Sound absorption evaluated by analytical and experimental approaches of a variable acoustic solution composed of a multi-layer acoustic absorber

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Abstract

Multiuse halls acoustic design is crucial in order to provide adequate acoustic conditions for each type of performance, like music or theatre. To increase the versatility of these spaces, variable acoustic solutions can be implemented. These solutions modify the sound absorption/scattering provided by the surfaces of the space, hence it becomes important to accurately predict their acoustic behaviour. This work compares experimental measurements with analytical predictions of sound absorption coefficients provided by a variable acoustic solution composed of a multi-layer acoustic absorber, containing two perforated panels, porous material, and air gaps of varying thicknesses. The analytical model makes use of the transfer matrix method to obtain normal incident sound absorption provided by the sound absorber systems, while the experimental approach uses the transfer-function method in impedance tube (ISO 10534-2). The comparison between experimental and analytical results aims to understand the consistency of the characterization of this variable acoustic solution.

Keywords: Passive variable acoustics, perforated panels, sound absorption.

1 Introduction

In the context of room acoustics, the development of an acoustic project to adapt a multipurpose auditorium for different uses (different types of music and oratory) is a challenge. The solution to be implemented should meet the acoustic requirements needed for a multipurpose room and be aesthetically interesting. Generally, designers opt for a solution that serves all types of use, with consequent limited acoustic performance.

To achieve the multifunctionality of the environment, solutions are used that are based on variable acoustic techniques through architectural modifications (passive variable acoustics) or the implementation of electroacoustic systems (active variable acoustics). These solutions can offer a greater range in the acoustic behaviour of environments by changing the acoustic parameters, such as the reverberation time [1].

The active variable acoustic systems that are based on electroacoustic behave in a way that rectifies the reverberation of the room, making use of microphones, amplifiers and loudspeakers, with the microphones receiving the sound signals and the loudspeakers emitting the amplified sound [2],[3].

The use of solutions based on passive variable acoustics corresponds to strategies that can change the volume of the room or vary the acoustic absorption/dispersion of the surfaces, consequently changing the reverberation time, controlling the direction of the initial energy and other relevant parameters to obtain greater versatility in the use of the auditorium [1]. The solutions that generate changes in the volume of the space are influenced by the geometry or architecture of the room, while the solutions that modify the sound absorption/dispersion have their influence on the type of coatings which are chosen, whose acoustic performance and percentage of application, influence the equivalent sound absorption area of the surrounding surfaces of the space [4],[5]. The passive strategies usually require manual control, however, the development of electromechanical systems at affordable costs has given rise to innovations in the application of such systems in this field [6],[7].

This paper aims to contribute to the development of a variable acoustic solution, composed of a multi-layer acoustic absorber, by validating the use of the analytical model applied to a multilayer system for obtaining the sound absorption coefficient for normal incidence. Analytical results are compared with those obtained through laboratory tests using the impedance tube according to ISO 10534-2:2001 [8]. From the consistency in the results, it is possible to check the reliability of the analysed methods. The solution investigated is a variable passive acoustic system with the capacity to be automatized that uses two perforated panels with circular perforations, the first being installed in a steady position, while the second has an absorbing material attached and may vary its positions inside the cavity. The influence of variables such as the width of the air gap, the position of the porous material within the system, and also the properties of each perforated panel, are addressed.

2 Background theory

2.1 Passive variable acoustics

Fundamentally there are three ways to achieve variation in the acoustic behaviour of the hall, using passive variable acoustics solutions. They allow the reverberation time to be reduced or increased, the direction of the early energy to be controlled, and consequently the values of the acoustic parameters to be adjusted for each use of the space [1],[9]. The first alternative would be altering the volume of the space. The second way consists of the use of sound absorbing material solutions, whose acoustic performance and application percentage, influence the equivalent absorption area of the surrounding surfaces of the space. The third would be through the use of diffusion surfaces allowing to change the early reflections.

The strategies used to adjust the volume of the room make use of three possibilities: is the use of movable partitions to change the seating capacity; the second way consists of installing suspended ceiling panels that move vertically or work in the form of "opening or closing" areas of openings that are in the false ceiling, the third option is to use reverberant chambers that work as a coupled space [1],[9].

Movable partition solutions allow to divide the environment by decreasing the area available to the audience, thus it is possible to decrease the reverberation time and first order reflections are altered [10]. An example of a space that has used this type of solution is the Calzedonia Auditorium [5] having a total of 12 possible layouts. It is a multi-purpose space that managed to adapt the 10,200m^3 space into two other spaces (one with 5600m^3 and the other with 4600m^3) that guarantee optimum values for both speech and music across the entire frequency range.

The second strategy to perform volume variation through the use of suspended ceiling panels that "open and close" was applied in the Bruce Mason Theatre [1],[11]. An advantage of this method is associated with the first reflections, since if the panels have a proper inclination, they will be closer to the audience area. When the room is used for public speaking, the panels are not retracted, reducing the volume of the hall and also providing adequate strong reflections for speech intelligibility. When the room is used for symphonic music the panels are lifted to the proper angulation exposing the extra space and thus increasing the reverberation time. One case where suspended ceiling panels that move vertically were employed is employed in the São Paulo Room. Fifteen sets of three panels that move autonomously were used, providing a progressive adjustment in reverberation time. The extreme cases of panel positions can provide a variation of 1.7s to 2.8s in reverberation times [12].

The third possibility that uses reverberant chambers, work by interconnected to the perimeter area with the purpose of increasing the volume in the entire room, or allowing for the possibility of being closed when their use is not necessary. The solution provides the audience with a sensation of being in a larger environment than it is actually, particularly during breaks in the performance, when the sound decay is perceptible [9]. The Lucerne Culture and Congress Center has a 6000m^3 reverberation chamber that is located at the front and sides of the hall, accessed through doors that can be opened or closed to adjust the reverberation time between 1.6s and 3s [12],[13].

Regarding the use of absorptive and diffusion solutions, strategies of passive variable acoustics that correlate these two options have already application forms. Some examples of solutions are: the use of drapes, banners,

absorption membranes. Concerning the use of panels, there are basically a few ways to promote the change of acoustic performance: through the use of overlapping perforated panels, in which the exposed surface is fixed; through the use of hinged panel and the last way through rotating panels.
The most generally used solution concerning absorbent materials are moveable drapers, which to ensure flexibility, are placed in front of reflective walls. The absorption provided by this solution is influenced by the distance between the wall and its drape percentage [14]. The research by Aretz and Orlowski [15] analyses multiple auditoriums of reduced dimensions which are intended for music considering drapes as solutions for variable acoustics. In this analysis, it is verified that the use of curtains makes it possible to vary the reverberation time and adjust sound strength.
Concerning the use of panels, one possible application consists of the superposition system which works by putting two perforated reflector panels, one fixed and the other mobile, attached to an absorbing material. In this solution, if the perforations of the two panels coincide, they form a type of multi-cavity resonator, and when they are out of alignment, the absorbing part is no longer relevant [10]. A study of a system that uses this strategy is a slit absorber, where the air gap and the absorbing material are kept constant while the perforation rate (varies between 0.02 and 0.2) and the slit width are changed. With this system, it is possible to obtain a variation in sound absorption at medium and high frequencies, in extreme cases at 500Hz the variation is between 0.3 and 0.75 [16].
Another way is the application of a hinged panel where reflective and absorbent materials are combined, and which are mounted in front of the surface of interest. This solution is based on the strategy of moving the panels from their original position to take advantage of the absorption characteristics of the exposed faces [4],[10].
As for the case of using rotating panels, these are systems that provide 90°, 180°, or 360° rotations. For the situation where the rotation is 90°, there are reflector panels with a convex shape to avoid inconveniences such as echoes, and for the sound to be distributed in a better way. For the 180° condition, two configurations are presented, one having only absorbing material while the other presents a reflective behaviour. The solution with the greatest potential to offer possibilities would be with 360°, where each face of the structure can possess a different sound characteristic (absorbent, reflective, and diffuse) [4],[10].
There are some examples of solutions that are considered differentiated due to their structure, three of them being "Resonant Chamber", aQflex and BLOOM. An example of a differentiated solution that uses perforated panels is the "Resonant Chamber", is a structure whose design was based on origami, and is used as a flexible geometric system, by which it offers the ability to adjust its spatial, material, and electroacoustic properties in response to a change in the acoustics of the environment. The prototype has a flexible geometric structure formed by triangles, allowing a certain degree of freedom. This system is composed of electroacoustic panels that offer sound amplification, reflectors, and absorbers, in porous expanded polypropylene, and also has an electronic system of microcontrollers that are used to perform the movements of the structure [6]. The aQflex" solution from Flex Acoustics consists of thin inflatable absorption membranes that make it possible to change the sound absorption. The plastic material is specially designed with a high degree of internal damping and this system can absorb frequencies from 63-1000 Hz linearly [17]. The BLOOM system is a structure consisting of a textile surface that "opens and closes" and is intended to be applied as an acoustic solution for large spaces. The design concept follows the origami structure allowing the folding of the mesh and composed of independent and automated modular components. The geometry is based on a slightly unequal triangular shape that repeats itself randomly [7].

2.2 Active variable acoustics

Electroacoustic solutions are employed when the space reverberation does not reach the design values for each stipulated scenario or when the space has medium to large dimensions. Without the contribution of this type of system as a complementary aid, it would be impractical to obtain a good acoustic experience for the audience in large spaces and open environments, as the human voice and musical instruments alone cannot achieve the sound intensity needed to cover the space. To rectify the reverberation in the auditorium, a set of complementary systems consisting of microphones, signal processors, amplifiers and loudspeaker systems are employed, where the microphone receives music or speech signals to be adjusted and the loudspeaker radiates the amplified sound.

These types of solutions manipulate the sound field providing more sound energy, so the reverberation time can be increased in seconds. In addition, initial reflections can also be reinforced by inducing more sound energy and thus increasing speech intelligibility and music clarity [18]. The electroacoustic systems fall into three categories: in-line, regenerative and hybrid.

The in-line system adds reflections based on the original ones generated in the room. This system uses directional microphones (cardioid), which are placed close to the stage. It works by synthesizing the sound energy coming directly from the stage area without regarding the listener and then reproducing the sound to the audience through speakers. If the room is very absorbent, the system is controlled only by the inclusion of synthesized reflections, but if the room is not very absorbent, there will be a combination of the original and synthesized reflections [3],[19]. Some examples of in-line systems are: Acoustic Control System (ACS), Lexicon Acoustic Reinforcement and Enhancement System (LARES), System for Improved Acoustic Performance (SIAP), VIVACE [2]. The ACS uses the wave field synthesis method to sample and modify the sound field generated on stage, microphones are used in the stage area, and digital processors are used to generate early and late reflections in the loudspeakers [20]. LARES uses a large number of loudspeakers to have a better sound distribution in the room, to avoid sound coloration problems and time variation is applied to adjust the delay times of the reverberation algorithm [3],[21]. The SIAP can not only increase the reverberation time but also add reflections to improve speech intelligibility, being also able to reduce feedback through digital processing used for 'decorrelation in the input and output stages' [1],[22]. VIVACE combines the impulse responses with the signals collected by the microphones and from this creates the necessary reflections to adjust the environment for various uses [23].

The regenerative system amplifies the reflections already existing in the room by being conditioned to the pre-existing acoustics of the auditorium. This system provides stability through the use of multiple independent channels and uses acoustic feedback. Several (omnidirectional) microphone channels, amplifiers, and speakers are used to add acoustic energy with high loop gain [3].

Some examples of regenerative system solutions: Multiple-Channel Amplification of Reverberation (MCR) and Contrôle Actif de la Réverbération par Mur virtuel à Effet Naturel (CARMEN) [2], [3]. The MCR approach shows that full-bandwidth channels can be utilized as long as the channels are uncorrelated, implying they must have independently open-loop transfer functions. In this solution microphones and loudspeakers are distributed throughout the space and to achieve an increase in reverberation time a large number of channels are needed [24]. The CARMEN system is based on electroacoustic reflectors, and has the ability to reduce the sound absorption of the environment because it can reflect more energy than it receives [25].

The hybrid system is a combination of the In-line and regenerative systems. It uses the microphone arrangement and the small number of channels of the inline system. In relation to the regenerative system, a digital reverberator is used which can increase the reverberation time without necessarily increasing the acoustic energy through acoustic feedback [3],[20].

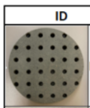
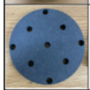
Some examples of hybrid system solutions: Virtual Room Acoustic System Constellation (Constellation) and Active Field Control (AFC) [2],[18]. The Constellation system uses the regenerative part to improve reverberation and the in-line part to improve initial reflection. This system uses the same number of microphones as the loudspeakers, and these are connected to a Digital Signal Processing (DSP) which allows for a lower number of loops between microphones and loudspeakers [2],[18]. The AFC system uses a loop levelling algorithm, so fewer independent physical channels are used to add sound energy to the environment. The microphones are positioned close to the stage area and then the captured sound is processed by finite impulse response (FIR) digital filters that are used to add initial reflections without causing coloration of the sound [3],[26].

3 Material and methods

3.1 Preparation of the specimens

The multilayer system studied consists of one or two perforated panels and a porous material positioned inside the airgap. One of the perforated panels is placed in a fixed position concerning the rigid surface, while the second is coupled to the porous material and may assume different positions inside the airgap. The diameter of the holes, perforation rate, the thickness of the panels and porous material´s relevant properties are shown in Table 1. Note that when performing analytical analysis, the first perforated panel (MPA) inside the system is always considered with a 10% perforation rate to resemble sample mounting conditions. Three sets of configurations are considered with a 113 mm air gap.

Table 1 - Properties of perforated panel and porous material.

ID	Perforated panels	Thickness (mm)	Diameter of the hole (mm)	Perforation rate of the sample (%)
 MPA	Macro-Perforated	12	6	11,5
 MPB	Macro-Perforated	12	8	5,8
 MPC	Macro-Perforated	12	5	28,5
ID	**Porous material**	**Thickness (mm)**	**Density (kg/m3)**	**Flow resistivity (Pa.s.m-2)**
 MW	Mineral Wool	20	70	28377

The first set of configurations (Table 2) assume the presence of one perforated panel and a cavity connected to a rigid surface. The influence of changing the position of the mineral wool, placed within the 113 mm thick air space, is evaluated using a system coated with an MPA perforated macro panel. Three positions of the absorbing material were tested: 1C-A-mineral wool is lined against the surface perforated panel; 1C-B- mineral wool is placed 25mm distance of the rigid surface; and 1C-C- mineral wool is positioned at 5mm distance from the rigid surface.

Table 2 - Geometries used in the first set of configurations to analyze the influence of the position of mineral wool.

ID Configuration	Layer 1	Layer 2	Layer 3	Layer 4	Configuration
1C - A	MPA	MW	Airgap(mm) 93	-	
1C - B	MPA	Airgap(mm) 68	MW	Airgap(mm) 25	
1C - C	MPA	Airgap(mm) 88	MW	Airgap(mm) 5	

In the second set of configurations (Table 3), again we assume the perforated panel MPA, in a steady position and an air cavity. Here, the aim is to analyze the influence of inserting a second perforated layer attached to the mineral wool, inside the air cavity. The properties of the second perforated panel are addressed, by testing MPA, MPB or MPC panels in this position.

Table 3 - Geometries used in the second set of configurations to analyze the influence of inserting a perforated panel in the air-gap of the acoustic absorber system.

ID Configuration	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Configuration
2C - A	MPA	Airgap(mm) 56	MPA	MW	Airgap(mm) 25	
2C - B	MPA	Airgap(mm) 56	MPB	MW	Airgap(mm) 25	
2C - C	MPA	Airgap(mm) 56	MPC	MW	Airgap(mm) 25	

In the third set of configurations (Table 4) the position of second perforated layer with mineral wool attached, inside the airgap of the acoustic absorber system, where the coating is the perforated macro panel MPA, is addressed. It is important to note that in the layout it is possible to form two air gaps of varying thicknesses. In this analysis three positions are considered, two extreme and one intermediate. As it will be discussed in the section regarding the results (section 4), the MPA was found to provide the best acoustic behavior when applied in the composite panel, therefore it was chosen for this analysis.

Table 4 - The geometries used in the third set of configurations to analyze the proposed solution of variable acoustics.

ID Configuration	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Configuration
3C - A	MPA	MPA	MW	-	Airgap(mm) 81	
3C - B	MPA	Airgap(mm) 56	MPA	MW	Airgap(mm) 25	
3C - C	MPA	Airgap(mm) 76	MPA	MW	Airgap(mm) 5	

3.2 Analytical approach

The approach used in this paper to evaluate the sound absorption of a variable acoustic conceptual system is based on the evaluation of the acoustic impedance of each layer of this multilayer system. Regarding the perforated panel, the acoustic impedance is based on converting a single hole into an average value corresponding to the open area of the panel. The non-perforated material is considered rigid and the perforated panel is considered as a set of short tubes of length similar to the thickness of the panel. This method includes terms due to radiation (from a hole in a baffle), air viscosity, interactions between holes and the effects of cavity reactance. An equivalent fluid is defined to describe the porous material whose skeleton is assumed to be rigid using its effective acoustic properties (i. e. complex characteristic impedance and wave number), and the air-gaps being modelled through a purely reactance term. The concept of the transfer matrix method [27] was used in the study of the multi-layer acoustic absorber, where the acoustic impedance along the normal direction of the surface of a material is defined taking into account that there is continuity of the particle velocity and knowing the acoustic properties of the medium (wavenumber or propagation constant, k_a and characteristic impedance, Z_{c_a}).

The configuration of an example multilayer absorber is shown in Figure 1. The system is considered to be locally reacting, considering the incidence of sound normal to the interface plane.

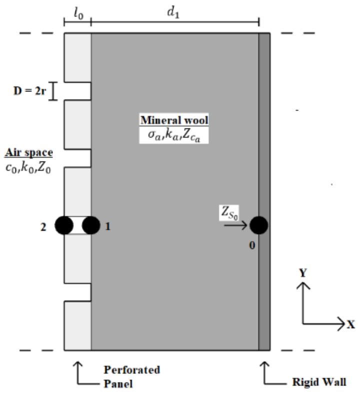


Figure 1 - Configuration of the perforated system.

At point 0, considering the rigid wall the normal surface impedance is assumed to be infinite ($Z_{s_0} = \infty$). The normal surface impedance at point 1 is:

$$Z_{s_1} = -i\, Z_{c_a}\cot(K_a d_1) \quad (1)$$

where Z_{c_a}, k_a and d_1 corresponds respectively to the characteristic impedance, the characteristic wavenumber of the porous material and the thickness of the absorbing material.

The surface impedance of the system (point 2) to the normal direction is calculated from:

$$Z_{s_2} = Z_{s_{panel}} + Z_{s_1} \quad (2)$$

where the normal surface impedance of a perforated panel $Z_{s_{panel}}$ is obtained by the ratio between the impedance of a hole (tube) $Z_{s_{tube}}$ and the perforation rate of the panel, ε:

$$Z_{s_{panel}} = \frac{Z_{s_{tube}}}{\varepsilon} \quad (3)$$

The impedance of a hole according to Crandall [16] is:

$$Z_{s_{tube}} = i\omega\rho_0 l_0\left[1 - \frac{2J_1(k_s r)}{(k_s r)J_0(k_s r)}\right]^{-1} + \left[2\sqrt{2\omega\rho_0\eta} + \rho_0 c_0 \pi^2\left(\frac{2r}{\lambda}\right)^2 + i\omega\rho_0\delta\right], \quad (4)$$

where ω is the angular frequency, ρ_0 is the air density, l_0 is the thickness of the perforated panel, J_n is the nth order of Bessel function, $k_s = \sqrt{-\omega\rho_0/\eta}$ is the Stokes wave number, r is the radius of the circular hole, η is the coefficient of air viscosity and λ is the wavelength. The term δ is the final correction which also explains the interaction between the holes through the expression [14],[28]:

$$\delta = \frac{16r}{3\pi}(1 - 1.47\sqrt{\varepsilon} + 0.47\sqrt{\varepsilon^3}) \quad (5)$$

The sound absorption coefficient for an incidence angle θ of sound to the normal surface is defined by

$$\alpha(\theta) = 1 - |R(\theta)|^2 \quad (6)$$

where R(θ) is the reflection coefficient that can be approximated in terms of the normal surface impedance Z_{s3} of the system:

$$R(\theta) = \frac{Z_{S_3}cos\theta - Z_0}{Z_{S_3}cos\theta + Z_0} \quad (7)$$

which $Z_0 = \rho_0 c_0$ is the acoustic impedance of air.

3.3 Impedance tube setup

For the validation of the analytical results, the evaluation of sound absorption coefficient in impedances tubes was performed according to ISO 10534-2: 2001 Standard [8]. The test operation is based on the system defined by a signal generator, capable of emitting white noise, which through an amplifier and a loudspeaker inserted at one end of the tube, allows the generation and propagation of plane waves along the tube. The sample is located at the other end of the tube which will absorb part of the energy and reflect the remaining incident sound energy. The incident sound waves and the reflected sound waves are then captured by two microphones and processed by a digital analyzer and later treated on a computer.

Figure 2 shows the experiment setup in the laboratory, where an impedance tube was used to measure the sound absorption coefficient of several sets of configurations. In this impedance tube, the diameter is 100 mm, the spacing between microphones is 5 cm and the distance between the microphone and the sample is 25 cm. The following equipments were employed: an amplifier Inter-M type M700; one digital analyzer of the brand National Instruments NI USB-4431 model and two microphones of the brand GRAS 46AE model ½ ". A code developed in Matlab was used for data analysis and the acoustic properties were measured in the frequency range from 100 Hz to 1500 Hz. The calculation of sound absorption coefficient for normal incidence was performed using equation $\alpha = 1 - |R|^2$, after the reflection coefficient. The reflection coefficient R of the sample is determined from the transfer function, H, using the following expression:

$$R = \frac{H - e^{-iks}}{e^{iks} - H} e^{i2k(L+s)} \quad (8)$$

where L is the distance from the sample face to the first microphone; s is the distance between the two microphones, $k = \frac{2\pi f}{c}$ is the wave number and f is the frequency. In order to correct for mismatch in both the amplitude and phase responses, the transfer function used in Eqn. (8) is obtained according to $H = \frac{\bar{H}}{\bar{H}_c}$, where $\bar{H}$ is the measured transfer function with the microphones in the standard configuration, defined by the complex ratio $\frac{p_2}{p_1}$, where p_1 is the complex sound pressure at the microphone in the reference channel.
$\overline{H_c} = (H^I/_{H^{II}})^{1/2}$ is the calibration factor obtained after performing a test on a rockwool sample, where H^I and H^{II} are the transfer function with the microphones in the standard and switched configuration, respectively.

Figure 2 - Equipment used for evaluation of sound absorption coefficient for normal incidence (a) and picture of one of the samples (b).

4 Results and discussion

4.1 Effect of the position of the porous material

The results presented in Figure 3 correspond to the experimental and analytical responses regarding the influence on the sound absorption coefficient when changing only the position of the porous material within the system. Analysis of these results allows to verify that analytical and experimental curves are in good agreement. The resonance peak in the three configurations is almost the same, varying between 350 Hz and 380 Hz. It is also interesting to notice that when the absorbing material is moved away from the perforated panel, the value of the sound absorption coefficient at the resonance peak varies between 0.99 and 0.33 (1C-A and 1C-C respectively).

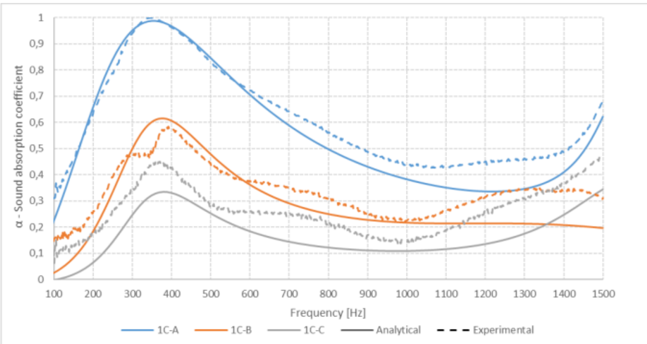


Figure 3 – Analytical and experimental results for the first set of configurations, to analyze the effect of the position of the mineral wool.

4.2 Effect of the perforation ratio and double air gap

In this second analysis (Figure 4a), the behavior of a multilayer system with two perforated panels, where one is steady and the second, which is coupled to the porous material, is movable, is addressed. Here the position of the second perforated panel is unchanged, while the perforation rate is analyzed. Three situations are considered where only the second perforated panel is modified with respect to perforation rate and the hole diameter. Again, the results obtained both by the analytical and experimental approaches are in good agreement, evidencing the presence of two resonance frequencies, related to the multi-layer acoustic absorber. When changing the perforation rate of the second panel we note that the configuration providing absorption in a broader range of frequencies is 2C-A, with both panels with the same perforation rate. This configuration will therefore be used for further assessment. In Figure 4b the result provided by configuration 2C-A is compared with that provided by a similar configuration but without the perforated panel (configuration 1C-B). It is possible to verify that, in general, sound absorption is more broadband and with higher amplitudes than those provided by the single perforated panel. It can also be noticed the first resonance of the multilayer system is related to that provided by the single perforated panel.

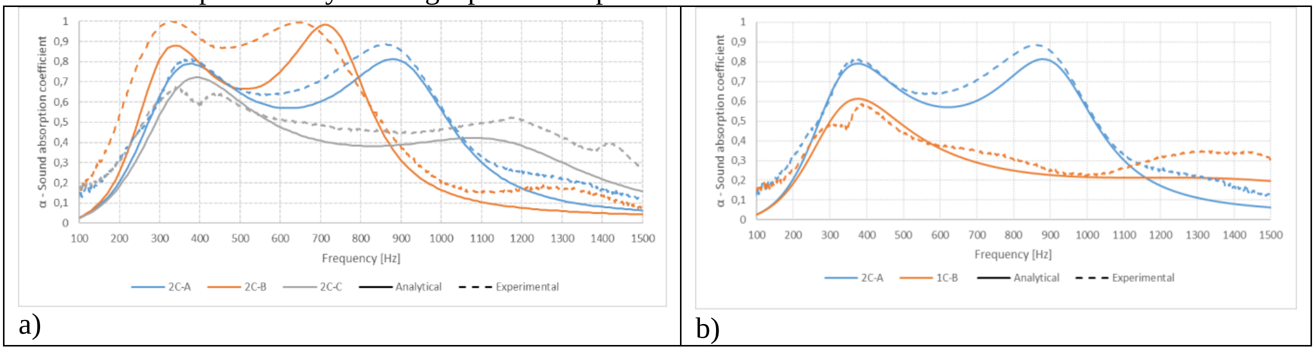


Figure 4 – Analytical and experimental results for the second set of configurations to analyze the effect of the different perforation rates and double air gap (a) ; comparative between a system with one and two perforated panels (b).

4.3 Variable acoustic solution

The third analysis concerns the general concept of the passive variable acoustic multi-layer acoustic absorber system to be developed. According to Figure 5, the analytical results agree well with the experimental ones. It is possible to see that the use of this type of system allows achieving absorption patterns. When moving the second perforated panel with the mineral wool attached, next to the first panel, a narrow resonance peak is achieved in the lower frequency ranges, resembling the behaviour of the single perforated panel. On the other hand, if the movable panel is placed so as two airgaps are created, then the absorption frequency range increases due to the resonance effect of the system.

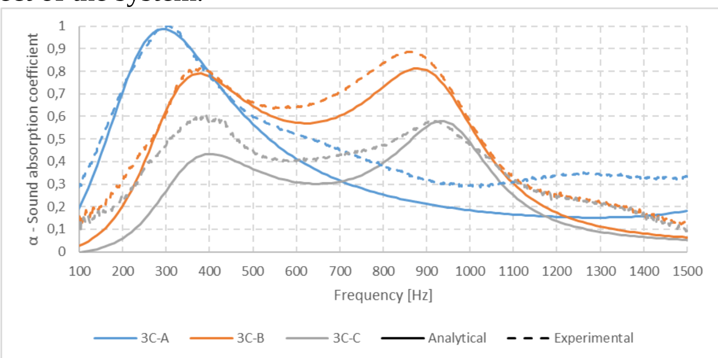


Figure 5 – Analytical and experimental results for the third set of configurations corresponding to the proposed variable acoustic solution

5 Conclusions

In this paper, validation of analytical results of sound absorption was performed through laboratory tests in an impedance tube to address a multi-layer absorber with the potential to be used as a passive solution of variable acoustics. The solution investigated uses two perforated panels with circular perforations, the first being

installed in a steady position, while the second has an absorbing material attached and may vary its positions inside the cavity.
Initially, the influence of the position of the absorbing material inside the system was analysed considering only the first perforated panel, thus being possible to verify that by moving the absorbing material inside the air gap it is possible to change the amplitude of sound absorption, while the resonance peak is kept in the same frequency range. In the second analysis, a second movable panel consisting of a perforated layer with a porous material attached is inserted in the air cavity. Here its position is kept, but different perforation rates and hole diameters of this panel were considered. Based on the results obtained, it was found that The solution that uses two equal perforated panels can provide a more interesting behaviour in relation to the frequency range of sound absorption. Moreover, the results evidence the presence of two resonance peaks, instead of one provided by a single absorber, allowing to achieve more broadband and better absorption. The third analysis is the idealized solution, where the second perforated panel, with a porous material attached, moves inside the cavity. It was found that the solution has the potential to provide versatility when moving the second movable perforated panel with the porous material attached inside the airgap and providing a change in the sound absorption frequency range.
The solution is interesting from an acoustical and architectural point of view since it can provide changes in the sound absorption and does not change the aesthetics of the hall in which it is applied.

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