Natural Ventilation and Indoor Noise Reduction

Development of a prototype of an architectural device

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ABSTRACT: The environmental characteristics of tropical zones promote the design of spaces that integrate the outdoor weather conditions through permeable enclosures, and the implementation of strategies that make efficient use of energy resources. The Natural Ventilation of a space is considered as a priority in order to provide welfare and hygiene conditions and prevent sick building syndrome. However, the incompatibility between the systems of natural ventilation and acoustic isolation leads to prioritize one over the other. Starting with the necessity of integrating natural ventilation and acoustic isolation, it was developed a prototype that allows efficient natural ventilation and at the same time reduces the entry of unwanted noise into indoor spaces. Both conditions were theoretically evaluated in 10 models. The ventilation was evaluated through a software simulation, and the acoustics through a sound wave geometrical analysis. The review of the data obtained led to the selection of the models that showed the highest values of acoustical isolation and the most efficient ventilation. The selected models were analyzed in real size prototypes. The data obtained in those analyses allowed determining which of the typologies is the most efficient of all in integrating both conditions.

Keywords: Natural Ventilation, Noise reduction, Acoustics

INTRODUCTION

The relationship between the human and its environment, constitutes the structural axis in designing confortable spaces. Regarding the architectural design in the tropics [1], Natural Ventilation is an important factor in order to generate welfare and to prevent sick building syndrome [2]. The favorability of the tropical weather makes it easy to design natural ventilated spaces. However, any traditional system of doors, windows, drafts or openings that allow the uptake of wind, brings, at the same time, acoustical vulnerabilities, since noise uses the air as an elastic means for its transmission.

The relation between ventilation and acoustics is intrinsic and decisive for the generation of thermal comfort in the case of Natural Ventilation and psychological comfort in the case of acoustics, in order to guarantee a healthy hearing environment for the proper development of cognitive activities.

According to the mentioned above, all architectural projects that favor natural ventilation strategies should be combined with the design of acoustical strategies. Nevertheless, is very common that one of the environmental phenomena is prioritized over the others. In this line of thought, those spaces that prioritize natural ventilation are highly vulnerable to acoustical contamination, and those who favor acoustical treatments, lack of possibilities to ventilate through natural means.

A search of methodological strategies and construction elements that include both phenomena in architectural design was conducted. It was found that for seasonal latitudes, in winter seasons, devices that allow the exchange of air at low velocities, where used, in order to preserve the gain heat in the interior of the space [3, 4]. This type of solutions, do not respond well to tropical needs [5], since there, the air volumes required to contribute to thermal comfort are higher.

In the field of HVAC systems, there were found two types of devices called Mufflers that contribute with the diminution of the noise conducted through the duct that contain injected air. These Mufflers are classified in tow types: Reactive and Dissipative [6]. However, for the design and operation of both systems of Mufflers, airflow and noise factors need to be known and constant. Conditions that are not meet in the case of natural ventilation and background noise.

The purpose of this investigation was to develop a real scale prototype of an architectural device that allows studying the airflow and the diminution of the exterior noise, through geometrical strategies. In order to determinate the possibilities for its implementation in the tropical architecture.

METHODOLOGY

The prototype development started from a quantitative and qualitative prospective analysis, through laminar flow simulation software and a geometrical analysis of the wave reflections, where the obstacle typologies were studied. Afterwards, those typologies that showed the best performance in both environmental factors, were evaluated through a deductive and quantitative, real scale analysis.

The tools listed below, were used to design and evaluate the prototype:

- Laminar flow simulation software.
- Computer Aided Design Software – CAD.
- Flat response monitor M-AUDIO, BX8 Deluxe (Sound Source).
- Sound level meter SAVANTEK – SVAN 957 (Acoustical measurement).
- White and Pink Noise audio files.
- Floor centrifugal fan of 3 blades, 18", 80 watts (Ventilation Source).
- Anemometer LA CROSSE TECHNOLOGY (Ventilation measurements).

For the prototype design principles, 500 Hz was taken as the tuning frequency and a total volume of 1 m^3 was considered. According to this, the device was designed as a square section; corresponding to the wavelength of 500 Hz, with the purpose of mitigate the sound pressure of this frequency forward. The prototype and the obstacle typologies are presented in Figure 1.

The homogeneity of the airflow was evaluated through fluid simulation software; regarding acoustics, to determine the percentage of reduction of reflections in each one of the studied typologies, the geometrical method was used [7].

In the real scale model, the ventilation was measured through the velocities (m/s) registered by the anemometer. In the acoustical evaluation two types of noises where emitted: White noise and Pink Noise. The use of these two types of noises, allowed evaluating the behavior of sound in all frequencies [8]. The sound pressure levels were measured with the sound pressure level meter, and the SCT index was calculated [6, 9].

The airflow simulation was analyzed in a qualitative way. An index from 1 to 5 was used to grade the homogeneity of the airflow evacuated by the device; 1 being the worst condition, equivalent to a turbulent flow, and 5 the best condition, corresponding to a homogenous flow (Fig. 2a).

The acoustical analysis was developed in a quantitative way, through the estimation of the number of specular reflections [5] that cross the device (Fig. 2b). The lower number of final reflections, the more efficient was considered the type of obstacle, therefore a 100% corresponds to the total reduction of the reflections.

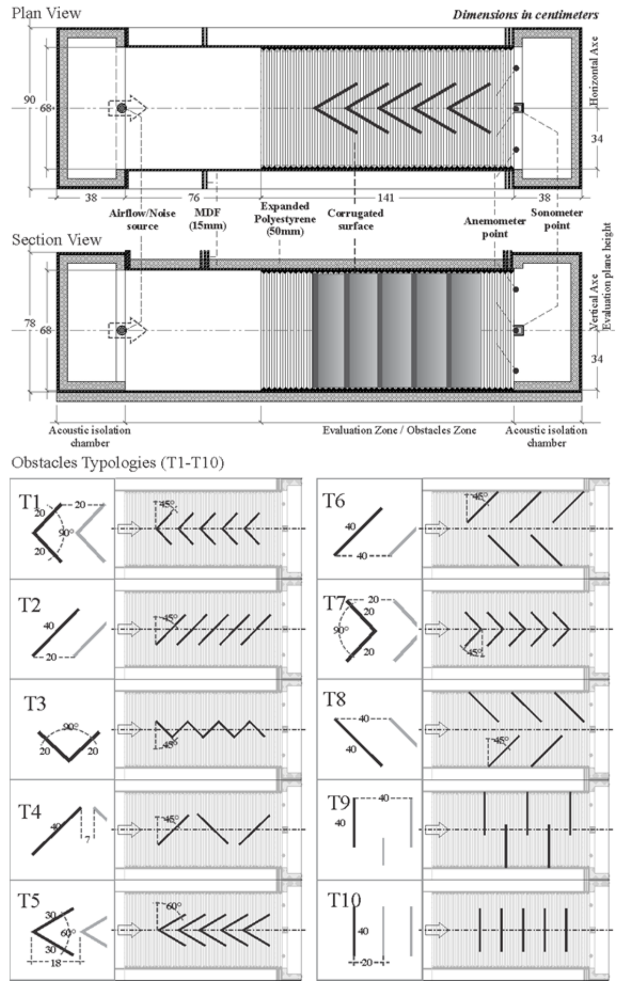


Figure 1. Prototype and obstacle typologies specifications.

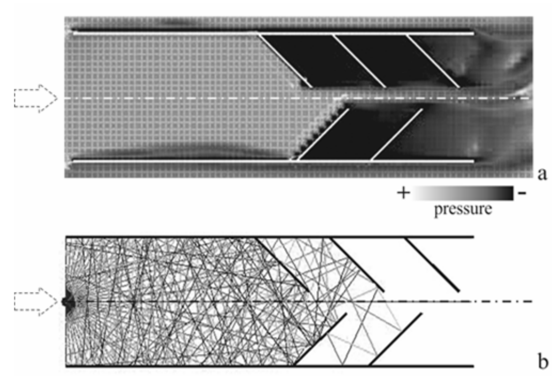


Figure 2 Evaluation outline
2a. Airflow simulation. 2b. Wave reflection study

The obtained results in the evaluation of both phenomena were compared in order to define the obstacle typologies, which presented the best performance regarding the airflow and the noise reduction. The selection criteria was a ventilation index equal or superior to 4 and a reflection reduction higher than 75%.

The real scale model of the device and the obstacle typologies were built of MDF (Medium-density fibreboard) with an absorption coefficient of 0,1. To isolate the duct, two cavities were placed at the edge of the device, and covered on the inside with foamed polyethylene of 5 cm thickness. On the outside, it was covered with the same material.

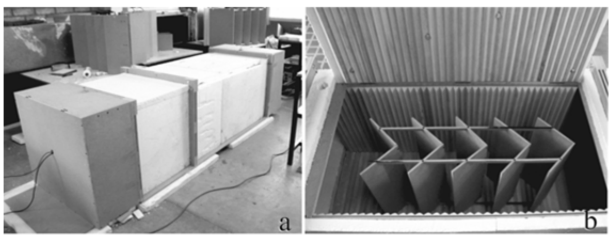


Figure 3. Real sacale Model. 3a. External isolation. 3b. Prototypes interior and obstacle location.

Measurements of each phenomenon were made in three different configurations:

1. **Flat:** Prototype with its interior smooth and without obstructions.
2. **Corrugated:** Prototype with its interior texturized and without obstructions.
3. **Combined:** Prototype with its interior texturized and with the selected types of obstruction.

The tests were made separately to avoid the contamination of the sound source by the fan.

Ventilation Measurements

These evaluations took place in a confined space. The sound proof chambers were not required because the exterior wind sources were dismissed.

The fan was located in the geometrical center of the emission area, and the initial velocity of the flow was registered. Afterwards, for each configuration, the flow velocity was measured in 9 points located on the evacuation area (fig. 1). The mean flow velocity was obtained as the average of the data.

The efficiency losses in the flow were estimated for all the studied obstacle configurations, comparing the initial velocity of the flow with the final average velocities. The smaller difference between the initial and final velocities, determined the most efficient typology.

Acoustical Measurements

The environment noise presented in the evaluation room was measured. The prototype interior was measured as well, while it was closed, to determine the starting point for the next acoustical tests. Once the acoustical environment was characterized, the Sound Source (The monitor) was located in the emission point and the sound pressure levels were registered at the source, as a control measure. These values should be higher than the once registered when the environmental noise was measured.

Subsequently, the sound level meter was located in the evacuation area and each configuration was measured. Once with the sound source emitting white noise and once emitting pink noise, always separately. Each emission was registered for two minutes in each test. This time lapse was defined to allow the emitted signal to stabilized.

The obtained data was analyzed according to the spectrum of frequencies between 125 Hz and 8000 Hz, for both white and pink noise. This helped to identify the frequencies in which the best performance is obtained. In the same way, the SCT index was calculated for the resulting prototype of the three configurations (Flat, Corrugated and Combined). This information allowed identifying and comparing the general performance of the typologies.

RESULTS AND DISCUSSION

The 10 design typologies (T1-T10) were evaluated using the methods described above (Fig 2). In this way, the ventilation qualitative grading between 1 and 5 was obtained as well as the reflection reduction percentage for each typology. The values obtained are presented in Table 1. The typologies where the ventilation grade was over 4 and the reflection reduction percentage was over 75% are highlighted.

The T5 Typology presented the best performance in both evaluations. It can be noted that obstacles location and geometrical disposition allows it to obtain high efficiency values in the airflow and the reduction of reflections. The Typologies T2, T4 and T1 were, respectively, the three following typologies with the best performance in both cases. These 4 typologies were built up for a real scale evaluation.

Table 1. Performance of the 10 evaluated typologies.

Obstacle Tipology	Ventilation Calification 1-5	Reflections Reduction %
T 1	**4**	**78**
T 2	**4**	**89**
T 3	3	67
T 4	**4**	**86**
T 5	**5**	**100**
T 6	2	97
T 7	2	78
T 8	2	97
T 9	1	100
T 10	1	95

The real scale ventilation measurements results in the three configurations (flat, corrugated and combined) are shown in table 2.

Table 2. Ventilation Measurements Results

Configuration		Average Speed (m/s)	Percentage Efficiency	Percentage Reduction
Source		5,86	100%	0%
Flat		3,50	60%	40%
Corrugated		3,75	64%	36%
Combined	**T1**	3,00	51%	49%
	T2	2,65	45%	55%
	T4	2,60	44%	56%
	T5	3,40	58%	42%

The typology T5 stands out as the most efficient, recording a final airflow velocity, similar to the one obtained in the flat configuration.

If typologies T1 and T5 are compared, it can be seen that a 15º modification in the inclination of the obstacles (T1= 45º and T5= 60º), represent a 10% difference in the airflow velocity. This lays out the possibility of increasing the angle to generate higher airflow velocities than the ones obtained in the Flat configuration. This can be done verifying further acoustic implications of this change.

In the acoustical test, first, it was characterized the external background noise and the performance of the closed device, in the typologies Flat and Corrugated without the sound source. The sound pressure levels measured in this case were compared with those registered at the source. This information can be seen in table 3, which indicates that the sound source stands over the background noise.

Table 4 collects the results obtain in each typology when they were evaluated with white and pink noise. The information is given in decibels for each of the octave bands, in the range of frequencies that was previously determine.

Table 3. Exterior background noise data (Leq) in the closed devise with and without the sound source (dB).

Medition		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Exterior		31	33	41	39	34	25	19
Closed duct	Flat	28	19	30	25	21	15	10
	Corrugated	29	19	30	27	26	21	10
Source	White Noise	38	51	61	66	69	73	69
	Pink Noise	51	59	67	70	70	69	62

Table 4. Sound pressure levels for each octave band, registered during the tests.

Configuration		Noise	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Source		**White**	38	51	61	66	69	73	69
		Pink	51	59	67	70	70	69	62
Flat		**White**	46	31	52	64	61	69	65
		Pink	59	40	58	68	62	67	59
Corrugated		**White**	46	32	49	64	57	68	59
		Pink	59	41	55	68	59	65	53
Combined	**T1**	**White**	47	34	44	58	53	57	50
		Pink	60	42	50	62	54	54	44
	T2	**White**	47	31	48	56	52	54	49
		Pink	59	40	54	60	54	52	43
	T4	**White**	47	32	45	59	56	60	53
		Pink	60	40	51	63	58	57	47
	T5	**White**	46	33	48	57	51	54	47
		Pink	59	42	54	61	52	52	41

Figures 4 and 5 show the performance of each typology in relation to the source, and for each evaluated noise.

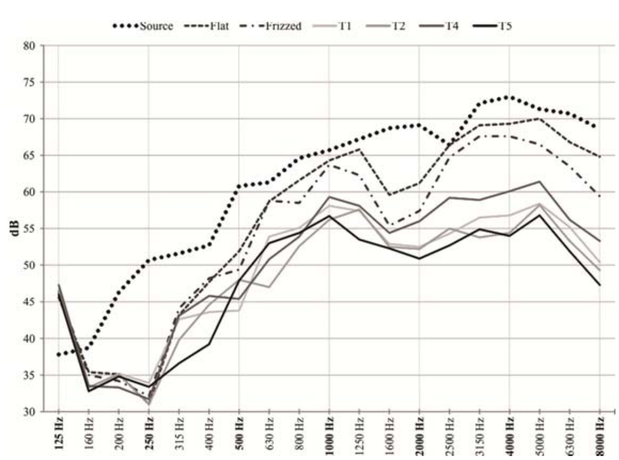


Figure 4. Configurations behavior with white noise

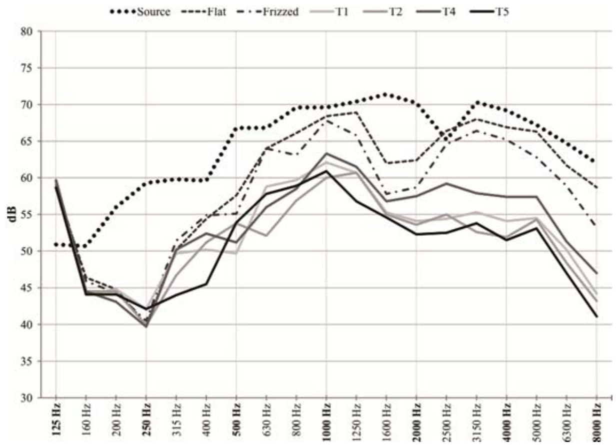


Figure 5. Configurations behavior with pink noise

It can be noted that there is insertion loss in all frequencies, except in the frequency of 125 Hz, where the sound is amplified in all three configurations. On the other hand, the greater insertion loss was registered in the frequency of 250 Hz in all the evaluated configurations.

In the perceptual sound scale [7], variations of 5 dB indicate a clearly perceptible modification in the sound level and 10 dB differences are associated to a 50% reduction of the subjective sound perception. According to the information above, it can be identified that in the configurations Flat and Corrugated, that evaluate the duct without any kind of obstructions, there is a significant insertion loss in the frequencies of 250 and 500 Hz, as they present differences greater than 10 dB, in relation to the source, while the reductions from 1000 Hz frequencies onwards do not exceed 5 dB.

The performance observed in low frequencies suggests that the square section of a device, with a determined wavelength (λ), has a tendency to suppress frequencies equivalent to 2λ and to amplify the frequencies corresponding to 4λ.

On the other side, the Combined configuration, , presents insertion losses superior to 10 dB in all frequencies, in regard to the source. When it comes to low frequencies, it presents a similar behavior to the one shown by the Flat and Corrugated typologies. This indicates that the performance in these frequencies responds to the section of the duct. The effects of the internal obstacles can be appreciated from 1000 Hz onwards, where variations regarding the Flat and Corrugated configurations can be seen. It is also identifiable that is in 1000 Hz that the lowest reductions can be perceived (under 10 dB). This may be due to the section of the obstacles, which corresponds to the wavelength of 1000 Hz and the separation from the duct walls are half this size. To generate offsets in the location and dimensions of the obstacles could help to improve their efficiency in high and medium frequencies.

As to analyze the individual performance of the obstacle typologies, table 5 shows the SCT index for each evaluated configuration.

Table 5. STC indexes for each one of the configurations

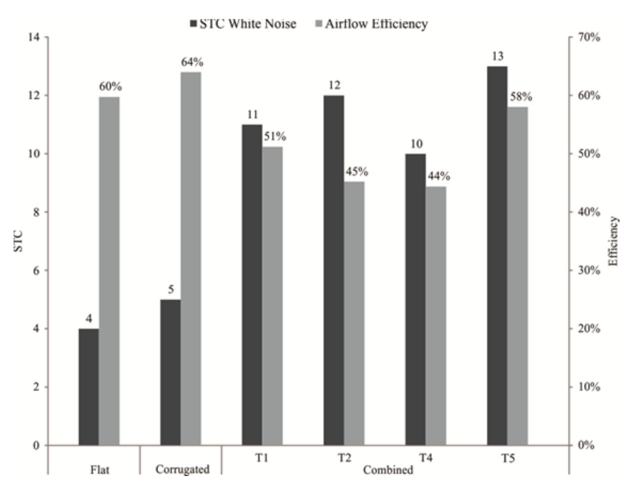
		STC	
Configuration		**White Noise**	**Pink Noise**
Flat		**4**	**3**
Corrugated		**5**	**5**
Combined	**T1**	**11**	**11**
	T2	**12**	**12**
	T4	**10**	**10**
	T5	**13**	**13**

It can be seen, that in regard to the type of the emitted sound, the SCT results are similar. For this analysis, the white noise is taken as the reference.

The SCT Indexes fluctuate between a minimum of 10 and a maximum of 13. Taking the “Flat” configuration as a base case, which obtained a SCT Value of 4, it becomes evident that including the obstacles means at the least, a perceptible modification in the sound level in all the studied cases. In the same way, the typology that showed the best performance was the typology T5, with a SCT index value of 13. This value compared to the one obtained by the case base, represents a diminution of around 10 dB, which represents a 50% diminution of the noise.

Figure 6 shows the performance of the evaluated configurations.

Figure 6. Conjugate performance of the evaluated configurations



When the information of the performance is crossed, it can be highlighted that when the obstacles are included in the inside of the module, the acoustical behavior of the device was improved. All the evaluated obstacle typologies, reached noise diminutions of 5 dB or more, and guarantee that the airflow efficiency is maintain above 40%.

Nevertheless, it can be identified, that the Typology T5, was the most efficient typology in both acoustical and ventilation phenomena, as it obtained the minimal reduction of airflow velocity and achieved the greater insertion loss.

CONCLUSION

It is possible to design architectural devices that allow to obtain airflow efficiencies over 50% and at the same time that allow to reduce the incoming noise in a 50% in the perceptual scale of sound, through geometrical strategies.

In this way, the adaptation of reactive mufflers strategies to the design of natural ventilation devices is possible, even so when the environmental phenomena is variable.

The section dimensions device are directly related with the noise reduction of low and medium frequencies, while the geometrical disposition of the internal obstacles, is related to the diminution of the noise produced by high frequencies.

It is necessary to produce variations in the device that allow to determine the relation between the dimensions, length-wide-height, of the element, the frequencies to tune in and the behavior of the wavelength, associated to it.

To implement materials with high absorption coefficients, will allow to obtain significant reductions in high frequencies. Therefore, is considered as indispensable to study the relation between highly absorbent materials and the airflow efficiency.

This device, besides presenting applicability in natural ventilation and acoustical situations, may grant solar protection functions, using it as a modular element in building façades.

This research aims to evolve the device to the minimum scale possible while maintaining significant efficiencies and allowing its implementation as a constructive element such a concrete block or brick. The grouping of such elements by certain dimensions, angles and directions, may geometrically respond in different scales to the sound waves and favor natural ventilation.

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