Experimental study on the effect of row spacing in the sound absorption capacity of PET based baffle arrangements

Estudo experimental acerca da influência do espaçamento na absorção Sonora de arranjos de baffles a base de PET

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Abstract

In rooms with unsatisfactory auditory comfort, materials can be added to reduce the reflection of sound energy. These materials can be wools shaped in the form of panels, baffles or clouds, and the type of mounting in relation to the reflective surface greatly impacts their sound absorption performance. Therefore, the objective of this study is to verify the effect of row spacing in the sound absorption capacity of PET baffle arrangements. Sound absorption tests were performed in a reverberation room, testing PET wool baffles with a height of 50 cm and mounted in rows spaced 25 cm, 50 cm, 75 cm and 100 cm apart. The sound absorption results strongly correlate that the increase in row spacing in increments of 25 cm achieves considerable gains in sound absorption capacity of the baffles at each configuration starting from a spacing of 25 cm and up to 100 cm.

Keywords: Baffles. Fibrous sound absorbers. PET wool. Sound absorption.

Resumo

Em ambientes com qualidade acústica insatisfatória, materiais podem ser inseridos para reduzir a energia sonora refletida. Estes materiais podem ser constituídos por lãs na forma de painéis, baffles ou nuvens, sendo que o tipo de instalação, em relação às superfícies reflexivas, influencia na capacidade de absorção sonora. Desta forma, o objetivo deste trabalho é o de avaliar a influência do espaçamento entre fileiras de baffles a base de PET na sua capacidade de absorção sonora. Ensaios para verificação dos coeficientes de absorção sonora foram realizados em uma câmara reverberante, analisando baffles de 50 cm de altura, montados com espaçamentos de 25, 50, 75 e 100 cm. Os coeficientes de absorção sonora são fortemente relacionados com o incremento no espaçamento, com adições de 25 cm, para o intervalo de 25 a 100 cm de espaçamento, sendo que houve ganhos de desempenho entre cada aumento de espaçamento.

***Palavras-chave**: Baflles. Absorvedores sonorous fibrosos. Lã de PET. Absorção sonora.*

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Recebido em 19/04/23
Aceito em 23/05/23

Introduction

Many civil construction materials are composites containing polymers that decrease environmental impact with the use of recycled or repurposed materials. An application example is in noise control in internal spaces and studies have been conducted to develop composite materials that are both efficient and have lower environmental footprints (SCHEIRS, 1998; KARAYANNIDIS; ACHILIAS, 2007; ARENAS; CROCKER, 2010; LEPOITTEVIN; ROGER, 2011; GHOTBI *et al*., 2015; RUSSELL; SMITH, 2016; SINGH; MUKHOPADHYAY, 2016; MWANZA; MBOHWA, 2017; CAO *et al*., 2018).

In internal spaces, acoustic quality depends on adequate sound absorption. This is achieved through devices installed on surfaces, the quantity and arrangement of discrete objects present and the characteristic dimension and geometry of the space (COWAN, 2007; BARRON, 2009; KLEINER; TICHY, 2014; EVEREST; POHLMANN, 2015; COX; D'ANTONIO, 2017).

Proper space acoustic design includes the use of porous or fibrous materials that can be installed directly on surfaces or as discrete objects shaped as clouds or baffles. These devices modify the sound field through sound absorption, controlling the intensity and spectrum or reflected sound waves to ensure acoustic characteristics that allow the use of the space for its activity in purpose (SZYMANSKI, 2008; KLEINER; TICHY, 2014). Traditional acoustic materials used are glass and rock wools, which remain attractive despite new natural and more innovative options. Glass wool, for example, has attractive cost and reasonable environmental impact indices such as an embodied energy (EE) of around 35 MJ/kg and global warming potential (GWP) of around 0.6 $kgCO_2eq/FU$ to 1.2 $kgCO_2eq/FU$. Rock wool is widely used as thermal and acoustic insulation due to its good performance and low cost but is potentially hazardous to human health. Rock wool can cause skin irritation and, when inhaled, can deposit in lung alveoli (DRENT *et al*., 2000; YU; KANG, 2009; FIREMAN, 2014; YILMAZ, 2016; PEDROZO; DE BRITO; SILVESTRE, 2017; GRAZIESCHI; ASDRUBALI; THOMAS, 2021).

Compared to such well-established materials, current new trends make use of natural and artificial composites for sound absorption. These materials tend to be of ecological origin, biodegradable, recyclable and with a wider range of uses. For example, recycled textile fibers have an EE index of 16 MJ/kg, similar to glass wool, and are environmentally attractive due to high renewable embodied energy content (easily overpassing 50%) and carbon sink capacity, however at a price three times higher (ARENAS; CROCKER, 2010; GHOTBI *et al*., 2015; RUSSELL; SMITH, 2016; SINGH; MUKHOPADHYAY, 2016; PEDROZO; DE BRITO; SILVESTRE, 2017; CAO *et al*., 2018; GRAZIESCHI; ASDRUBALI; THOMAS, 2021). Despite higher cost, eco-materials such as textile blankets manufactured from recycled PET fibers are still attractive due to the re-purposing of a non-renewable material with considerable polluting potential to the environment. The lower environmental impact, acoustic performance and reduced fire reaction are sufficient to induce a favorable market placement (ARENAS; CROCKER, 2010; GHOTBI *et al*., 2015; RUSSELL; SMITH, 2016; SINGH; MUKHOPADHYAY, 2016; GIL *et al.*, 2017; KLIPPEL FILHO *et al.*, 2017; PEDROZO; DE BRITO; SILVESTRE, 2017; CAO *et al*., 2018; GRAZIESCHI; ASDRUBALI; THOMAS, 2021).

Sound absorbing materials are important elements that facilitate and allow practical sound control. These elements can be made of fibrous or porous materials and attached to ceilings and walls to combine aesthetics and functional use of the space. This is accomplished by adjusting the intensity and spectrum of impacting sound waves to ensure that only a controlled fraction of sound energy is reflected back to the space, thus providing ideal conditions for vocal communication (VIGRAN, 2008; BARRETT; ZHANG, 2009; LECHNER, 2012; KLEINER; TICHY, 2014; KUTTRUFF, 2017).

The form of installation of materials onto reflective surfaces affects their sound absorbing capacity. For example, if installed parallel to the surface they form acoustic cloud panels, or if suspended perpendicular to the floor they become acoustic baffles. Baffles are particularly efficient since both sides and their thickness are exposed to sound waves, which allow a greater sound-absorbing capacity than cloud panels for the same amount of material. However, baffles must be installed with row spacing wider than the height of each element to prevent acoustic shadowing (COPS, 1985; KANG, 2002; EGAN, 2007; MOMMERTZ, 2008; SZYMANSKI, 2008; COX; D'ANTONIO, 2017).

Baffle sound absorption is a function of combined total area and row spacing of the system. For most cases, wider spacing up to a limit of twice the height of the material produces the greatest sound absorption. However, when sound absorption coefficients are evaluated and made available by product manufacturers, results show considerable variations and inconsistencies probably due to mistakes in testing methodologies, calculations, improper normalization or results´ presentation (COPS, 1985; KANG, 2002; POHL, 2011; KNAUF-AMF, 2019; ECOPHON, 2022). Examples of variabilities in results were found in sound absorbing coefficients available from Knauf-AMF (2019) and Ecophon (2022) panel manufacturers. For the same spacing of 600 mm, baffles of the same model and thickness had sound absorption capacities decreased when the height was increased from 300 mm to 600 mm. However, another model had the opposite result for the same spacing with increased sound absorption when the baffle height increased. Another example arose when maintaining model and spacing but varying the thickness of baffles. Baffles with heights of 300 mm had the expected behavior of fibrous materials and increased sound absorption as the thickness increased. But for baffles 600 mm in height, the opposite trend was reported with thinner baffles producing higher sound absorption coefficients. The variation in results with respect to installation configurations and baffle material occurred even with samples of similar composition and with standardized testing methodologies from ISO 354 (INTERNATIONAL…, 2003). This pointed out the need of further and more detailed studies on samples from a single supplier with respect to geometry and installation configurations.

Thus, the objective of this study was to verify the effect of spacing between rows of baffles made from PET wool on sound absorption capacity. This was conducted in experiments under laboratory conditions.

Methodology

The study was conducted at the Acoustics Laboratory of itt Performance – located at the Universidade do Vale do Rio dos Sinos, São Leopoldo/Brasil and consisted of two phases.

(a) Phase I conducted the physical characterization of the material and prepared the panels to be installed as baffles. Three distinct compositions of a PET wool-based material were tested with a single thickness and 3 different densities. This provided a wide range of test data for each installation configuration; and

(b) Phase II performed tests in a reverberation room to determine sound absorption coefficients for the different baffle compositions and row spacing.

Test samples

Baffles were manufactured through dry laying and thermal consolidation with contents of 70% PET fiber and 30% bicomponent fiber. The PET fiber was produced from recycled material with round cross-section, density of 1.39 g/cm³, linear density of 7 dtex and length of 64 mm. The bicomponent fiber was produced from a PET core and circular CoPET sheath, density of 1.35 g/cm³, linear density of 4 dtex and 51 mm in length. The melting point of the PET fiber was 265 °C while the bicomponent fiber was 110 °C. The fiber contents were in accordance with the recommendations of Pourmohammadi (2007) and Kücük and Korkmaz (2015).

The PET wool baffles were supplied by Planalto Têxtil and had dimensions of 100 x 50 cm. The physical characteristics of the baffles were measured at the Acoustics Laboratory of itt Performance under standard atmospheric conditions from recommendations of standards NBR 13908 (ABNT, 1997), NBR ISO 139 (ABNT, 2008), NBR 12984 (ABNT, 2009), ISO 5084 (INTERNATIONAL…, 1996) and previous setup of Mao, Russel and Pourdeyhimi (2007). Average results on thickness, mass per unit area, apparent density and porosity are shown in Table 1.

The physical characteristics showed some deviations from requested specifications. These were expected at different portions of non-textile materials as noted by Mao, Russell and Pourdeyhimi (2007) and were the result of variations in processes, equipment and quality control in the manufacture of the material.

Table 1 – **Average results of thickness, mass per unit area, apparent density and porosity of the PET wool based baffle samples**

Baffle sample	Thickness (mm)	Mass per unit of area (kg/m²)	Apparent density (kg/m³)	Porosity (%)
65 mm and 30 kg/m³	64.75	1.93	29.78	98.00
65 mm and 35 kg/m³	64.49	2.23	34.62	97.00
65 mm and 40 kg/m³	64.27	2.51	39.08	97.00

Sound absorption measurement procedures

Sound absorption coefficients of the samples and reverberation time with and without the samples were measured in the reverberation room at the Acoustics Laboratory of itt Performance. The chamber itself and test procedures were in accordance with the recommendations of standard ISO 354 (INTERNATIONAL…, 2003). The room had a volume of 200.3 m³, total surface area of 218.0 m² and was equipped with 20 acrylic diffusers with a total surface area of 22.6 m². Samples were placed with Type J mountings and one composition at a time was evaluated, in simulation of a realistic scenario. Baffles were installed vertically from the floor of the room and placed in rows 50 cm in height. Spacing between rows for each test were of 25 cm, 50 cm, 75 cm and 100 cm, designated as configurations J250, J500, J750 and J1000, respectively. The type of mounting made use of a plywood structure coated in plastic, 1.0 cm in thickness and 50 cm in height placed at two ends of the row and wires to support the upper portion of the baffles.

Standard testing also required that the baffle systems be tested in 2 to 3 rows and with sufficient material to cover de 10 m² to 15 m² of the floor of the reverberation room. This requirement was not possible to fulfill for configuration J250 due to the narrow spacing requiring additional rows to reach the minimal area. Full testing parameters with the dimensions and number of baffles, total area of the samples and area of floor projection by the system are shown in Table 2 for all materials and configurations.

The identification of each configuration was designated by its thickness, density and spacing. Sample mountings for each configuration are shown in Figure 1 with one of the corners of the room set as the point of reflection and containment of the samples on their mountings.

Measurements were taken with a Class 1 Brüel&Kjaer sound analyzer model 2270. The analyzer was equipped with a ½" microphone model 4189 and pre-amplifier model ZC0032. Sound emission was conducted with a Brüel&Kjaer dodecahedron speaker model 4292-L and power amplifier model 2734-A. Sound was emitted from 3 positions on the floor of the room while 4 reception points, for each source position, were selected 1.2 m from the floor for a total of 12 measurement locations. Reverberation time was obtained from the interrupted method with pink noise and 3 decays per position. Measurements were taken in 1/3 octave bands with central frequencies varying from 100 Hz to 5,000 Hz. Once the sound absorption coefficients were obtained, the weighted sound absorption coefficient (α_w) was calculated per the procedures of standard ISO 11654 (INTERNATIONAL…, 1997), allowing a facilitated comparison between the different sample compositions, although it is not a parameter that describes accurately the frequency performance of the material and serves only for comparison purposes.

Results and discussion

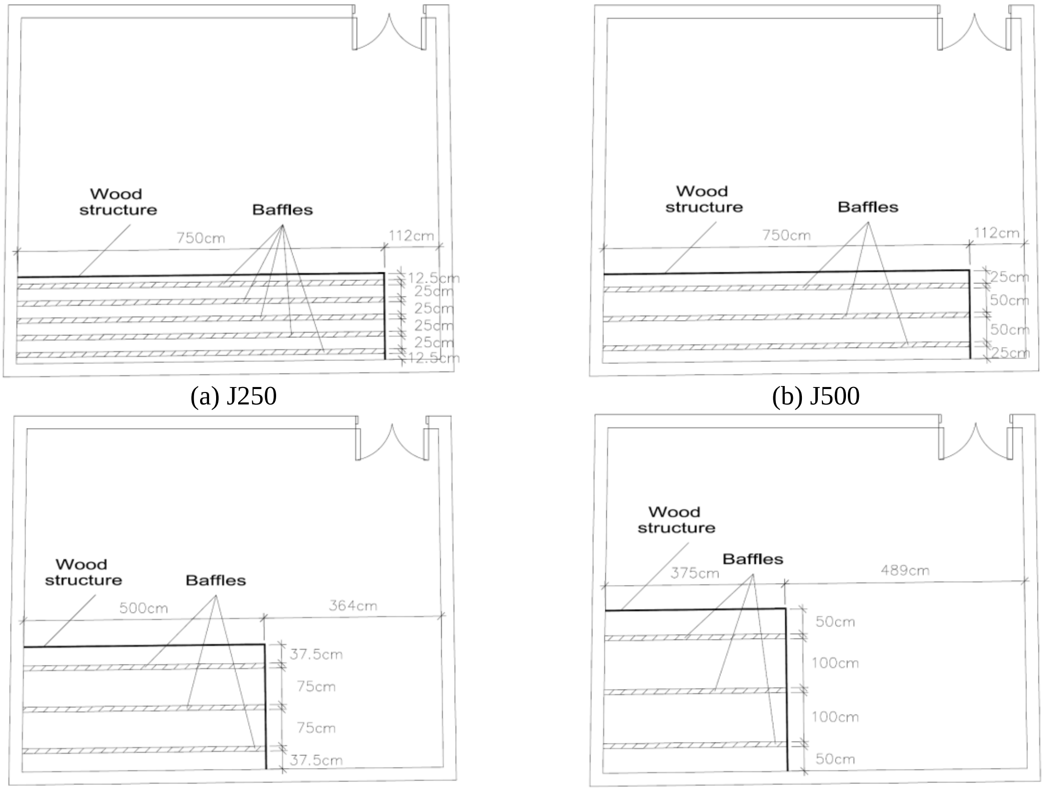
Figure 2 presents sound absorption coefficients in 1/3 octave bands for frequencies between 100 Hz and 5,000 Hz in samples 65 mm thick with three densities and four installation configurations.

The sound absorption coefficient spectrum pointed to an overall increase with respect to frequency for most sample compositions and spacing. However, some fluctuations were noted at frequencies between 250 Hz and 630 Hz, that can be explained by the high uncertainty expected around the Schroeder Frequency, explained by Skalevik (2011), of the reverberation room (around 350 Hz), and a slight dip at the 4,000 Hz range.

Table 2 – **Baffle rows mounting types and characteristics**

Mounting type	Rows		Baffles	Area of floor projection (m²)
	Spacing (cm)	Quantity	Area (m²)	
J250	25	5	18.75	11.25
				12.19
J500	50	3	11.25	12.38
				12.94
J750	75	3	7.50	12.00
				12.37
J1000	100	3	5.62	11.81
				12.09

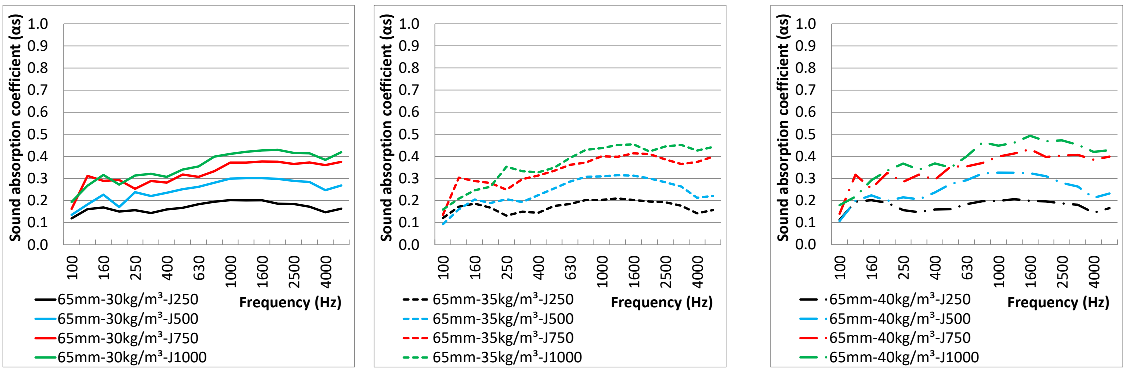
Figure 1 - **Baffle arrangement disposition on the mounting type**



(a) J250 (b) J500

(c) J750 (d) J1000

Figure 2 - **Sound absorption coefficients with respect to frequency and row spacing in baffles 65 mm thick and densities of: (a) 30 kg/m³, (b) 35 kg/m³ and (c) 40 kg/m³rot**

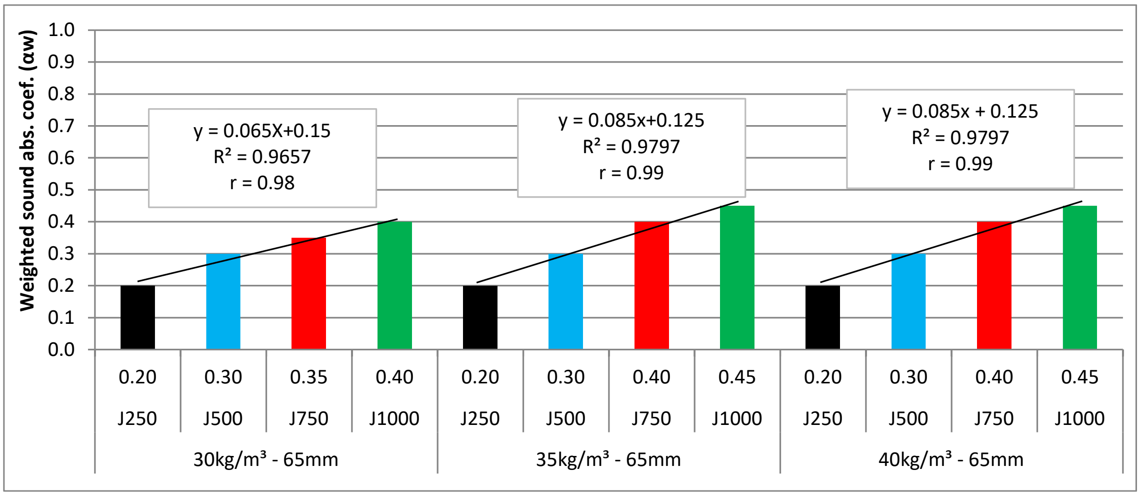


(a) 30 kg/m³ (b) 35 kg/m³ (c) 40 kg/m³

The effect of row spacing for all three densities of material tested was of an increase in sound absorption with increasing baffle spacing across most of the frequency bands of this study. Some outlier variations were noted at the spacing of 25 cm and with 75 cm slightly outperforming wider spacing at low frequencies but, in general, sound absorption coefficients increased with row spacing increase, for the tested interval. This result was in agreement with Egan (2007) in that wider spacing allows a wider exposition angle of baffle surfaces to the sound field, which results in less shadowing between elements and increases incidence of sound waves on the material. In addition, it is expected that this behavior tends to neutralize and change direction at a determinate row spacing, even with the decrease in shadowed material area, because of the reduction of material, and consequently sound absorption capability, per square meter.

Figure 3 shows weighted sound absorption coefficients for the 65 mm thick samples grouped with respect to density. This allowed the analysis of the effects of spacing within the same composition.

Figure 3 - **Effect of row spacing influence on weighted sound absorption coefficients for baffles 65 mm in thickness**



Weighted sound absorption coefficients increased for all compositions as row spacing increased. This was an expected result from the spectral analysis of frequency bands as decreased shadowing occurred between adjacent rows of baffles. The Pearson correlation coefficient suggested strong linear relations with slopes of 0.065 and 0.085 for the best and worst cases, respectively, in 25 cm spacing increments. In addition, the coefficients of determination were high, with the lowest value confirming that 96.57% of the variations of weighted sound absorption coefficient were related to baffle row spacing in the experimental data. The effect of density of material density was only observed with spacing of 75 cm and 100 cm, with slight increases in weighted sound absorption coefficients with higher densities.

Following the spectral and weighted analyses of the sound absorption coefficient, with respect to material density and row spacing, the weighted coefficients were compared with respect to the amount of material used per unit of area. For this analysis, the number of baffles and consequently their area were considered. It should be noted that, as presented in Table 2, their area was selected in order to satisfy the constraints of the installation configuration and occupied area on the floor of the room. Results are shown in Figure 4 as the weighted sound absorption coefficient with respect to the area ratio of baffles and occupied ceiling surfaces which varied in accordance to row spacing.

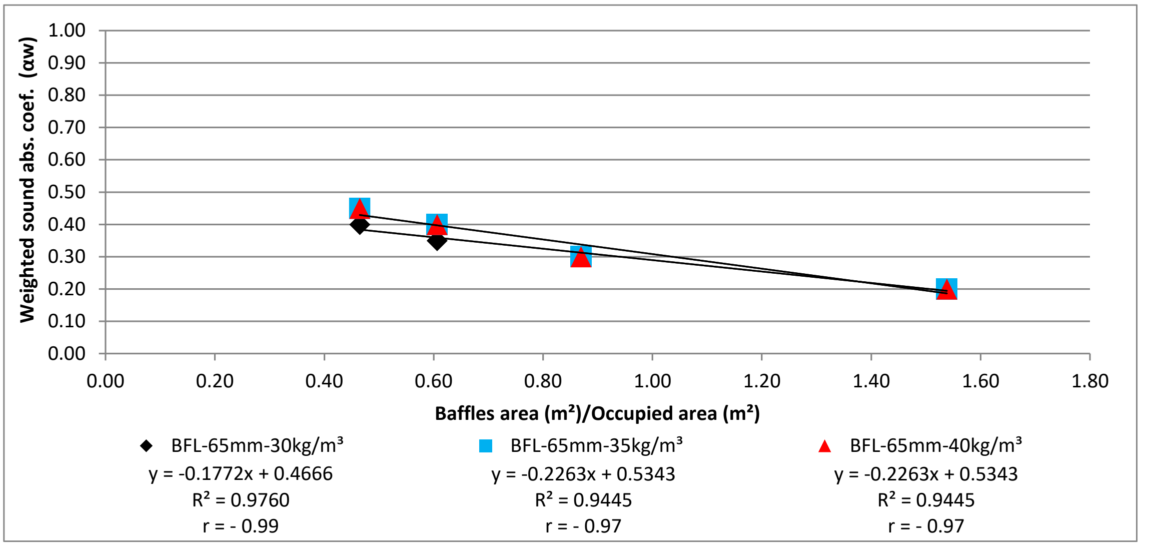
Results showed that, for the baffle configurations tested (ranging from 25 to 100 cm of row spacing), the material density had a higher effect with smaller area ratios (baffles area/occupied area) and higher densities yielded higher weighted sound absorption coefficients. The Pearson correlation coefficient (r) presented a strong decreasing trend, meaning that as the number of baffles increased per unit of occupied area, less sound absorption capacity was achieved. In this case, the coefficients of determination were also elevated: at worst, 94.45% of the variations presented in the relation between the two parameters were in conformity with the data.

Additionally, taking the variation in area ratio (baffles area/occupied area), as this ratio became smaller and approached the limit of 0.46 m² of this study, the rate of increase in weighted sound absorption coefficient decreased as well. This suggested that there might be a limit value in area ratio which would result in a maximum, stable or inflection point in behavior for the dataset available. This, as described before, is due to the lack of material area per square meter when the incidence angle in the diffuse sound field is prioritized (zero row shadowing; approaching sound waves angle near 90 degrees to the baffle surface). Nonetheless, the results corroborated with hypothesis of Egan (2007), which predicted the occurrence of shielding between baffle rows when the ratio of absorbers exposed surface area to ceiling area exceeded 0.5, and this was indeed observed in the plotted measured data.

Conclusions

Baffles are flexible sound absorbing systems with attractive applicability for sound proofing in internal spaces despite the relative lack of studies in this area. Thus, the objective of this study was to evaluate experimentally the effect or row spacing on the sound absorption capacity of PET fiber-based baffles.

Figure 4 - **Weighted sound absorption coefficient with respect to the ratio of baffles and ceiling areas for 65 mm thick baffles**



Baffle arrangements were proposed with three variations of material density and 4fourinstallation configurations. Results pointed to an increase in sound absorption coefficient as frequency bands increased. This increase was observed in differing rates for all row spacing tested and was expected based on previous studies.

Density of baffle material showed some effect under some row spacing with slight increases in sound absorption capacity with increasing density. However, variations in density had negligible effects for shorter row spacing. This suggested that less dense materials could be used for the same performance and, by extension, less raw materials would be used in their production as a positive environmental and financial corollary.

Baffle row spacing was shown to be the main factor in the sound absorption capacity of the material. A strong linear correlation was found in the sound absorption coefficient of baffles 50 cm high with respect to increases of 25 cm in spacing for the tested spacing from 25 cm to 100 cm. This result was also expected on spacing wider than baffle height based on previous studies. Wider row spacing allowed a wider angle of exposure to each individual baffle panel and resulted in more efficient systems. Additionally, as spacing increased from 25 cm to 100 cm, less material was used per square meter for increased sound absorption capacity. Thus, this study confirmed the behavior of PET-fiber baffle panels for sound absorption both with respect to spacing and material composition, and a similar behavior must be expected with other fibrous materials in the same conditions.

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Ambiente Construído
Revista da Associação Nacional de Tecnologia do Ambiente Construído
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