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The effect of absorber placement on absorption coefficients obtained from reverberation chamber measurements

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Abstract

The standard procedure of sound absorption measurements in reverberation chambers relies on the well-established reverberation theory, which assumes isotropic sound incidence on the absorbing specimen. Yet, due to the non-uniform placement of absorbing material in the room, this condition cannot be fulfilled in practice. Some angles of incidence are emphasized over others, especially at low frequencies. The current practice to obtain a more isotropic distribution of sound incidence is to install sound scattering elements in the form of panel or boundary diffusers. However, recent studies have shown that in spite of the presence of scattering elements, the sound field incident on the sample is not isotropic. This study investigates the effect of different absorber placements on the decay rates and absorption coefficient values. Measurements are conducted in a reverberation chamber with absorbers mounted in the corners and edges of the room. Such setup is expected to allow for a more uniform distribution of sound incidence, leading to increased decay rates. In this work we will discuss if such mounting setup should be added to ISO 354.

Keywords: Absorption coefficient, reverberation chamber

1 INTRODUCTION

This work investigates the influence of the placement of absorbers in a reverberation chamber on the decay rates. The typical test situation according to ISO 354 [1] renders the establishment of a diffuse sound field rather difficult because the absorber is placed on a single surface of the chamber. Although diffusing elements like boundary or panel diffusers prove to be very useful in increasing the sound field diffusivity, the optimum state of diffusion is rather ambiguous [2]. The use of the well known reverberation formula [3] to calculate the absorption coefficient requires a diffuse sound field and an even distribution of absorption in the room. This yields a challenging task, since the state of diffusion is not quantifiable and the test specimen is usually placed on a single surface. Investigations on the dependence of decay rates on the wall diffusion have been carried out in Ref. [4], where the author simulated sound decays for various conditions. Simulation results showed that the placement of the absorber on three walls perpendicular to each other provides a test setup in which the decay rates are less sensitive to the state of diffusion than in the case when the absorber is placed on a single surface. Less sensitive means in this case that the decay rates do not change with the state of diffusion and that the energy decay curves are linear, when plotted on a logarithmic axis. Yet, splitting the absorber apart and placing it on three different walls most likely increases the edge diffraction of the absorber [5]. Besides, the energy density in room edges is higher than far away from the walls, which can lead to an increased absorption coefficient at low frequencies [5]. Despite those difficulties, the question remains if an improved absorber placement can lead to more reliable measurements in the reverberation chamber. For the past decades multiple round robin test have pointed out the poor interlaboratory reproducibility of absorption coefficient measurements [6, 7]. The aim of this investigation is to analyze five different absorber placements and the influence of three different diffuse field conditions on the decay rates experimentally. Measurements are carried out in a rectangular reverberation chamber and impulse responses are measured when the absorber is placed in a typical testing situation as well as split apart and spread in the edges of the room. The amount of diffusion is varied by changing the number of panel diffusers in the chamber.

2 MEASUREMENTS

Measurements are carried out in a box-shaped reverberation chamber (V = 245 m^3) at the Technical University of Denmark in Lyngby. The box-shape is chosen to compare a sound field with the least amount of diffusion (where no panel diffusers are installed) to a configuration with increased diffusion (with six additional panel diffusers) and to a configuration which complies with the current standard for absorption measurements (with 20 panel diffusers randomly hung from the ceiling) [1]. Figure 1 shows the empty chamber as well as five different mounting setups. The setup 'Iso' corresponds to the typical test situation according to ISO 354, where the absorber (S = 3 m x 3.6 m = 10.8 m^2) is placed on the floor with covered edges. Then the absorber is split apart into three patches (each S = 1.2 m x 3 m = 3.6 m^2, setup 'Split'), leading to an increased edge length. In the next step the three patches are distributed on the floor in the room edges, as shown by setup '1D'. In the next configuration '2D', one of the patches is set upright, so that only two patches remain on the floor. The last setup '3D' shows the three patches distributed on three different walls.

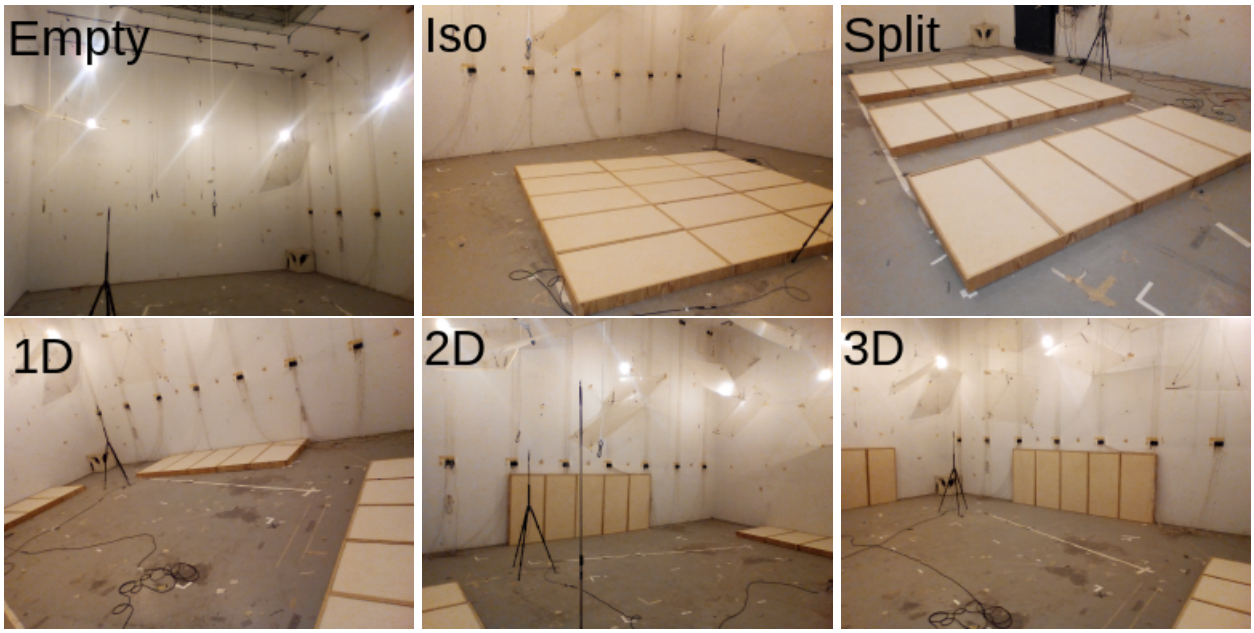

Figure 1. Measurement setup: empty chamber and five different configurations of absorber placements.

Impulse responses are measured at 12 independent source receiver positions and energy decay curves are calculated by applying the Schroeder backwards integration to the squared impulse response. 12 energy decay curves are averaged to obtain a single decay curve for every octave band from 125 Hz to 4 kHz.

3 RESULTS AND DISCUSSION

Figure 2 shows the energy decay curves of the empty chamber without the absorber for the octave bands from 125 Hz to 4 kHz for three different diffuser setups (0, 6, and 20 panel diffusers randomly hung from the ceiling). The dashed red line shows a linear decay, which indicates if the decay curves are multiple sloped when plotted on a logarithmic axis. Independent of the amount of diffusers installed, the energy decay curves are multiple sloped at low and high frequencies (125 Hz, 250 Hz, 2 kHz, 4 kHz). At 500 Hz and 1 kHz the energy decay curves are mostly linear. With increasing number of diffusers, the decay rates decrease at all frequency bands. Figure 3 shows the energy decay curves of the setup 'Iso', where the absorber is placed on the floor according to ISO 354. At 125 Hz, 250 Hz, and 4 kHz the energy decay curves are multiple sloped,

independent of the amount of diffusers installed. At 500 Hz, 1 kHz and 2 kHz the energy decay curves are mostly linear when the amount of diffusers is increased. With increasing number of diffusers, the decay rates decrease at all frequency bands.

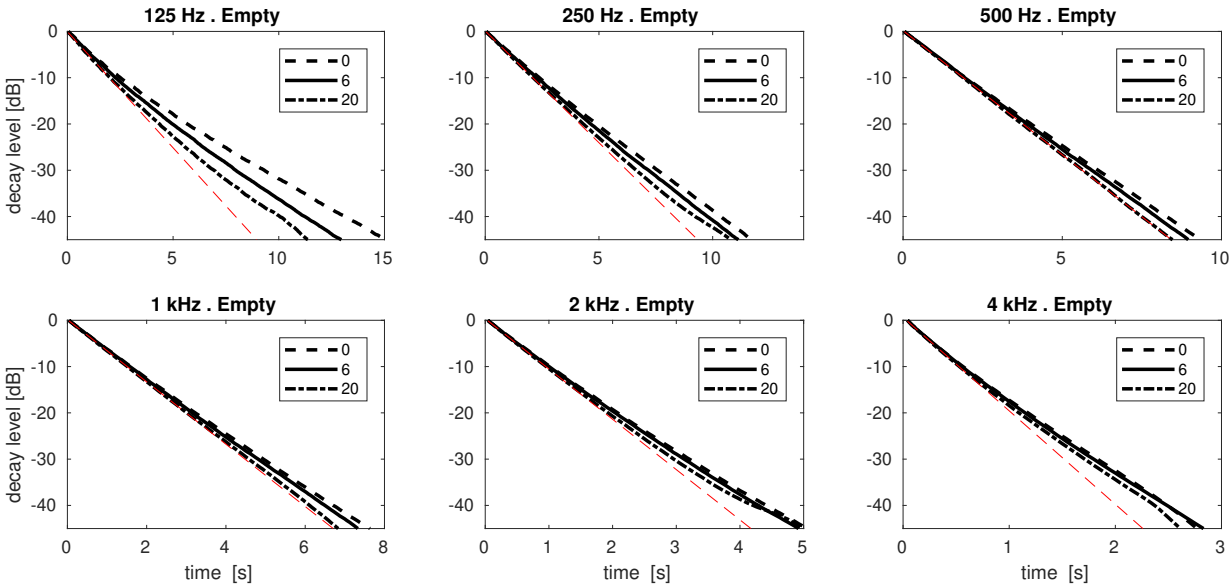

Figure 2. Comparison of energy decay curves in the empty reverberation chamber without the absorber. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

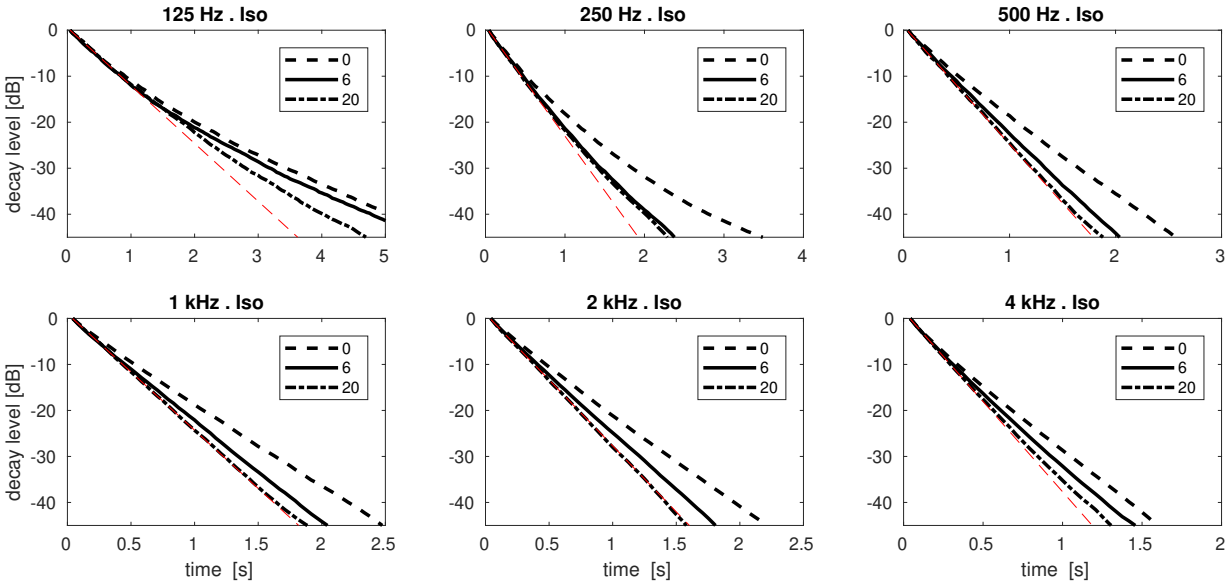

Figure 3. Comparison of energy decay curves at setup 'Iso'. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

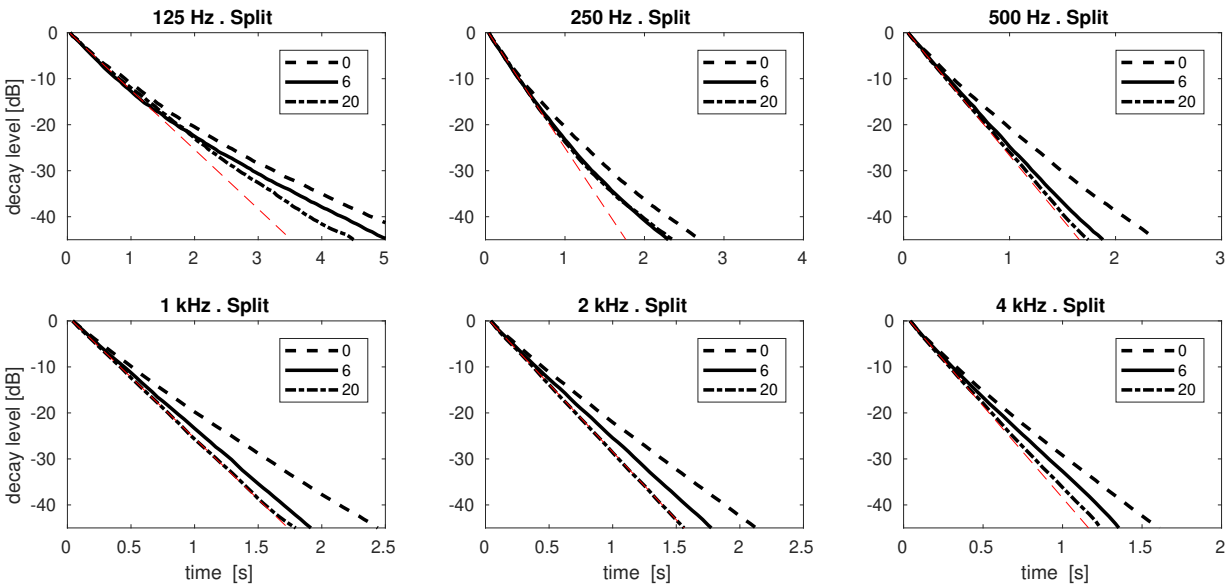

Figure 4. Comparison of energy decay curves at setup 'Split'. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

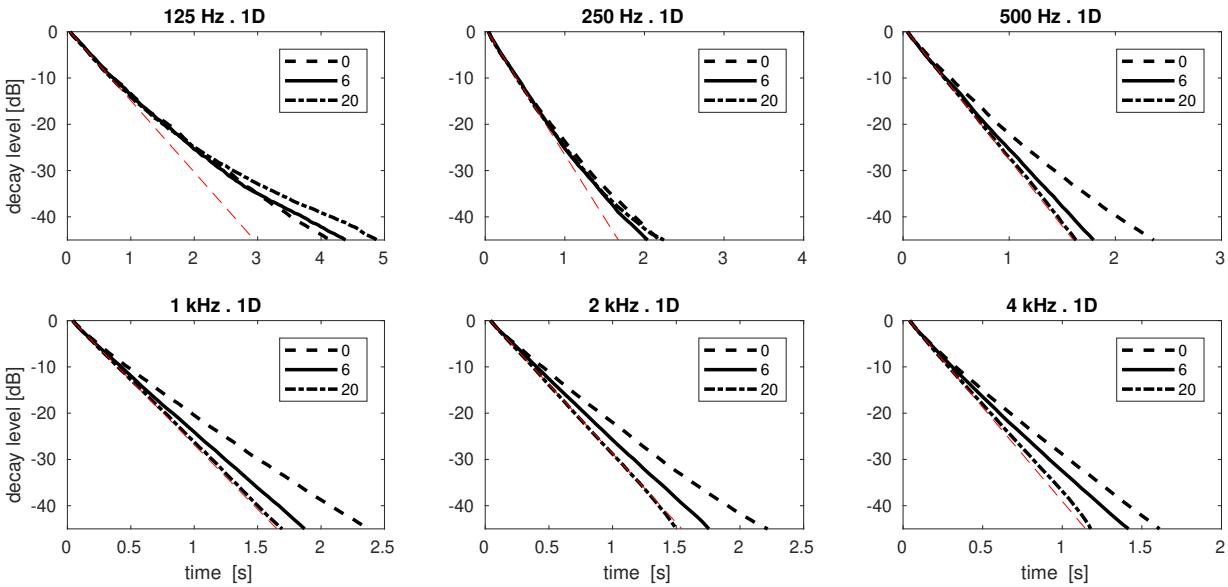

Figure 5. Comparison of energy decay curves at setup '1D'. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

Figure 4 shows the energy decay curves of the setup 'Split', where the absorber is split into three patches and placed in the middle of the floor. The characteristics of the energy decay curves are similar to the setup 'Iso', but the decay rates are decreased when the absorber is split apart. Figure 5 shows the energy decay curves of the setup '1D', where the absorber is distributed on the floor in the edges of the chamber. The characteristics

of the energy decay curves are similar to the previous setups. At low frequencies the curves are multiple sloped but at 250 Hz the initial decay seem to be less dependent on the amount of diffusers installed. Figures 6 and 7 show the setups '2D' and '3D', where the three patches are distributed on two and three walls respectively. Again, the decay curves behave similarly. At low frequencies the decay curves are still multiple sloped.

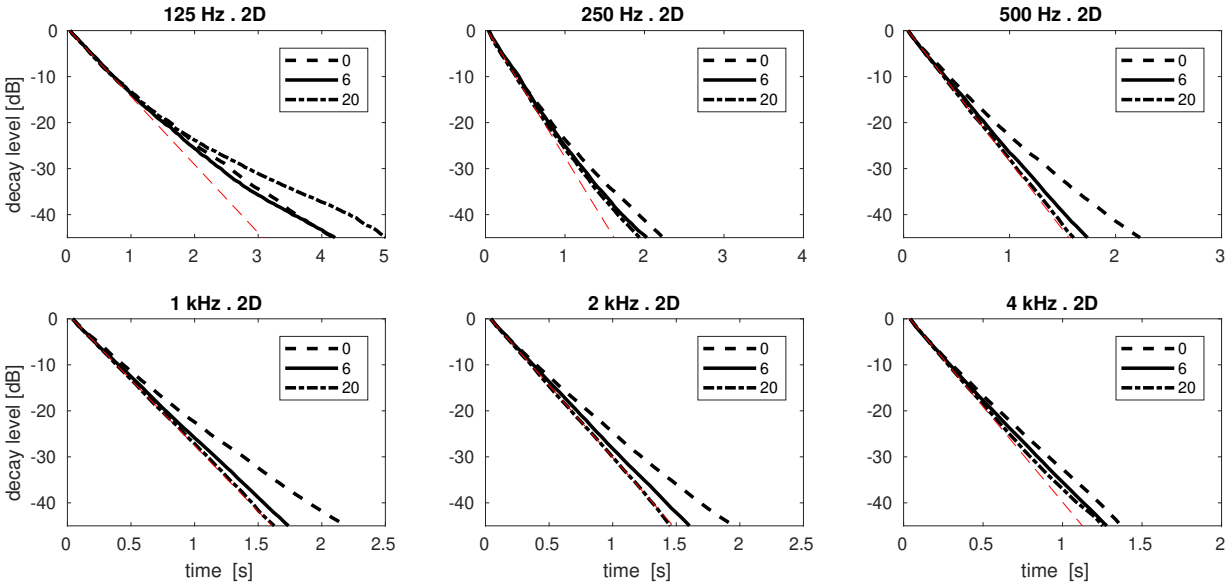

Figure 6. Comparison of energy decay curves at setup '2D'. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

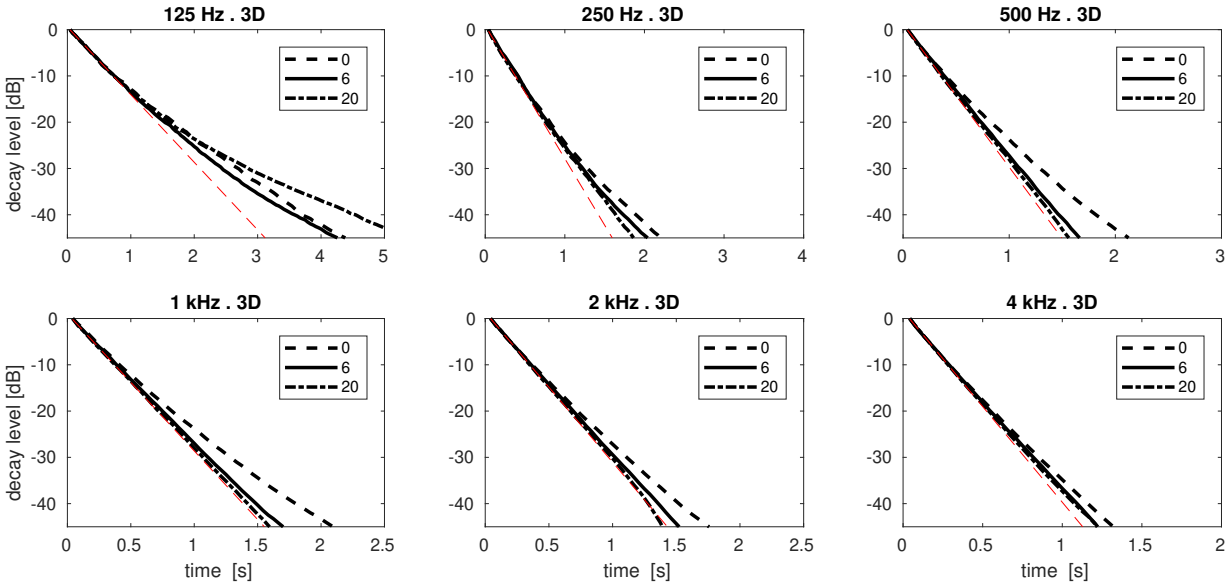

Figure 7. Comparison of energy decay curves at setup '3D'. The amount of diffusers is varied between 0, 6 and 20 panel diffusers randomly hung from the ceiling. The dashed red line indicates a linear decay.

In Fig. 8 different absorber setups are compared for each frequency band and diffuser state. In all configuration the setup '3D' results in the shortest decay rates, indicating that most of the energy is absorbed when the absorber is spread on three surfaces. Even at high frequencies the decay rates can be decreased when the absorber is distributed on three walls. The greatest differences between the decay rates of different absorber setups can be observed at low frequencies, when no diffusers are present.

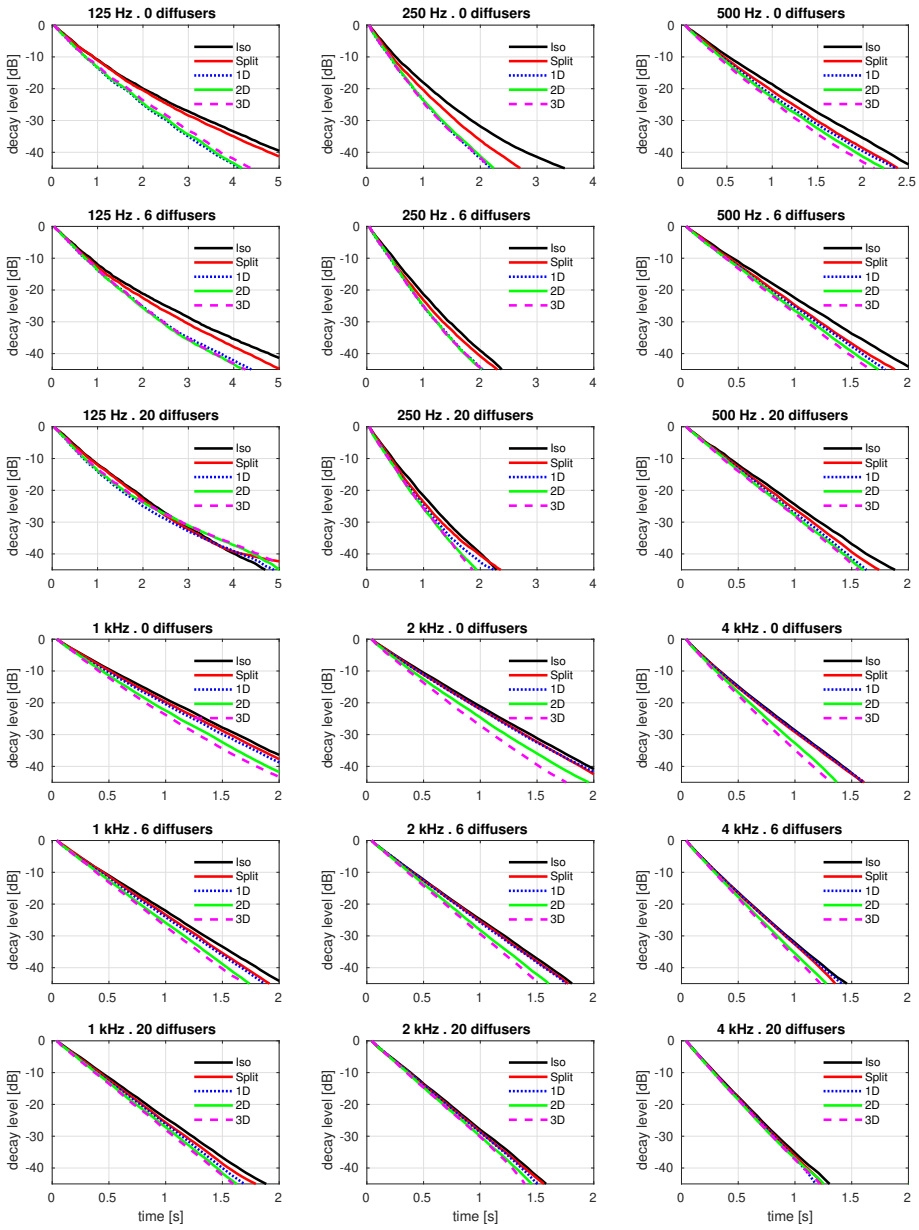

Figure 8. Comparison of absorber placements for each octave band and each diffuser configuration

3.1 Difficulties with comparing absorber setups

Difficulties arise from the boundary effects due to the increased energy density at the rigid wall, usually referred to as 'Waterhouse effect' [8]. It takes into consideration that the square of the sound pressure amplitude in front of a rigid wall exceeds its value far from the wall. The same holds for the energy absorbed per unit time and area by the test specimen which perpendicularly adjoins the wall. To account for this effect, the geometrical area S of a test specimen can be corrected with [5]:

$$S_{eff} = S + \frac{1}{8} \cdot L' \cdot \lambda, \tag{1}$$

where λ is the wavelength corresponding to the centre frequency of the selected band, L' is the length of the edges adjacent to perpendicular walls. When the absorber patches in this investigation are split into three parts and distributed in the room edges, as it is done in configurations '1D','2D', and '3D', the total length corresponding to L' is 9 m. The corrected geometrical area is shown in tab. 1, where the effect is most prominent at low frequencies.

Table 1. Correction of the geometrical area of the specimen due to the placement in the room edges.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
S_{eff} [m^2]	13.9	12.3	11.3	11.2	11.0	10.9

Another difficulty to deal with, is the finite size of the sample and the diffraction of sound at the edges of the absorber, which can lead to an increase in absorption at certain frequencies. To account for the finite size of the sample, Thomasson derived a theoretical absorption coefficient which depends on absorber shape, size, and frequency [9]. The size correction holds for an absorber which is mounted on an infinite rigid baffle, which cannot be applied if the absorber is placed the room edges.

3.2 Evaluation of decay parameter

As apparent from Fig. 2 to Fig. 7, at 125 Hz and 250 Hz the energy decay curves are always multiple sloped, in the empty reverberation chamber as well as with the absorber. No absorber placement or diffuser setup leads to a straight decay when plotted on a logarithmic axis. Evaluating the reverberation parameter T_{20}, as it is required according to ISO 354, leads to questionable results in this case. Therefore it is not paractical to calculate absorption coefficients for low frequencies with the reverberation time T_{20}. As suggested in Ref. [10], if a decay is multiple sloped, a different framework has to be used to calculate decay parameter. For coupled rooms, a Bayesian framework was introduced to estimate multiple decay parameter. In case of a double sloped decay, two decay times could be estimated, namely an initial and a late decay time. For calculating the absorption coefficient, it would be reasonable to take the initial decay time as suggested in Ref. [11]. The initial decay contains all excited modes within the frequency band, whereas the late decay contains only the less attenuated modes.

The shortest decay rates can be achieved with absorber setup '3D' and 20 panel diffusers, as shown in Fig. 8 for all frequency bands. Although it requires to split the absorber apart, Fig. 7 shows that it provides the setup where the initial part of the energy decay seems to be less sensitive to the state of diffusion compared to the typical test situation according to ISO 354. Furthermore, the boundary effects can be corrected according to Eq. 1, where the geometrical area of the absorber is replaced with the effective area S_{eff}.

In almost every case the shortest decay rates can be achieved when 20 panel diffusers are randomly hung from the ceiling. Although it is expected that this allows for a more uniform distribution of sound incidence on

the absorber, additional investigations should be carried out which allow for experimentally characterizing the distribution of sound incidence [12].

4 CONCLUSION

This work investigated different absorber placements and its effect on the decay process in a reverberation chamber. Measurement results suggest that at low frequencies, namely 125 Hz and 250 Hz the energy decay curves are multiple sloped with every test setup and diffuser configuration. Also at 4 kHz the energy decays are multiple sloped, even when diffusers are installed. At mid frequencies, adding diffusers resulted in many cases in a linear decay, although sometimes already a low number of diffusers was sufficient to produce a linear decay. Regarding absorber placement, spreading the test material on three walls resulted in the lowest decay rates. Also, measurement results suggest that if the absorber is spread on three walls, the initial portion of the energy decay seems to be less sensitive to the state of diffusion in the chamber. It should be discussed if a new evaluation method is required due to the curvature of the energy decays at low frequencies.

ACKNOWLEDGMENTS

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