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# DEVELOPMENT OF SLOTTED PANEL TO ACOUSTIC TREATMENT OF ROOMS

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**Abstract.** A project of acoustic treatment of rooms aims to control sound reverberation to ensure acoustic comfort. The designer's challenge is to combine the aesthetics of solutions with the functionality of acoustic elements. In this context, the development of slotted acoustic panels allows for the combination of design with acoustic performance. This work aims to know the development of a slotted acoustic panel. The idea is to combine slotted MDF wood panels which are supported by PET wool absorbent material. The optimum frequency range chosen refers to human voice, that is between 500 Hz to 2 kHz. The constructed samples were evaluated in reverberation chamber (Laboratory of Acoustics and Vibration - UFSC) and installed in a meeting room. Thus, this environment was analyzed before and after installation, demonstrating that the developed acoustic solution presents excellent control of sound reverberation time of the room.

**Keywords:** acoustic treatment, slotted acoustic panels, sound reverberation time

## 1. INTRODUCTION

An excessively reverberant environment can have undesirable consequences, for example, in the lack of speech intelligibility. An acoustic treatment of rooms is essential to provide the acoustic comfort (Brandão, 2016). In this context, the use of fibrous absorbent materials (e.g. rock wool, glass wool, PET wool) and slotted/perforated panels could be the solution to control the sound reverberation of rooms (Cox and D'antonio, 2009). This control is very important for instance, in music studios, meet rooms, theater, auditorium and cinema. The main challenge for engineers and designers is to tune the acoustic performance with cost. Specially at underdeveloped countries that needs to pay so high taxation in acoustics products from Europe or United States of America. In Brazil, there are few acoustics companies which has certified products with data sheet, such as standard tests in laboratory. Figure 1 shows some examples of slotted acoustic panels.

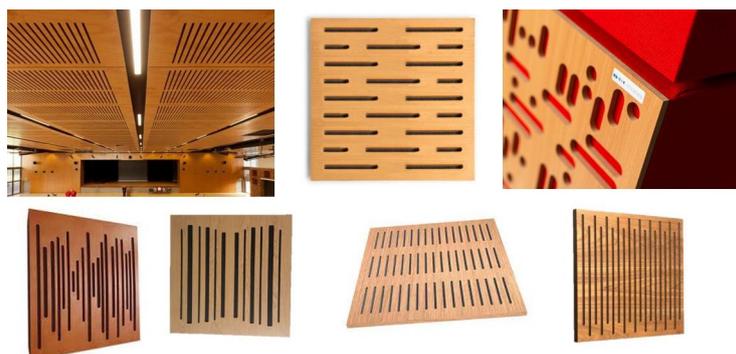


Figure 1. Examples of the slotted panel absorber.

Zhao *et al.* (2022) presented an study comparative about the behavior sound absorption coefficient of porous materials measurement in impedance tube and in a small self-made reverberation room to random incidence. The authors show a similar trend and reasonable agreement when predicting the acoustic properties of fibrous materials. Robin *et al.* (2019) proposed a measurement method based on a sound field reproduction approach and a synthetic array of acoustic monopoles, where report numerical and experimental results concerning the behavior of the diffuse field sound absorption coefficient of several porous materials in laboratory and *in situ*. Using two-dimensional (2D) Finite Element Method and a three-dimensional (3D) Boundary Element Method, Pereira *et al.* (2021) proposed an study to better describe the behavior of the sound absorption coefficient in diffuse field conditions of porous concrete materials. The authors compares the numerical results with analytical equations and experimental data from the reverberant room, studying the influence of the porous material panel size in the sound absorption coefficient in diffuse field conditions.

Considering the acoustical design and the results of an case study, we highlights the work by Ruggiero and Russo (2016). An acoustical design of music rooms in an Italian public school was presented. To obtain a good acoustics with reasonable cost was achieve ding by using sound-absorbing panels made from low density polyethylene foam with a closed calibrated cell structure, placed on the walls and on the ceiling and sound-insulation panels made of geometrically spherical composites. The *in situ* results show a substantial accordance with the simulation in the design phase, allowing the authors to conclude that the proposed development is characterized by good performance in terms of cost-benefit. The noise problem, self-generated by lingual or musical communications in small to medium-sized rooms is study and an solution was proposed by Fuchs and Lamprecht (2013). The solution consists is provided by broadband bass absorber elements to be mounted only at a few edges of the rooms. These preferably cover always less than 20% of the ground surface along the walls and leave the ceiling completely untouched for other installations or tasks. The authors presented application examples of classrooms, cafeterias, seminars and multi-purpose assembly halls prove the practicability of novel passive or reactive edge absorbers. The parameters Reverberation Time and Definition of the environments were compared after and before installation of the acoustic elements.

This work proposed and developed a project slotted acoustic panel to act in frequency range 500 Hz to 2 kHz which is the critical range to human voice. The formulation is based in an analytical perforated panel supported by absorbent material of PET wool (*Polietileno tereftalato* polymer). Although this work has been motivated by the works mentioned above, the structure proposed here differs from the previously mentioned structures to be acoustic material with wide-band absorption low-frequency and mainly to be of low-cost. The validation of the absorber proposed occurs in two stages. First in a reverberation chamber and then the panels were installed in a meeting room's LVA (Laboratory of Acoustics and Vibration - UFSC). In this sense, the *in loco* analysis were realized to compare the acoustics parameters T20 (reverberation time), D80 (Definition) and STI (Sound Transmission Index), before and after the acoustic treatment. According to Fukuchi and Ueno (2004); Portela (2005) the ideal parameters are listed in Tab. 1 for meet room:

Table 1. Ideal acoustic parameters of room analysis.

T20 [s]	D80 [-]	STI
0.5	0.9	0.75-1.00

This paper is organized as follows: The general aspects of the slotted acoustic panel and the theoretical method are presented in Section 2. Section 3 present the theoretical and experimental results and discussions, respectively. Finally, the Section 4 describes the conclusions and final remarks the work.

## 2. METHODOLOGY

### 2.1 Slotted panel absorber

The structure absorbing present dimensions  $L \times H$ , as illustrated in Fig. 2. The panel has thickness total  $t$ , the slits has width  $d$  with height  $l$  variable. The porous layer (e.g. PET wool or Melamine foam) present thickness total  $D$ . It is so important to emphasize that the slotted panels of absorber was manufactured on maker bench using a hand router.

The absorber proposed is based on series coupling of a slotted panel with a porous layer. Therefore, the total acoustic impedance of the absorber is obtained by Eq. (1),

$$Z_t = Z_p + Z_f, \quad (1)$$

with  $Z_p$  representing acoustic surface impedance of the panel and  $Z_f$  the acoustic impedance of porous material layer.  $Z_p$  is determined by Eq. (2) (Maa, 2000; Almeida *et al.*, 2021, 2022)

$$Z_p = \frac{j\omega\rho_0 t}{\Theta} \left[ 1 - \frac{\tanh(\sigma\sqrt{j})}{\sigma\sqrt{j}} \right]^{-1}, \quad (2)$$

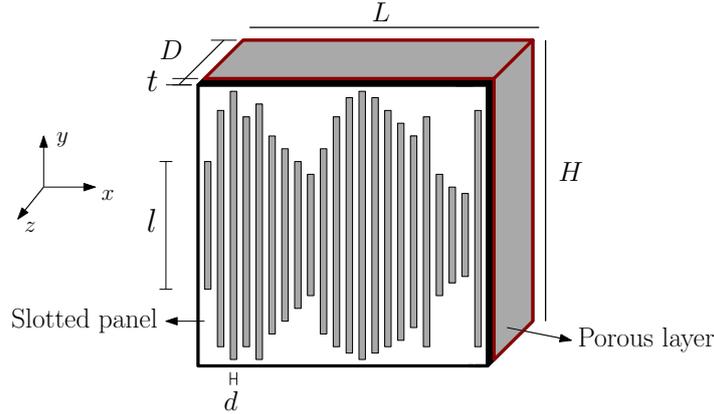


Figure 2. Schematic diagram of the slotted panel absorber.

in which  $\Theta = (S/S_p)$  is the porosity, being  $S = N \times ld$  the cross-sectional area of the all slit,  $S_p = L \times H$  the cross-sectional area of the absorber and  $\sigma = d\sqrt{\frac{\rho_0\omega}{4\eta}}$  is the ratio of the gap diameter to the thickness of the boundary or constant perforation layer (Maa, 1998). In addition, it is necessary to account for the final corrections of the impedance of the panel containing the slits. First, the resistivity correction due to the friction of the air flow in the viscous boundary layer that produces an additional viscous effect ( $4\sqrt{2\rho_0\omega\eta}/\Theta$ ), then the correction of the reactance of the mass due to the sound radiation from the position at both ends of the slit ( $0.936d_f F_\epsilon(\epsilon) \ln[\sin(\pi\Theta)]/(2\Theta)$ ) (Cobo *et al.*, 2020). Here  $F_\epsilon = [1 - 1.25\epsilon]$  represents the modified correction Fok function due to the interaction of air radiation between the slits when AMS cells are coupled and  $\epsilon = \Theta$ .  $Z_f$  is given by (Allard and Atalla, 2009; Vergara *et al.*, 2022)

$$Z_f = -j \frac{\sqrt{\rho_{ef} K_{ef}}}{\phi} \cot(k_{ef} L_f), \quad (3)$$

where  $\phi$  is the filling fraction of the porous layer and  $k_{ef} = \omega\sqrt{\rho_{ef}/K_{ef}}$  is the wave number, with  $\rho_{ef}$  representing the effective density and  $K_{ef}$  the bulk modulus. These functions are given from Johnson-Champoux-Allard model (Johnson *et al.*, 1987; Champoux and Allard, 1991), that is

$$\rho_{ef} = \rho_0 \alpha_\infty \left( 1 + \frac{\sigma_r \phi}{j\omega \rho_0 \alpha_\infty} \sqrt{1 + \frac{4j\alpha_\infty^2 \eta \rho_0 \omega}{\sigma_r^2 \Lambda^2 \phi^2}} \right), \quad (4)$$

$$k_{ef} = \frac{\gamma P_0}{\gamma - (\gamma - 1) \left( 1 + \frac{8\eta}{j\omega P_r \rho_0 \Lambda^2} \sqrt{1 + \frac{j\omega \rho_0 P_r \Lambda^2}{16\eta}} \right)^{-1}}, \quad (5)$$

where  $\alpha_\infty$  is the tortuosity,  $\sigma_r$  is the flow resistivity,  $\Lambda$  is the viscous characteristic length,  $\gamma = 1.41$  is the specific heat ratio,  $P_0 = 101325$  Pa is the atmospheric pressure,  $P_r = 0.71$  is the Prandtl number and  $\hat{\Lambda}$  is the thermal characteristic length.  $q_0 = \eta/\sigma_r$  and  $q'_0 = q_0 \alpha_\infty$  are the viscous and thermal permeability, respectively.  $\eta = 1.81 \times 10^{-5}$  Pa·s is the viscosity of air and  $\rho_0 = 1.21$  kg·m<sup>-3</sup> is the air density (at 20°C).

Using Eqs (3) and (2) with the respective final corrections, the total acoustic impedance of absorber  $Z_t$  (Pa·s·m<sup>-3</sup>) on the slotted panel can be determined as follows

$$Z_t = \frac{j\omega \rho_0 t}{\Theta} \left[ 1 - \frac{\tanh(\sigma\sqrt{j})}{\sigma\sqrt{j}} \right]^{-1} + \frac{4\sqrt{2\rho_0\eta\omega}}{\Theta} - j0.936\omega\rho_0 \frac{d_f F_\epsilon(\epsilon)}{2} \frac{\ln(\sin(\pi\Theta))}{\Theta} - j \frac{\sqrt{\rho_{ef} K_{ef}}}{\phi} \cot(k_{ef} L_f). \quad (6)$$

Considering a normal wave incidence, the sound absorption coefficient of absorber is given by Eq. (7) can be obtained from the Eq. (6) as being,

$$\alpha = 1 - \left| \frac{Z_t - Z_0}{Z_t + Z_0} \right|^2. \quad (7)$$

The Johnson-Champoux-Allard (JCA) model is used for the wave propagation for rigid porous material to represent it like an equivalent fluid. The macroscopic parameters of the porous material are represented by the following symbols:  $\sigma_r$  is the airflow resistivity,  $\phi$  is the porosity,  $\alpha_\infty$  is the tortuosity,  $\Lambda$  is the viscous characteristic length and  $\Lambda'$  is the thermal

characteristic length (Champoux and Stinson, 1990; Johnson *et al.*, 1987). Figure 3 shows the absorption coefficient of the porous medium which are listed in Tab. 2 and the thickness considered of porous material is 50 mm. The inverse acoustic characterization techniques of porous media were used with the apparatus impedance tube<sup>1</sup> measurements (Barbosa, 2017). Mainly, the effect from the lower airflow of PET wool contributes to the absorption coefficient slotted panel to maximum amplitude 0.8. It is noted that below 1 kHz the model predicted the highest amplitude for slotted acoustic panel.

Table 2. Acoustic properties of porous layer.

Porous material	$\sigma_r$ [Pa.s/m <sup>2</sup> ]	$\phi$ [-]	$\alpha_\infty$ [-]	$\Lambda$ [ $\mu$ m]	$\Lambda'$ [ $\mu$ m]
PET wool	4683.0	0.9	1.0	362.1	362.2

Table 3. Porosity and geometric parameters (in mm) used for the slotted acoustic panel.

Parameters	$\Theta$ [%]	$d$	$L$	$H$	$t$
Slotted panel	12.6	8.0	600.0	600.0	6.0

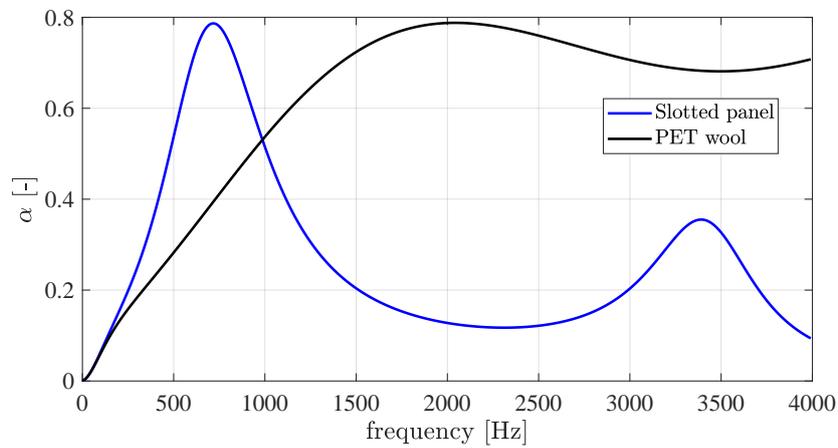


Figure 3. Absorption coefficient of the porous layer material and slotted panel for analytical modeling.

<sup>1</sup>diameter of tube: 107 mm and frequency range analysis: 200 Hz to 2 kHz

## 2.2 Experimental analysis

The LVA reverberation room (145 m<sup>3</sup>) can be seen in Fig. 4, and the samples were placed on the floor to determine the absorption sound. Calculations and technical procedures are follow the guidelines of ISO 354 (2003). The low-cost electronics equipment used for the experimental analysis is listed in Tab. 4. In this context, the ITA-Toolbox was employed for acoustic measurements and signal processing (Berzborn *et al.*, 2017). All technical researches could validate low cost equipment for acoustic measurement as Aguirre *et al.* (2016); Oliveira *et al.* (2016); Deshpande and Rao (2014); Portela (2005).

Table 4. List of low cost equipment for experimental analysis.

Equipment	Model	Quantity
Omnidirectional sound source	-	1
Sub-woofer 10"	-	1
Omnidirectional microphone	Behringer ECM 8000	4
Power amplifier sound	Behringer KM 700	1
Audio interface <sup>(1)</sup>	TASCAM 16x08	1

<sup>(1)</sup> Digital Analyzer Converter (DAC).

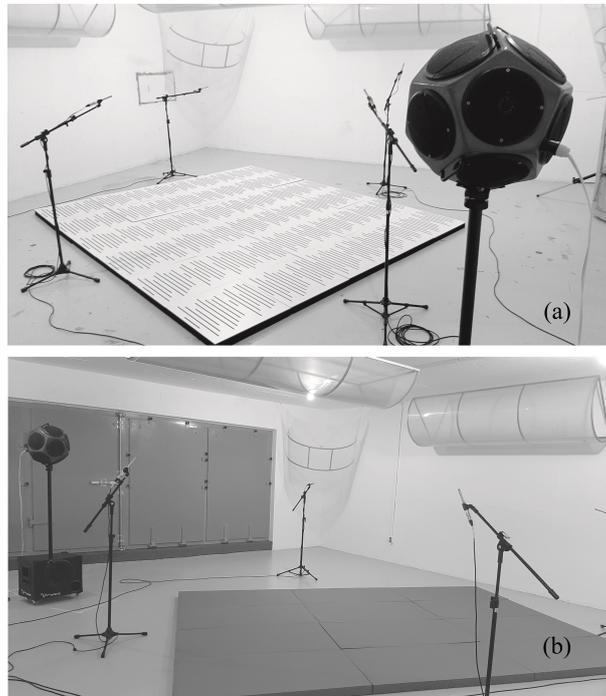


Figure 4. LVA reverberant chamber with samples installed: a) slotted panel and b) PET wool.

The characteristic of each acoustic sample for room reverberation test are listed in Tab. 5. Indeed the PET wool used for the samples has density 30 kg/m<sup>3</sup> and the wood MDF (*Medium Density Fiber*) has thickness of 6 mm. Also these commercial materials are employed in building (acoustic double wall of drywall) and woodwork (residential furniture), respectively.

Table 5. Samples used for the room acoustic analysis.

Description	Dimensions [mm]	Total area [m <sup>2</sup> ]
Slotted acoustic panel $\Theta = 12.6\%$	620 x 620 x 50	11.5
PET wool evolved by polyester fabric	620 x 1250 x 50	9.3

## 2.3 Room acoustics analysis

The meeting room, Fig. 5, where the acoustic panels were installed has 5.03 x 3.40 x 3.38 m (57.80 m<sup>3</sup>). The acoustic panels were fixed on the walls and ceiling of it. The quantity of acoustic materials and their characteristics are described in

Tab. 6. The engineering method for room analysis was chosen which is based on ISO 3382-2 (2017) and the measurement procedure is integrated impulse response. Two source positions and three microphones were used positions.

Table 6. Characteristic of acoustic panels installed in LVA's meet room.

Description	Dimensions [mm]	Total area [m <sup>2</sup> ]	Local
Slotted acoustic panel $\Theta = 12.6\%$	620 x 620 x 50	4.6	walls
PET wool evolved by polyester fabric	620 x 620 x 50	8.5	walls
PET wool evolved by polyester fabric	620 x 1250 x 50	4.6	ceiling

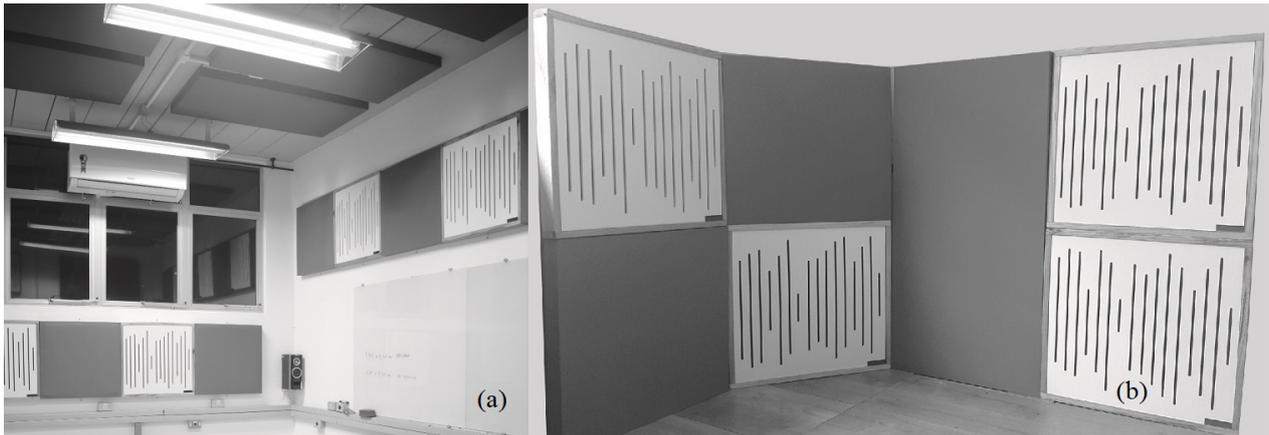


Figure 5. Acoustic treatment proposed: (a) LVA's meeting room and (b) samples.

### 3. RESULTS AND DISCUSSION

The first experimental validation is the calculation of sound absorption coefficient for the proposed samples in reverberation room. Figure 6 emphasized for slotted acoustic panel that the optimum frequency range is from 400 Hz to 1 kHz which amplitude varies since 0.8 to 1.0. For PET wool samples, the highest absorption occurs for 800 Hz to 1.25 kHz. It is possible to notice above the frequency of 1 kHz the tendency of the curve to be flat in the amplitude range between 0.7 and 0.8. In fact, using both types of samples becomes a good solution for a wide frequency range, i.e., from 400 Hz to 4 kHz.

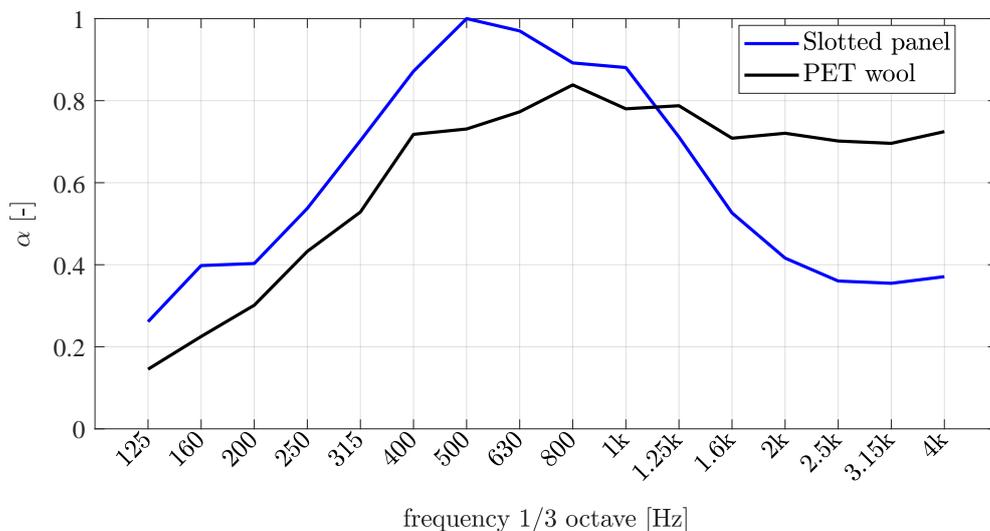


Figure 6. Sound absorption coefficient: slotted acoustic panel and PET wool.

Figure 7 shows the T20 parameter of the meeting room with a good performance for the proposed acoustic treatment with the developed acoustic panels. Especially above the frequency of 250 Hz it is noted that the T20 is less than 0.5 s.

Also Fig. (8) shows parameter D80 emphasizing the optimal amplitude close to 1.0. The result calculated for STI is 0.71 and 0.84, without and with the acoustic treatment of the analyzed meeting room, respectively.

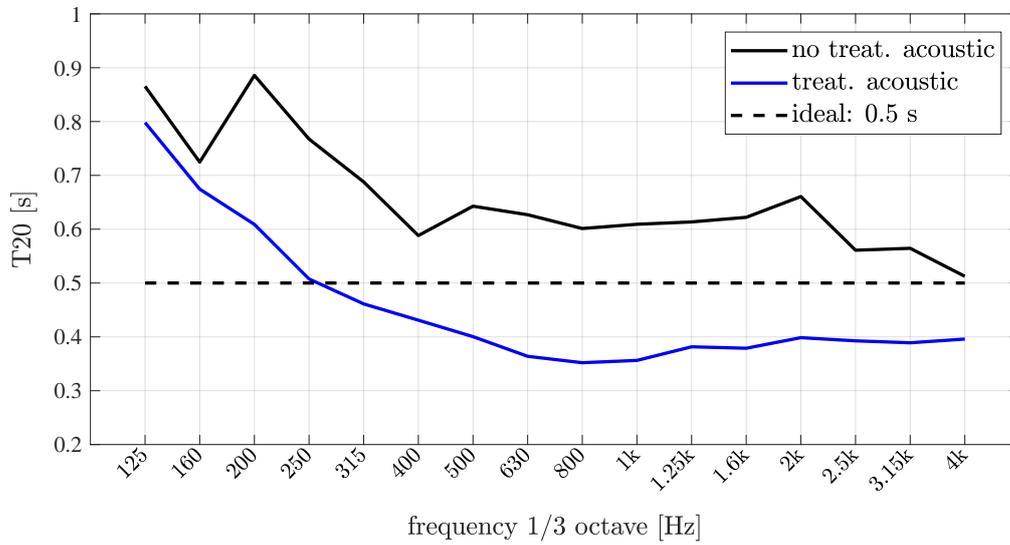


Figure 7. Objective parameter T20: effect of the acoustic treatment.

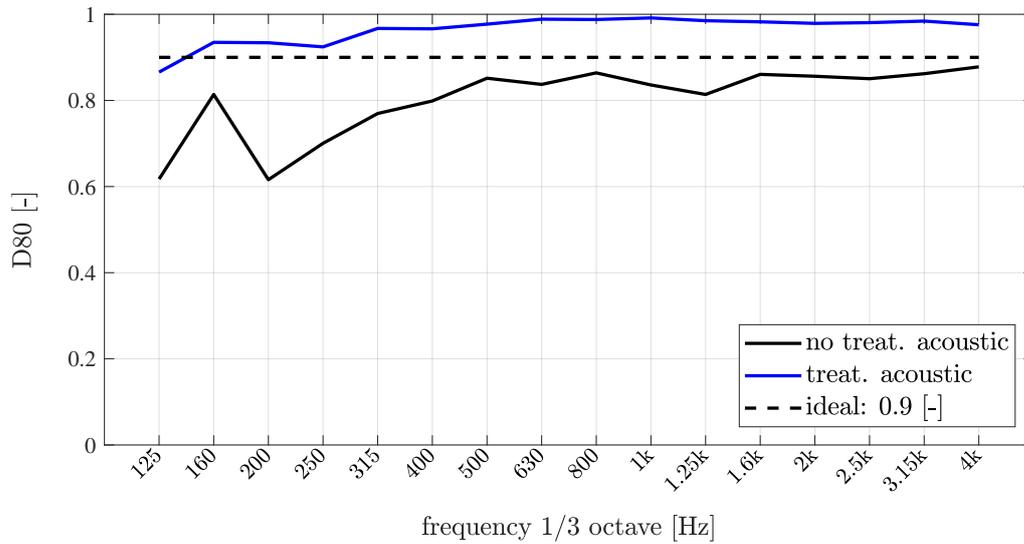


Figure 8. Definition parameter D80: effect of the acoustic treatment.

#### 4. CONCLUSIONS

In this work, the acoustic performance of a grooved panel was developed and evaluated. The acoustic absorber consisted of combining grooved MDF wood panels and PET wool absorbent material. The optimal frequency range chosen was the human voice, which is between 500 Hz and 2 kHz. The constructed samples were evaluated both in a reverberant chamber and in a meeting room. Thus, this environment was analyzed before and after the installation of the sound absorber and it was verified that the developed acoustic solution presented an excellent control of the reverberation time of the room.

#### 5. ACKNOWLEDGEMENTS

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