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Optimizing Acoustic Privacy in Open-Plan Offices: A Simulation-Based Study of Desk Partition Designs and Material Choices

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ABSTRACT

Open-plan offices are often criticized for irrelevant speech, negatively impacting productivity and well-being. Therefore, sound-absorbing screens are widely used to enhance acoustic privacy in workplaces. Yet, isolating their acoustic impact from other elements, like ceilings and wall treatments, presents a challenge. Quantifying the role of partition design in affecting the ISO 3382-3 and ISO 22955 room criteria needs further investigation. This study explores how different desk screen materials and configurations influence the reduction of speech propagation throughout the environment. The method involves the acoustic calibration of a digitally reconstructed full-scale model of an existing open plan with in-field measurements. Using advanced simulation tools, i.e., a hybrid approach combining finite-element and ray-tracing modeling, the work evaluates the impact of partition height and absorption coefficients on key acoustic parameters, including the rate of speech level spatial decay per distance doubling ($D_{2,S}$) and the comfort distance (r_c). The study's primary outcomes are compared with experimental data found in the literature concerning experimental studies on sound-absorbing surfaces in open-plan offices.

Keywords: *open-plan offices, speech spatial decay, wave-based simulations, multi-resonator screens.*

1. INTRODUCTION

Open-plan offices have been increasingly spread as workplace design. However, they are often associated with significant acoustic challenges. Noise, particularly intelligible speech, has been consistently identified as a major source of distraction and annoyance for employees [1, 2]. The propagation of speech sound within these environments can negatively impact cognitive performance, reduce speech privacy, and decrease overall work satisfaction. Consequently, the acoustic quality of open-plan offices is a critical factor influencing the productivity and well-being of occupants [3, 4].

To evaluate and characterize the acoustic conditions in open-plan offices, the ISO 3382-3 standard provides a framework for measuring room acoustic metrics [5]. These single number quantities include the spatial decay rate of speech ($D_{2,S}$), the A-weighted sound pressure level of speech at 4 meters ($L_{p,A,S,4m}$), and the distraction distance (r_D), which is based on the spatial decay of the Speech Transmission Index (STI). These metrics quantify the ability of open-plan offices to attenuate speech levels and reduce the intelligibility across workstations.

Notwithstanding the robustness of ISO 3382-3 criteria, prediction models for the design phase of open-plan offices need further investigation. Moreover, they are influenced by various design factors, such as furniture arrangement, room geometry, and the sound absorption characteristics of surfaces like ceilings, walls, and screens. In this context, numerical models can provide substantial benefits for predicting speech spatial decay.

Recent advancements in computational power have facilitated the use of hybrid wave/ray-based simulation methods for room acoustics, especially for non-sabinian spaces, such as open-plan offices. These techniques are increasingly applied to large-scale environments, allowing accurate computation of wave phenomena, such as the edge diffraction caused by screens and partitions.

This paper aims to contribute to a deeper understanding of the acoustic performance in open-plan offices by assessing the impact of screens' features on speech decay criteria. This work is intended to extend the findings of previous research by the same authors [6].

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2. METHOD

This study evaluates the acoustic impact of multi-resonator (MR) screens in an open-plan office within a virtually reconstructed scenario, in comparison with traditional screens (glass and porous panels). The assessment is carried out using hybrid wave/ray-based techniques and comparing the outcomes with the initial configuration without screens calibrated on experimental data.

2.1 The multi-resonator unit module

A unit module was designed for a semi-transparent partition, consisting of nine Helmholtz resonators optimized to absorb in the frequency range important for the speech signal (500 – 1500 Hz) [7, 8]. Finite element modeling (FE) allowed for optimizing absorption by adjusting cavity and aperture sizes within a 100 mm cylindrical sample. Then, 3D printed samples were manufactured and tested in laboratory using impedance tubes, according to ISO 10534-2 standard (see Fig. 1) [9]. The unit module is a cylindrical sample intended for replication in a semi-transparent partition screen.

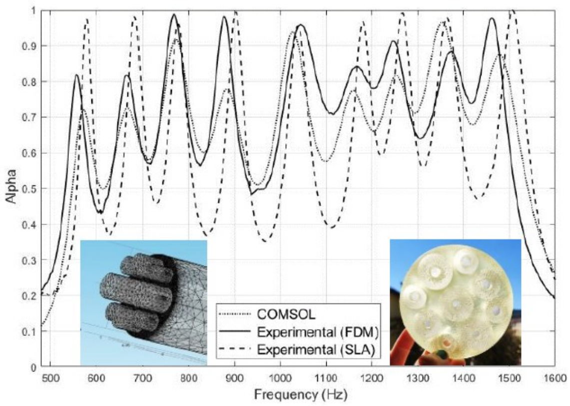

Figure 1. Sound absorption across the frequency of the multi-resonator unit module. Experimental values are compared with FE simulations.

The acoustic impedance of the single neck-embedded resonator is expressed as:

$$Z = AS_n(Z_n + Z_c + 2\sqrt{2\omega\rho_0\eta} + i\omega\rho\delta i)$$

where:

- $A = \pi(d_c/2 + b)^2$ is the whole frontal area of the sample in-cluding the wall thickness;
- Z_n is the acoustic impedance of the neck of each resonator;
- Z_c is the acoustic impedance of the cavity of each resonator;
- $S_n = \pi(d_n/2)^2$ is the neck area of each resonator;
- $2\sqrt{2\omega\rho_0\eta}$ e $i\omega\rho\delta i$ are end corrections.

2.2 The open-plan office

The selected environment is a recently constructed open-plan office with a volume of approximately 750 m^3. As it often occurs in this kind of environments, the room exhibits a notable geometric disproportion (33 meters long vs 7.5 m large), leading to an anisotropic sound field. Consequently, the reverberation time is not sufficient to describe the acoustic conditions and comfort in the space. The application of ISO 3382-3 is essential for quantifying spatial speech level decay using parameters such as $D_{2,S}$, $L_{p,A,S,4m}$, and r_c. The office hosts 26 workstations (approximately 10 m² per workstation) and adheres to the "small amount of collaborative work" classification according to ISO 22955. The workstations are arranged in islands separated by 3 m, with 1 m-high storage units between them. The office features a suspended ceiling composed of porous mineral fiber and perforated gypsum tiles. The design follows standard architectural practices without specific acoustic optimizations beyond ceiling treatments. For instance, the space under study lacks effective acoustic barriers. As such, this environment serves as an appropriate baseline for evaluating the introduction of various types of screens through numerical modeling.

2.3 ISO 3382-3 measurements

In-field acoustic measurements were performed to determine the speech spatial decay throughout the space. The setup included pink noise as the test signal, a high-SPL dodecahedral loudspeaker, and an NTI Audio MA220 microphone. The microphone was moved to seven locations along a linear measurement path across the workstations, while the omnidirectional sound source was positioned at one end of the path. The extracted experimental data were analyzed using ISO 3382-3 criteria.

2.4 Hybrid simulation setup

The 3D modeling phase of this study adhered to best practices, striking a balance between physical accuracy and computational feasibility. The air gap between the suspended and structural ceiling was omitted; details smaller than 0.1 m were not included; closets between workstations were represented as simplified box structures.

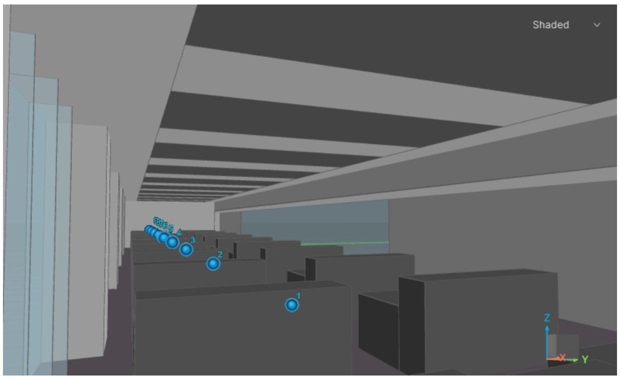

Figure 2. View of the 3D virtual model for the hybrid wave/ray-based simulations [10].

The virtual 3D model of the office was developed using SketchUp 2022. The surfaces, totaling approximately 1250 m², were categorized into primary room components: floor, walls, windows, furnishings, and ceiling surfaces. The model was subsequently imported into the Treble Acoustic simulation suite through the specific plug-in. The room acoustic simulator applies a hybrid computational approach combining wave-based and geometrical acoustics methods [10]. The low-frequency domain is modeled using the discontinuous Galerkin finite-element (DGFEM) method, i.e., directly solving the numerical wave equation exploiting high-performance computing clusters utilizing GPUs. Surface boundary conditions were defined using complex, frequency-dependent impedance values. For high-frequency modeling, the geometrical acoustics (GA) solver used a hybrid approach. Initial specular reflections were calculated via the Image Source Method (ISM), while scattered energy contributions were accounted for using the Ray-Radiosity (RR) method. The RR method produced energy histograms per octave band, which were then processed into impulse responses. These were subsequently combined with ISM results to generate a broadband impulse response. The transition frequency (TF) between the wave-based and GA methods was set to 500 Hz. With an office volume of 750 m³ and a measured reverberation time of 0.69 s (averaged over octave bands from 125 Hz to 8000 Hz), the selected TF was approximately 8 times higher than the Schroeder frequency (~60 Hz). Each simulation required approximately 5 minutes.

Boundary conditions were assigned based on materials present in the office, as referenced in the software database, scientific literature, and manufacturer data. The wave-based model necessitated a conversion of absorption coefficients (α) into complex impedance values, performed using established mathematical procedures [11]. The ray-based model incorporated energy-based $\alpha random$ values, while scattering coefficients (s) were assigned according to the software guidelines. The GA solver was configured with an impulse response length of 1000 ms and 40,000 rays.

Table 1. Boundary conditions assigned to the 3D model's surfaces. The wave-based part of the algorithm converts the frequency-dependent absorption coefficients α into complex acoustic impedances, while the ray-based part of the algorithm directly employs the absorption coefficients α and the scattering coefficients s given.

Materials	α_{random}							s
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	
Floor	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.05
Walls (plasterboard)	0.15	0.16	0.15	0.13	0.12	0.10	0.10	0.05
Windows	0.11	0.10	0.09	0.09	0.09	0.09	0.09	0.05
Furnishing	0.06	0.09	0.15	0.20	0.20	0.10	0.10	0.30
Porous ceiling tiles	0.41	0.63	0.86	0.94	0.90	0.60	0.60	0.05
Perforated ceiling tiles	0.73	0.81	0.83	0.82	0.79	0.70	0.60	0.15
Glass screens	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.20
Porous screens	0.37	0.81	0.83	0.82	0.79	0.70	0.60	0.10
MR screens	0.18	0.32	0.76	0.84	0.37	0.20	0.18	0.20

The 3D model was calibrated on the experimental data from ISO 3382-3 measurements in the no-screen configuration. The primary calibration metric was $D_{2,S}$. The calibration involved fine-tuning the surface boundary conditions within reasonable material property ranges. Simulations were iterated until the difference between measured and simulated $D_{2,S}$ values was reduced to 1 dB.

4. RESULTS

The present section presents the results of numerical simulations carried out with different screens, varying:

- materials (glass, porous, and MR screens)
- height (0.0 m. 1.3 m, 1.7 m).

Table 2 provides the outcomes in terms of ISO 3382-3 room criteria compared with experimental data.
Figures 3 and 4 show the same data compared with data from previous literature on screens effect [12]. Outcomes show that simulated $D_{2,S}$ and $L_{p,A,S,4m}$ of the present study are lower than the previous works.

Table 2. Simulated ISO 3382-3 acoustic metrics in the open-plan office under study. The starting scenario without screens (3D virtual model calibration) is compared with scenarios simulating the effects of glass, porous, and MR screens on desks (overall height 1.7 m above the floor level).

	$D_{2,S}$ (dB)	$L_{p,A,S,4m}$ (dB)	r_c (m)	r_D (m)
Without screens (measurements)	5.9	50.8	7.9	10.5
Without screens (calibration)	5.2	49.7	7.5	9.4
Glass screens (h = 1.3 m)	5.6	48.8	6.4	7.7
Porous screens (h = 1.3 m)	5.2	48.3	6.2	7.8
MR screens (h = 1.3 m)	5.3	48.0	5.9	7.8
Glass screens (h = 1.7 m)	6.4	48.1	5.6	6.7
Porous screens (h = 1.7 m)	6.7	47.6	5.2	6.4
MR screens (h = 1.7 m)	7.2	47.0	4.9	6.4

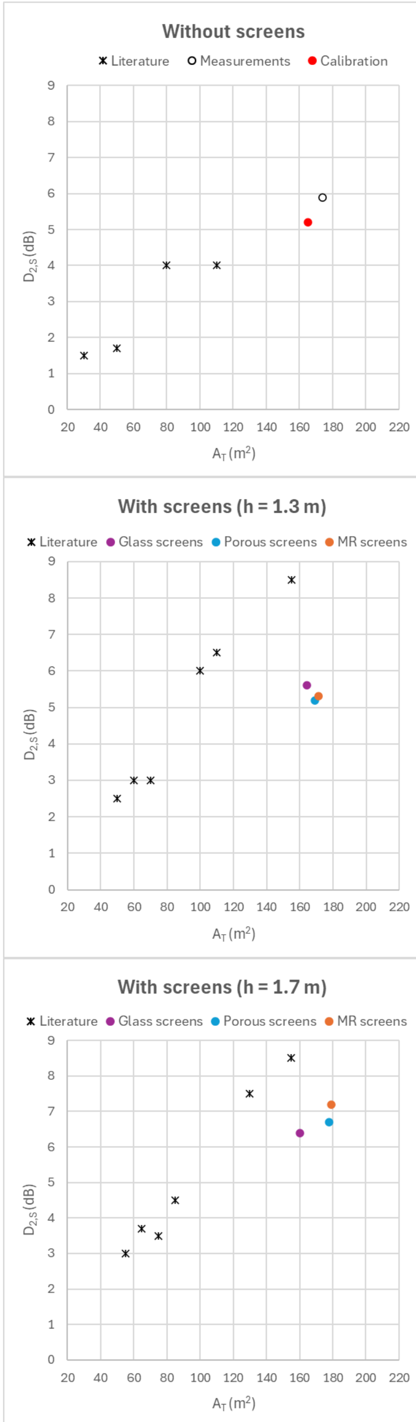

Figure 3. Simulated values compared to literature [12].

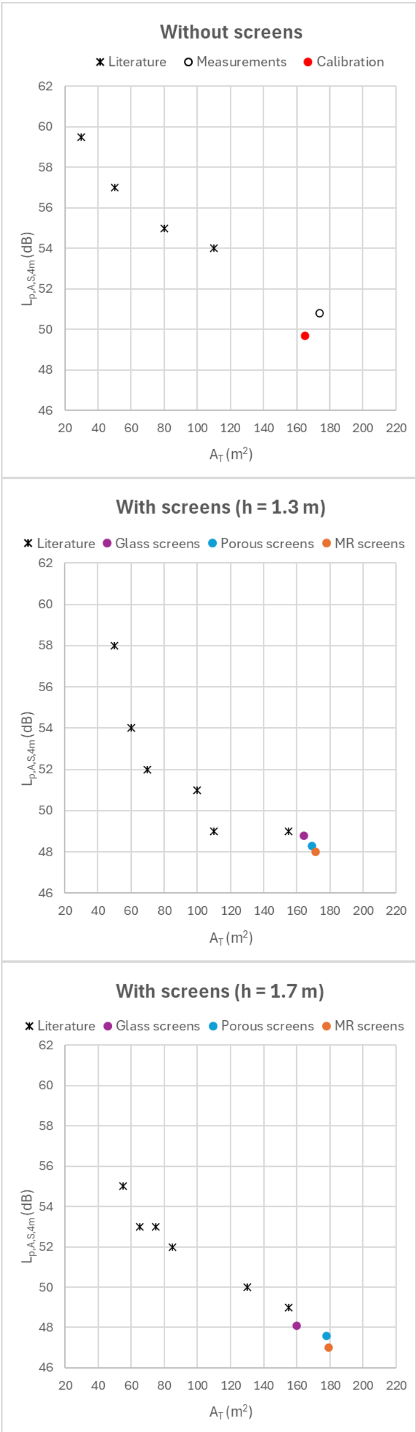

Figure 4. Simulated values compared to literature [12].

5. CONCLUSIONS

This study evaluates the acoustic impact of multi-resonator (MR) screens in an open-plan office within a virtually reconstructed scenario, compared with traditional screens. The assessment is carried out using hybrid wave/ray-based techniques and comparing the outcomes with the initial configuration without screens calibrated on experimental data. Results from combinations of different materials and heights are provided. Simulated speech decay metrics ($D_{2,S}$ and $L_{p,A,S,4m}$) of the present study are lower than the previous works.

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