the Reverberation Time calculation (TR) in the program, we used the Sabine equation (1922).

2.4. Data processing

The sound quality evaluation was performed at two levels. Initially, comparatively analyzed the most critical values in each of the models, ie, the amounts recorded in less favored seat of the classroom. Thus, it was possible to assess the most damaging situation for the student/listener, with the assumption that in the classroom, should be guaranteed satisfactory conditions of speech intelligibility, regardless of location in the area of seating/audience area.

The results of the acoustic parameters obtained were checked for compliance with the technical recommendations and related standards (Table III). On the second aspect analyzed, evaluated the spatial distribution of the results of the parameters, aided by observation of acoustic maps of the models.

Table III. Acoustic parameters with the respective concepts and references.

ACOUSTIC PARAMETERS	CONCEPT	REFERENCES
Reverberation Time (RT)	This is the time required for the sound pressure level decay the first 60dB after stopping beep (MEHTA et al, 1999).	ANSI S12.60 [2]
Clarity (C_{50})	The C_{50} parameter is indicated to measure the setting in which sounds are perceived in a room in dB.	Marshall [9]
Speech Transmission Index (STI)	Considers the interference of background noise and reverberation.	IEC 60268-16 [6]
Percentage Articulation Loss of Consonants (%ALCons)	The %ALcons intended to quantify the percentage loss in the joint which is based on the perception of words by listeners. Considers the characteristics of the sound source and the room, the room volume and RT.	IEC 60268-16 [6]

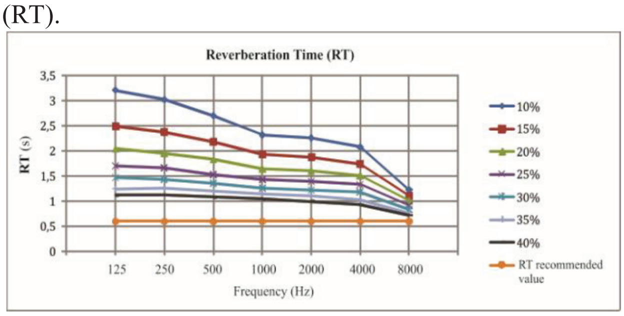
3. Results and Discussion

3.1. The influence of openings size in the critical results of the acoustic parameters

When considering the effect of the openings dimension variable, it appears that the Reverberation Time values (RT) exceed the recommendations in ANSI S12.60 standards: Acoustical performance criteria, requirements design, and guidelines for schools [2].

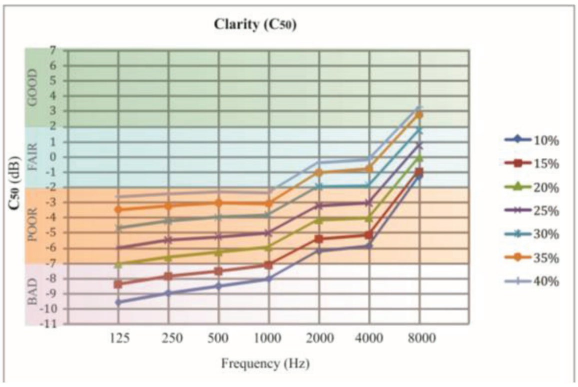
Since the ANSI S12.60 [2] indicates RT up to 0,6 seconds for unoccupied classrooms, volume up to 283m³, at 500, 1000 and 2000 Hz, the model at 40% opening relative to the floor area obtained the most favorable values of RT, while having values greater than 1s in most frequencies considered (Graphic 1). The simulations show that the change of the opening area, the lowest percentage for the highest percentage opening from 10% to 40%, the RT is only for 2,7s 1,08s (in the frequency of 500 Hz), which points a decrease of about 60% of the value of RT. It can be seen that each increase of 5% window opening area, there is an improvement in RT values (500 Hz) in around 10% to 19%.

Graphic 1. Critical results of the Reverberation Time (RT).



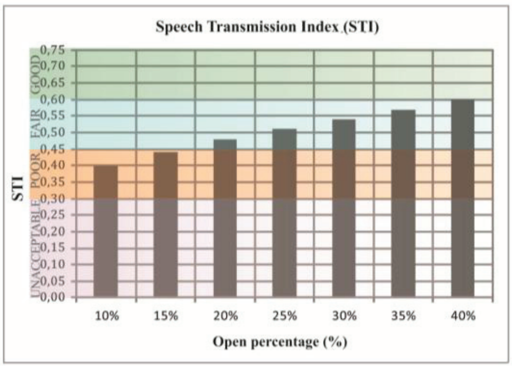
The results Clarity (C_{50}), as shown in Graphic 2, indicate that increasing the size of the apertures leads to improvements in parameter values. By comparing the variation of C_{50} as a function of values for every 5% increase in the opening area of the models, there is the increase in the C_{50} (500 Hz) in around 12% and 24%, depending on the model.

Graphic 2. Critical results of the Clarity (C_{50}).



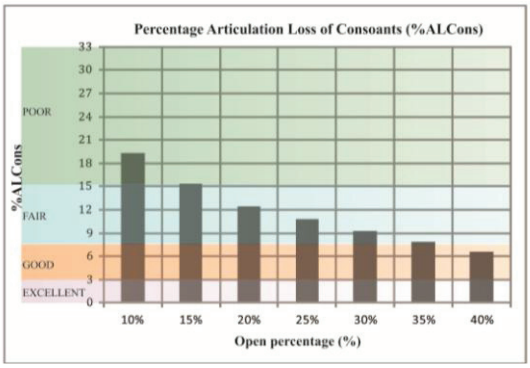
The results indicate that with increasing opening area, the more favorable values of Speech Transmission Index (STI) are observed, as shown in Graphic 3. Regarding the improvement of STI results due to the increased aperture size, it is noted that the change model with 10% to 40% open, respectively, the value changes from 0,40 to 0,60, which represents an increase of about 33% results. The increase in 5% open area of the models is the gain of around 5% to 10% for STI values.

Graphic 3. Critical results of the Speech Transmission Index (STI).



According to the results of the previously discussed parameters, the more favorable critical values Percentage Articulation Loss of Consonants (%ALCons) were obtained with increasing openings size, as shown in Graphic 3. The effect of increasing the size of the opening from 10% to 40% relative to the floor area, involves an improvement in %ALCons values about 65%, from %ALCons 19,28% (10% model) 6,64% %ALCons (40% model). By relating the variation of values %ALCons due to the increase in 5% open area of the models, the results suggest that an improvement ranges from around 13% to 20% of the values.

Graphic 4. Critical results of the Percentage Articulation Loss of Consonants (%ALCons).



In Table IV, it is possible to observe an improvement in classification due to the increase of the opening area, the results in the critical seats for the parameters: C_{50}, STI and %ALCons, in addition to obtaining more favorable RT results with increasing size opening.

Table IV. Summary of results in the critical seats

OPENING PORCENTAGE / ACOUSTIC PARAMETERS	10%	15%	20%	25%	30%	35%	40%
Reverberation Time (RT) (500 Hz)	2,70	2,18	1,83	1,53	1,36	1,20	1,08
Clarity (C_{50}) (500 Hz)	-8,49 BAD	-7,50 BAD	-6,26 POOR	-5,24 POOR	-3,97 POOR	-3,01 POOR	-2,31 POOR
Speech Transmission Index (STI)	0,40 POOR	0,44 POOR	0,48 FAIR	0,51 FAIR	0,54 FAIR	0,57 FAIR	0,60 GOOD
Percentage Articulation Loss of Consonants (%ALCons)	19,28 POOR	15,40 POOR	12,45 FAIR	10,86 FAIR	9,29 FAIR	7,90 FAIR	6,64 GOOD

3.2. Spatial distribution of the results

As discussed earlier, increasing the percentage of open area brings about an improvement in all parameters evaluated. Acoustic maps are gathered in Appendix.

As the opening area percentage increases, Clarity values (C_{50}) (500Hz) tend to get better results, especially in the seats next to the sound source. For example, for the model with 40% percentage opening, C_{50} values reach 2,79dB mark (500Hz) in one of the seats, so classified, according to the Marshall scale [9]. However, in this same model (40% model), the values of C_{50} (500Hz) can reach the seats -2,31dB located at the back, which can be regarded as poor, according to the scale of Marshall classification [9].

The spatial distribution of the Speech Transmission Index (STI) shows a low amplitude (range of values) between seats near the sound source (STI = 0,48) and most of the seats located at the ends of room (STI = 0,40), the configuration with 10% open area. It is noteworthy that the lowest value of STI, and therefore the most critical, is observed in the first seat of the first row. As the percentage open area increases, the dispersion of the STI values tends to decrease, however, remains the same amplitude. The Percentage Articulation Loss of Consonants (%ALCons), in the configuration with 10% opening presents the most favorable situation on the seat next to the source, with %ALCons value of 12,42%, considered reasonable according to IEC 60268-16 [6]. In the first seat of the first row, there is the most critical value, which corresponds to 19,28% of %ALCons, classified as bad as this standard.

4. Conclusions

In view of the importance of openings for the thermal comfort in hot humid regions, the variable size of the openings is one of the most studied aspects under natural ventilation. By involving design decisions by the architect, also the investigation becomes necessary about the implications of these architectural components in the internal acoustic quality.

By the results of the acoustic parameters in the critical seats, it was shown that the increase in opening area is constituted as a strategy to achieve better results, since the openings represent expressive ability of sound absorption. It is observed that the increase in opening area contributes to greater uniformity of the results of the acoustic parameters in the classroom, especially regarding the models with larger opening, more than 20% opening.

The increase in the size of the openings, and favors natural ventilation inside the classroom also helps to capture natural lighting. The openings, considered as environmental control components, when properly planned, can contribute to the design of school buildings more sustainable, environmentally sound and comfortable.

You must be the exception that the school buildings that require the use of natural ventilation should be associated with planning the location in the urban context, in order to avoid noise levels above the tolerable, since the openings can interfere significantly in the isolation of decrease sound environment. In addition to the concern with the environment, the zoning of schools can promote greater protection of classroom environments in relation to external sound sources.

Acknowledgement

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Appendix. Acoustic Maps: effect of variable size of the openings in the spatial arrangement of acoustic parameters.