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THREE-DIMENSIONAL SOUND FIELD VISUALIZATION AND MODAL CHARACTERIZATION OF A REVERBERANT CHAMBER

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This paper investigates the three-dimensional sound field inside a reverberant chamber with the aim of characterizing its modal behavior and assessing its impact on standardized sound absorption measurements. Scanning measurements were conducted over a horizontal plane for two different source positions to evaluate source-position dependency. The combined visualization of sound pressure, and three-dimensional sound intensity provides insight into local modal structures and acoustic energy flow within the chamber. Based on the spatial distribution of sound pressure, regions corresponding to local pressure maxima were identified and used to define a subset of microphone positions for reverberation time measurements. These results were compared with measurements obtained using randomly distributed microphone positions, following the procedures of ISO 354 for the determination of sound absorption. The experimental findings enhance the understanding of reverberant room acoustics and demonstrate that the estimated absorption coefficients remain relatively unbiased when microphone positions are selected at local pressure maxima, indicating that the sound absorption estimation is robust against the local modal behavior of the reverberant testing chamber.

Keywords: reverberant chamber, modal analysis, sound intensity, sound absorption.

1. Introduction

Reverberation chambers are widely used for the determination of sound absorption properties of materials, based on the assumption of a diffuse sound field in which acoustic energy is uniformly distributed throughout the room [1]. Under such conditions, the measured reverberation time becomes independent of source and receiver positions [2], allowing the derivation of absorption coefficients according to standardized procedures such as ISO 354 [3]. In practice, however, this assumption is only approximated above a certain frequency range, and some authors have suggested that the lack of a truly diffuse field is the main cause of the measurement spread often observed [4]. At low frequencies, the sound field is dominated by discrete room modes, leading to pronounced spatial variations in sound pressure and deviations from ideal diffuse conditions.

These spatial non-uniformities in the low-frequency range raise questions regarding the validity and robustness of standardized measurement procedures, particularly with respect to microphone placement. While ISO 354 mitigates spatial variability using multiple microphone and source positions, it remains unclear to what extent localized acoustic phenomena, such as modal pressure maxima and minima, may influence the measured decay rates and derived absorption coefficients. Previous studies have investigated room diffuseness and modal behavior [5], including detailed experimental characterizations of the sound field in reverberation rooms using microphone arrays [6] and geometrical acoustic modelling [7]. However, a comprehensive spatial analysis of a full room directly linking these observations to standardized absorption measurements remains limited.

Recent advances in acoustic measurement techniques enable the acquisition of spatially resolved sound field data, including not only sound pressure but also particle velocity and sound intensity [8]. These quantities provide a more complete description of the acoustic field, allowing the visualization of modal structures and energy flow within enclosed spaces. In particular, three-dimensional scanning methods offer the possibility to directly observe spatial variations that are otherwise averaged out in conventional measurements.

In this work, the sound field inside a reverberant chamber is investigated using three-dimensional sound field scanning. Measurements of sound pressure and three-dimensional sound intensity are used to characterize the modal behavior of the room and to assess the influence of source position on the spatial distribution of acoustic energy. Based on these results, microphone positions are systematically selected in regions of high and low sound pressure to evaluate their impact on the resulting reverberation times and the estimated absorption coefficients. The objective is to determine whether spatial non-uniformities in the sound field introduce measurable bias in standardized absorption measurements.

2. Measurement methodology

This section describes the experimental procedures used to investigate the sound field inside a reverberant chamber and to evaluate its impact on standardized absorption measurements. First, the implementation of the ISO 354 measurement procedure is outlined, including the selection of microphone positions and test configurations. Subsequently, the 3D sound field mapping approach based on the Scan & Paint 3D system is presented and used to characterize the modal behaviour of the chamber.

2.1 Standardized testing of sound absorption: ISO 354

Sound absorption measurements were conducted according to the ISO 354 standard, which prescribes the determination of sound absorption coefficients based on reverberation time measurements in a reverberant chamber of 220 m^3. Two source positions, denoted as A and B, were used to comply with the requirement of multiple excitation conditions. For each source position, six microphone locations were defined within the room, ensuring a spacing of at least 1 m between positions, a minimum distance of 1 m from any boundary surface, and at least 1.5 m from the sound source.

To investigate the influence of spatial variations in the sound field, three different microphone configurations were evaluated: (i) a reference configuration based on randomly distributed positions, representative of typical measurement practice, (ii) a set of positions corresponding to local sound pressure maxima, and (iii) a set corresponding to local sound pressure minima. The latter two configurations were derived from the spatial pressure distributions obtained through 3D scanning, as described later in this paper.

Reverberation times were determined using the standard T20 decay range, and the corresponding absorption coefficients were calculated from the difference between the empty room condition and the configuration with a test specimen installed. The specimen consisted of a 20 mm mineral wool absorber with a thin protective facing, selected to allow potential differences in measured absorption to be more clearly observed. Figure 1 illustrates the experimental setup and the test specimen used for the ISO 354 measurements.

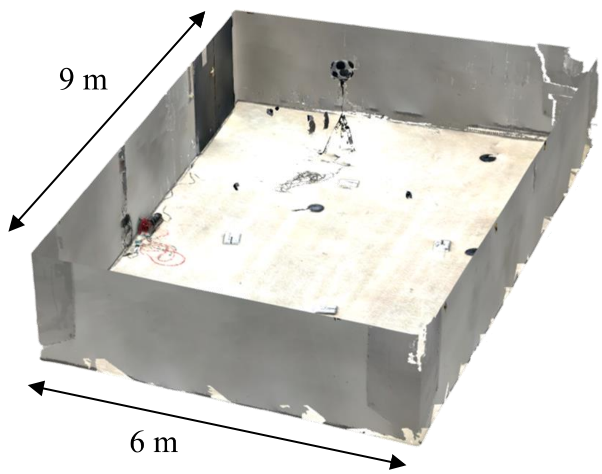

Figure 1: 3D model of the reverberant chamber (left) and photo of the sample used during ISO 354 tests (right).

2.2 3D sound mapping using Scan&Paint 3D

The spatial characterization of the sound field was performed using the Scan & Paint 3D measurement system [9]. This system employs a three-dimensional sound intensity probe comprising a pressure microphone and three orthogonally oriented particle velocity sensors, enabling the simultaneous acquisition of sound pressure and three-dimensional particle velocity.

The probe was mounted on a handle equipped with infrared reflective markers, allowing its position and orientation to be tracked in real time by a stereo camera system. The measurements were conducted by scanning horizontal planes within the room at heights of 160 cm and 150 cm, corresponding to source positions A and B, respectively.

A spatial resolution of approximately 50 mm was achieved, resulting in on the order of 15,000 measurement points per source position. The total scanning time amounted to approximately 160 minutes, performed over one day. Figure 2 shows the data acquisition process, along with the corresponding scanning trajectories for both source positions, illustrating the spatial coverage achieved during the measurements.

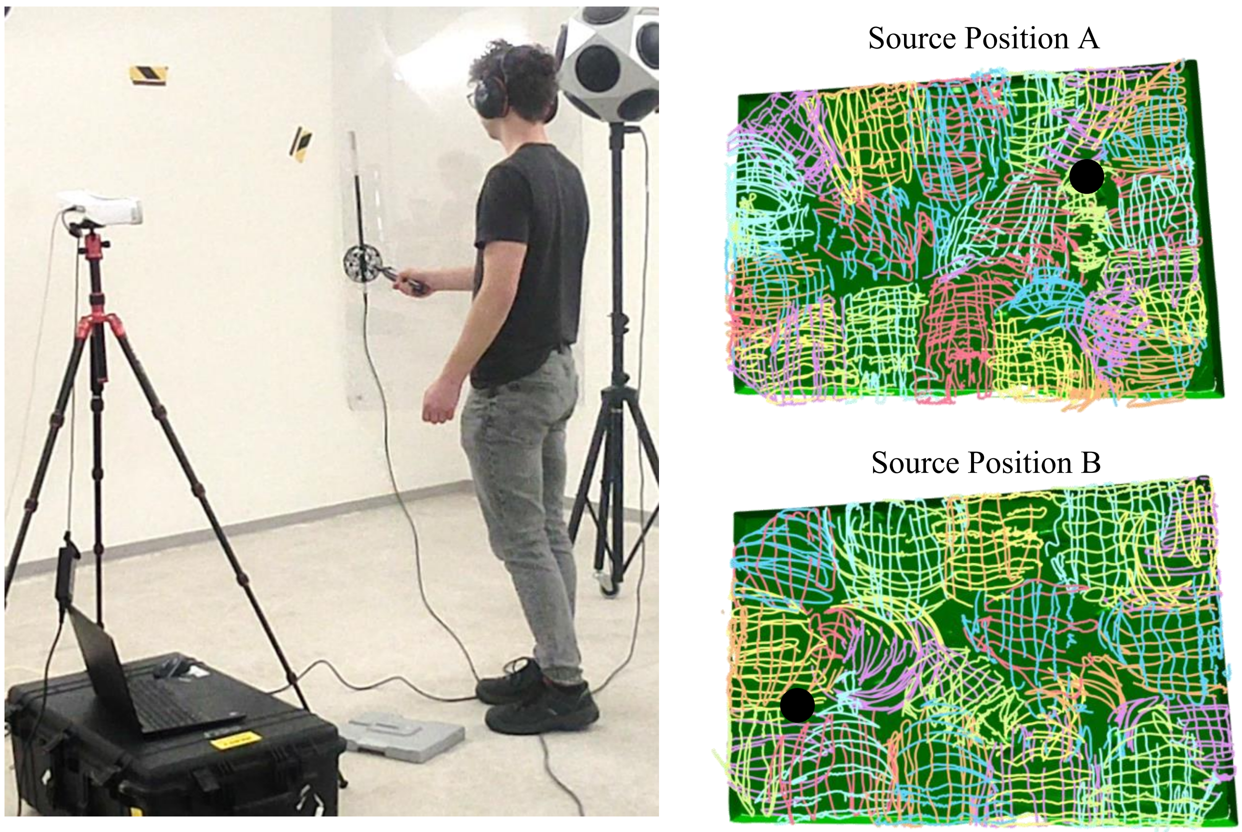

Figure 2: Photo of the data acquisition process with Scan & Paint 3D (left) and tracking paths for both source position A (top right) and position B (bottom right).

3. Sound Field Characterization

The spatial distribution of sound pressure within the reverberant chamber was first analyzed to assess the influence of source position on sound field homogeneity. Figure 3 presents top-view maps of the sound pressure level for source positions A (top) and B (bottom) at representative frequency bands in the low-frequency range.

At low frequencies, outside the effective working range of the chamber, the sound field is dominated by clear modal behavior, resulting in pronounced spatial variations associated with standing wave patterns. It should be noted that, despite the different source positions, the overall distribution of sound pressure remains largely unchanged. This indicates that, in this frequency range, the natural room modes govern the sound field, and the influence of source location is minimal.

As frequency increases, a gradual transition is observed. The sound field becomes less dominated by individual modes, and the influence of the source position becomes more apparent. In particular, regions in the vicinity of the source exhibit elevated sound pressure levels, reflecting the combined effect of source directivity and reduced modal dominance.

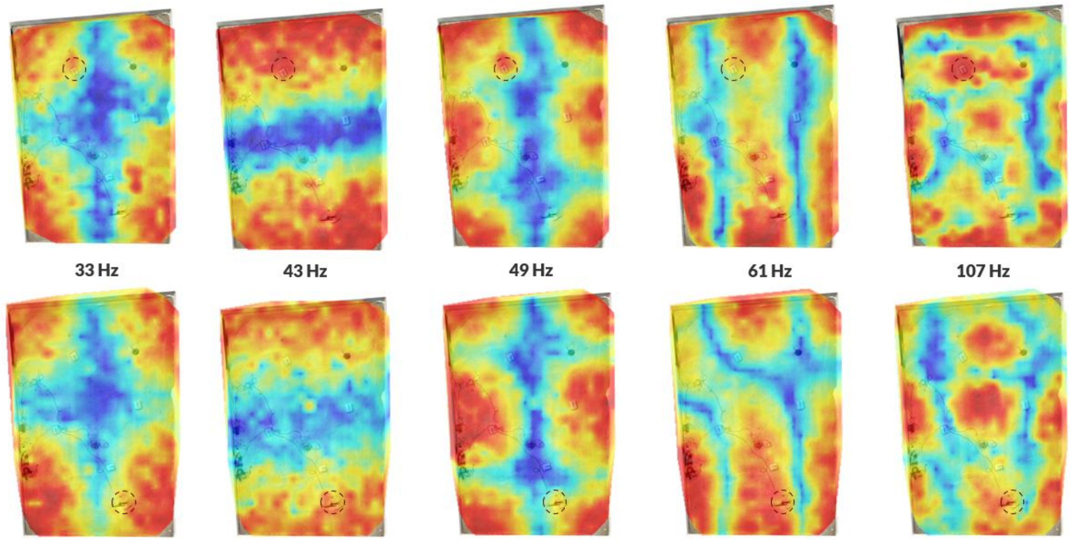

Figure 3: Spatial distribution of sound pressure over the first natural modes of the room for source position A (top) and position B (bottom).

To further investigate sound field isotropy and room diffuseness, top-view three-dimensional sound intensity maps are shown in Figure 4 for both source positions A and B over selected frequency ranges.

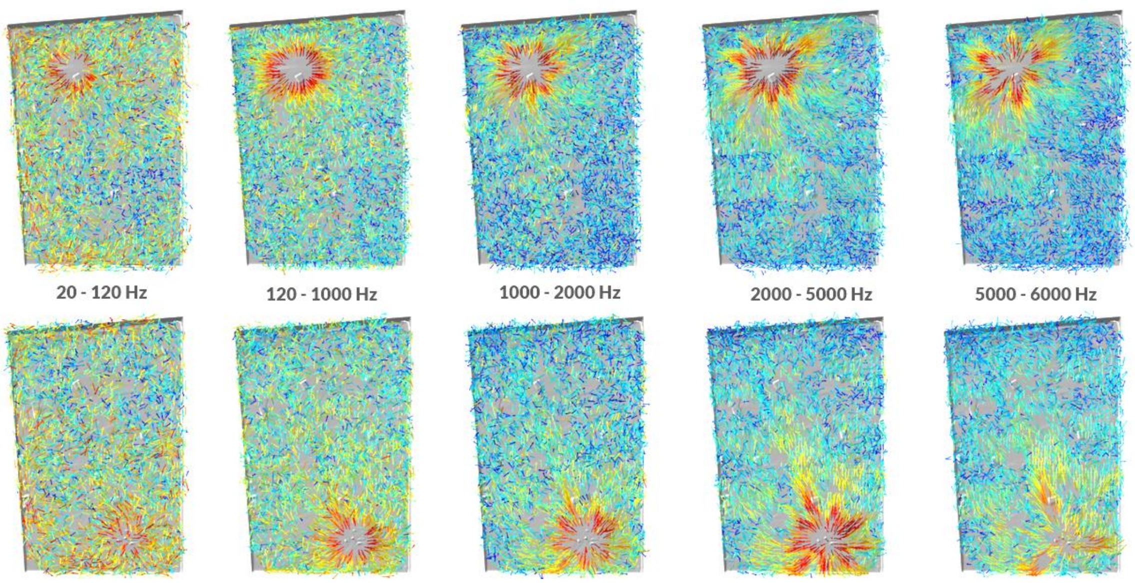

Figure 4: 3D active intensity sound field for source position A (top) and position B (bottom) across multiple frequency ranges of interest.

In this case, the three-dimensional sound intensity clearly shows a consistent radiation pattern from the location of each source into the sound field, with a rapid transition toward diffuse behaviour at low and mid frequencies. However, at higher frequencies, distinct interference patterns emerge in the immediate vicinity of the source. These patterns are characterized by localized regions of constructive and destructive interference of the dodecahedral sound source, leading to strong spatial gradients in sound pressure. In this region, the measured sound field can be significantly biased by proximity to the source, and the assumption of diffuseness is no longer valid. In particular, above 2 kHz, the region surrounding the source that can be considered within the direct field extends for several meters due to consistent energy propagation.

4. Microphone position selection

To investigate the influence of spatial sound field variations on standardized reverberation time measurements, a procedure was developed to select microphone positions based on the measured sound pressure distribution. The objective was to evaluate whether positioning microphones in regions of systematically high or low sound pressure, associated with modal antinodes and nodes, could introduce a measurable bias in the estimated reverberation time and derived absorption coefficients.

The optimization process was based on the spatial sound pressure maps obtained from the Scan & Paint 3D measurements. For each third-octave band, the measurement grid was treated as a set of candidate positions. An iterative selection algorithm was applied to identify subsets of positions that either maximize or minimize the spatially averaged sound pressure level, while complying with the geometric constraints defined in ISO 354. These constraints include a minimum spacing of 1 m between microphone positions, a minimum distance of 1 m from room boundaries, and at least 1.5 m from the sound source.

As a result, two distinct microphone configurations were generated: one corresponding to regions of relatively high sound pressure (high-energy regions), and one corresponding to regions of relatively low sound pressure (low-energy regions). A third configuration, consisting of randomly distributed positions, was used as a reference, representing typical measurement practice. The resulting microphone position selections are shown in Figure 5, along with the corresponding pressure response measured at each location.

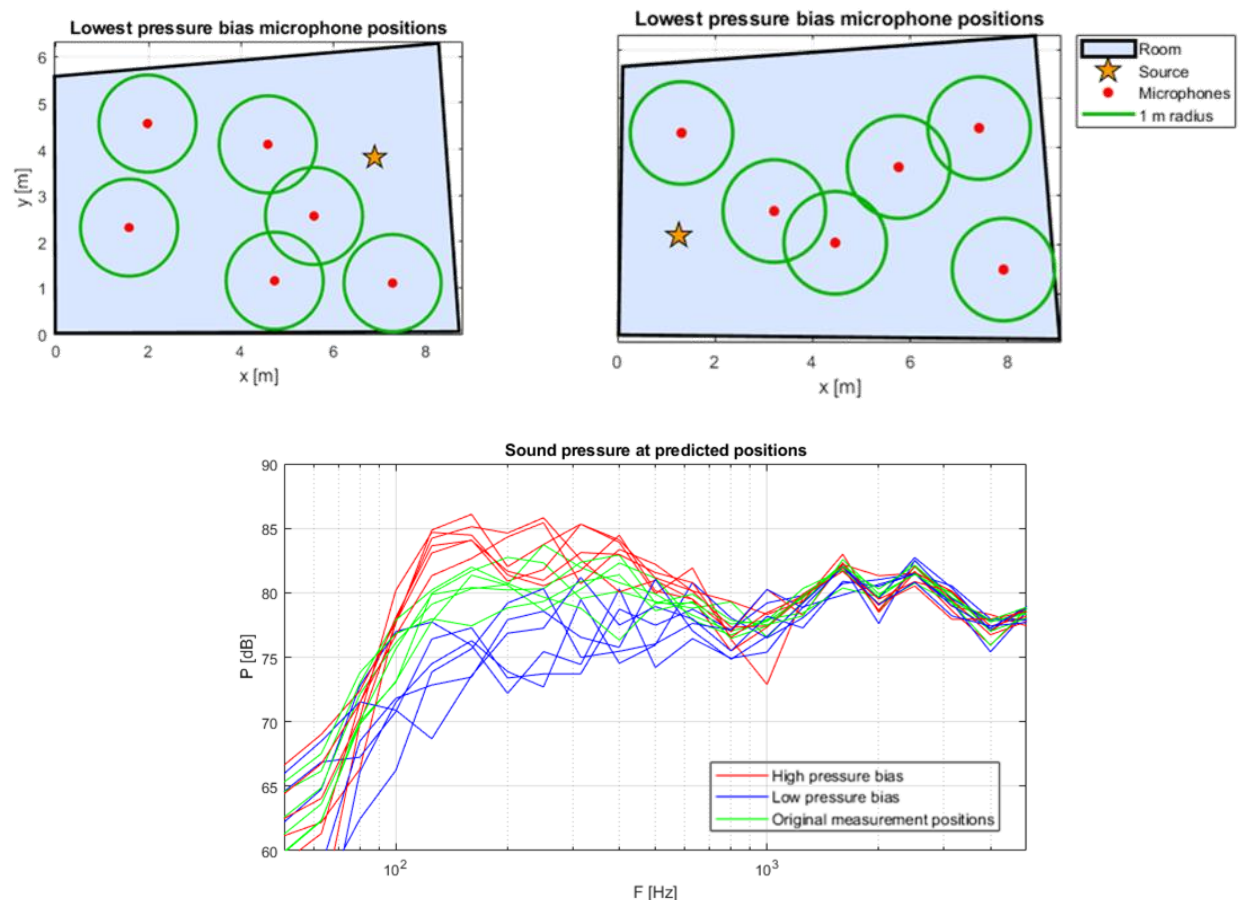

Figure 5: Selected positions for source position A (top left) and B (top right), and sound pressure response for each selected location (bottom).

5. Reverberation time and sound absorption

The influence of microphone position selection on reverberation time and derived sound absorption coefficients was evaluated by comparing three measurement configurations: (i) randomly distributed microphone positions, representative of standard practice, (ii) positions corresponding to local sound pressure maxima, and (iii) positions corresponding to local sound pressure minima. Measurements were conducted in accordance with ISO 354, using both the empty room condition and a test specimen consisting of a 20 mm mineral wool absorber.

Figure 6 presents the resulting absorption coefficients as a function of frequency for the three configurations. Across the full frequency range, the general trend of increasing absorption with frequency is consistent for all configurations.

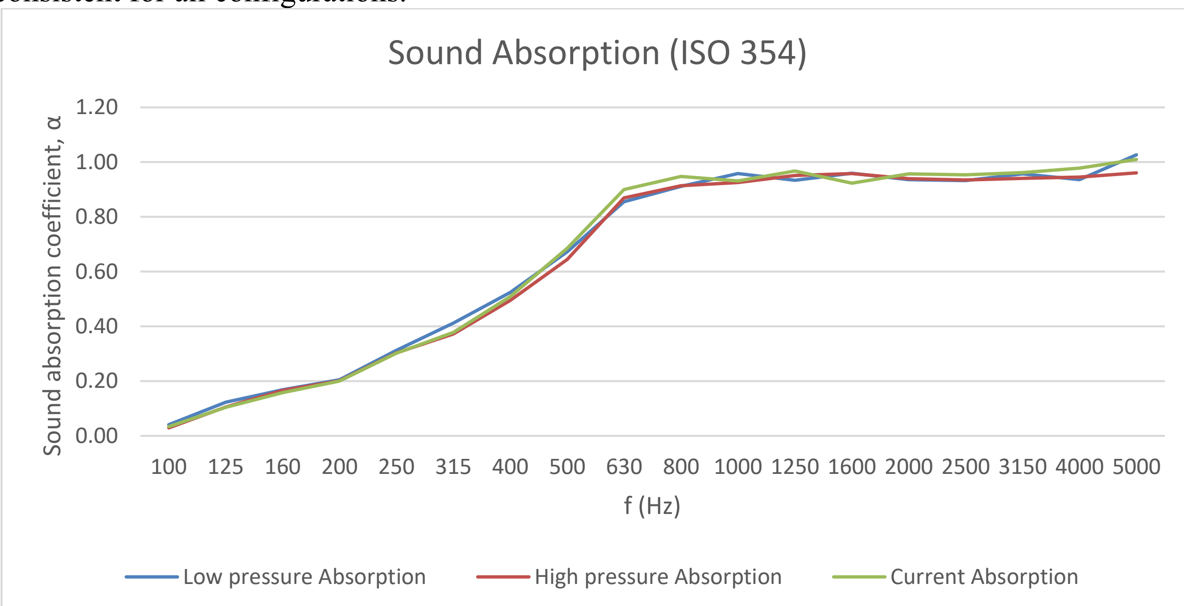

Figure 6: Sound absorption response measured following ISO 354 for several microphone position sets.

Despite the clear spatial variations observed in the sound pressure distribution, the differences between the absorption curves obtained from the three microphone configurations are negligible, remaining below 0.05 for all third-octave bands.

The weighted sound absorption coefficient (α_w), calculated according to ISO standards, yields identical values for all three configurations (0.6), indicating that the overall absorption performance is not significantly affected by the choice of microphone positions.

The results suggest that, although local modal behavior can significantly affect the spatial distribution of sound pressure and energy within the room, its impact on standardized absorption measurements remains limited. Even when microphone positions are deliberately selected to represent extreme acoustic conditions, such as pressure maxima or minima, the resulting reverberation times and derived absorption coefficients remain largely unchanged.

6. Conclusions

This study presented a spatial characterization of the sound field inside a reverberant chamber using three-dimensional sound field measurements, with the objective of assessing the influence of modal behavior and microphone position selection on standardized absorption measurements. The results show a clear frequency-dependent behavior of the sound field, with strong modal dominance at very low frequencies and a gradual transition toward a more diffuse field. While the overall spatial distribution of sound pressure is largely independent of source position, source-related effects become increasingly significant at higher frequencies, particularly in the vicinity of the source where interference patterns can affect the local excitation of the field.

Based on the measured sound pressure distributions, microphone positions were systematically selected to represent regions of high and low acoustic energy. Despite these deliberately extreme configurations, the resulting reverberation times and derived absorption coefficients showed negligible differences when compared to those obtained using randomly distributed microphone positions. The variations in absorption remained below 0.05 across all third-octave bands, and identical weighted absorption coefficients were obtained for all configurations. These findings demonstrate that, although the sound field within a reverberant chamber exhibits significant spatial non-uniformities, the ISO 354 methodology is robust with respect to microphone placement. The spatial averaging inherent to the standard effectively mitigates the influence of local modal effects, ensuring reliable and consistent absorption measurements. It should be noted, that the present measurements were limited to two horizontal planes; future work could extend this approach to cover the volume more extensively.

On the other hand, the use of 3D sound field mapping provides valuable insight into the behavior of the chamber, enabling the visualization of acoustic modes and local energy flow that are not accessible through conventional measurement techniques. Such approaches can serve as a complementary diagnostic tool for understanding room performance and validating measurement conditions.

REFERENCES

1 Kuttruff, H., *Room Acoustics*, 6th ed., CRC Press, (2016).

2 Schultz, T. J., “Diffusion in reverberation rooms,” *Journal of Sound and Vibration,* 16, pp. 17–28,(1971).

3 International Organization for Standardization, *ISO 354:2003 Acoustics — Measurement of sound absorption in a reverberation room*, Geneva, Switzerland, (2003).

4 Vercammen, M., “Improving the accuracy of sound absorption measurement according to ISO 354”, In Proceedings of the International Symposium on Room Acoustics, Melbourne, Australia, (2010).

5 Nolan, M., Berzborn, M., Fernandez-Grande, E., “Isotropy in decaying reverberant sound fields”, *JASA,* 148, pp. 1077–1088 (2020).

6 Nolan, M., Verburg, S. A., Brunskog, J., Fernandez-Grande, E., “Experimental characterization of the sound field in a reverberation room” *JASA* 145, pp. 2237–2246, (2019).

7 Martellotta, F., Ayr, U. and Rubino C., “On the use of geometrical acoustic models of a reverberant chamber to improve the reliability of sound absorption measurements”, In Proceedings of the 23rd ICA, (2019).

8 D. Fernandez Comesana, *Scan-based sound visualization methods using sound pressure and particle velocity*, University of Southampton, Institute of Sound and Vibration Research, PhD Thesis, (2014).

9 Microflown Technologies, Scan & Paint 3D, https://www.microflown.com/products/sound-localization-systems/scan-paint-3d, (accessed March 2026).