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COMBINING ABSORPTION COEFFICIENT MEASUREMENTS IN REVERBERATION ROOMS WITH DIFFERENT VOLUMES

Heinrich Bietz[1*] **Volker Wittstock**[1]
[1]Physikalisch-Technische Bundesanstalt, Germany

ABSTRACT

One way to reduce the uncertainty of absorption coefficient measurements in reverberation rooms could be the combination of measurement results from rooms with different volumes. To investigate this, a round robin was conducted at PTB using two regular reverberation rooms and five rooms of 50 m³ volume which belong to the building acoustic test stands of PTB. The diffusivity was adjusted following the procedure described in ISO 345. Eight samples were measured in each room employing different staff and equipment, so the results can be regarded as statistically independent. The results show that the "50 m³" rooms deliver reasonable absorption coefficients over a wide frequency range, but in most cases fail at frequencies below 250 Hz. Furthermore, the approach taken to reduce the uncertainty by combining results from two rooms with different volumes provided promising results. One drawback certainly is the small database produced by the round robin; further research is necessary to support the findings presented in this article.

Keywords: *absorption coefficient, reverberation room, room volume, uncertainty, ISO 354.*

1. INTRODUCTION

The measurement of absorption coefficients α_s in reverberation rooms with a volume of at least 150 m³ (200 m³ for newly built rooms) is standardized in ISO 354 [1] at frequencies between 100 Hz and 5 kHz. ISO 12999-2 [2] describes a procedure to assess the uncertainty of these measurements. The uncertainty here is defined as the standard deviation of reproducibility σ_R, which is expressed as a linear relation:

$$\sigma_R = m\alpha_S + n \quad (1)$$

where the slope *m* and the offset *n* are frequency dependent constants which had been derived by evaluating a large amount of round robin data from the last decades [3]. The uncertainty can also be expressed as relative uncertainty in decibels, which may be useful for practical applications:

$$u(L_{\alpha s}) = 10\,\lg(1 + \sigma_R/\alpha_s\,)\;\mathrm{dB} \quad (2)$$

The resulting relative uncertainties are shown in Fig. 1 [4]. They increase at both ends of the frequency range, whereas the influence of the absorption coefficient is much more pronounced at higher frequencies.

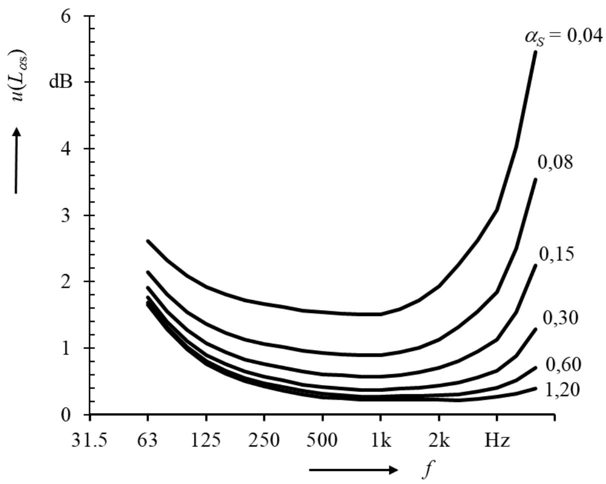

Figure 1. Relative uncertainty of α_s.

*Corresponding author: heinrich.bietz@ptb.de.

For certain applications, e.g. prediction of the speech transmission index (STI), an extension of the frequency range up to 10 kHz is sometimes desirable. As the large uncertainties at high frequencies are commonly attributed to air absorption, one possible way of improvement could be the use of a reverberation room with a smaller volume. If i.e. a room volume of 50 m³ is chosen, this would in theory cause a frequency shift of the figures *m* and *n* from Eqn. (1) and thus also of the relative uncertainty in Fig. 1. For low frequencies, modal density is assumed as the governing factor. We then get

$$\frac{f_2}{f_1} = \frac{\sqrt[3]{V_1}}{\sqrt[3]{V_2}} = 2^{2/3} \text{ when } \frac{V_1}{V_2} = \frac{200}{50} = 2^2, \quad (3)$$

so *m* and *n* would be shifted upwards by two 1/3 octave bands. For high frequencies, air absorption is assumed as the dominant factor influencing the uncertainty. With

$$\frac{4m_1V_1}{\alpha_1S_1} = \frac{4m_2V_2}{\alpha_2S_2} \quad (4)$$

where $m_{1/2}$, are the air damping constants in rooms with volumes $V_{1/2}$, $\alpha_{1/2}$ the absorption coefficient of the samples of size $S_{1/2}$ to be measured and the assumption

$$\frac{m_1}{m_2} = \left(\frac{f_1}{f_2}\right)^2, \quad (5)$$

we finally get

$$\frac{f_2}{f_1} = 2^{1/3} \quad (6)$$

under the assumption that the absorption coefficient α to be measured does not change at high frequencies. As a result, the uncertainty at high frequencies would be shifted by one 1/3 octave band to higher frequencies. It must be pointed out that these considerations include numerous simplifications, and the uncertainty is probably influenced by further effects. For the first investigation concerning these aspects, an internal round robin was conducted at PTB.

2. INTERNAL ROUND ROBIN

2.1 Scope

For the round robin, five rooms, all parts of building acoustics test stands, were used. The room volume ranged from 49 m³ to 58 m³. Eight different test samples were examined. In each room, these samples were measured by a different member of the working group staff with mostly different equipment. In addition, one member of the staff measured the samples in all test rooms, and in two reverberation rooms with 204 m³ and 237 m³ volume. For the measurements in the “50 m³” rooms, the area (or number) of the samples was scaled down accordingly, resulting in a sample area of about 4 m².

2.2 Test samples

As the uncertainty is directly dependent on the absorption coefficient, the samples were selected to cover a wide range of absorption coefficients. Tbl. 1 gives an overview of the employed samples. “Poly” refers to absorbers consisting of six rectangular metal frames with a thickness of 100 mm, and filled with a polyester fleece, which has absorbent properties like mineral wool. One side is open, and one side is covered with coated chipboard, which has a thickness of 8 mm for three boxes and 16 mm for the remaining boxes. These boxes were used to create six different absorber setups. For three setups, the boxes were laid out in a 2 x 3 configuration to create an absorber area. For the other three setups, three individual elements, each made of two boxes standing together upright, were realised.

Table 1. Absorbers used in internal round robin

Absorber	Description	Area in m²
WG 35	200 mm mineral wool with wooden frame, like reference absorber suggested by WG 35	4,3
Carpet	Carpeted floor 10 mm thick	3,9
Poly 1	Flat, all open sides upwards	4,3
Poly 2	Flat, 3 open sides and 3 8 mm chipboards upwards	4,3
Poly 3	Flat, all chipboard sides upwards	4,3
Poly 4	Single elements, both outward sides open	4,3
Poly 5	Single elements, 1 outward side open and 1 outward side 8 mm chipboard	4,3
Poly 6	Single elements, both outward sides chipboard	4,3

2.3 Preparation of the test rooms

The test rooms were fitted with diffusers following Annex A of ISO 354. Here, using a broadband absorber, an increasing number of diffusers is employed until a certain saturation of the absorption coefficient is realised. All absorbers that may have been present have been removed beforehand. Polycarbonate sheets with an area of 1,48 m x 0,9 m and 4 mm thickness were used as diffusers. A 100 mm thick, porous absorber with an area of 4,5 m² has been used for the diffusivity test. The rooms were finally fitted with five or 6 absorbers, making up (double-sided) between 15 % and 18 % of the room surface. An example for the qualification test is shown in Fig. 2.

ISO 354 specifies an upper limit for the equivalent absorption area A_1 of the empty room. Fig. 3 shows A_1 for rooms 1-5. The red line is the upper limit as specified by ISO 354 with frequency and magnitude adjusted for 50 m³ room volume. While three rooms stay well under the maximum limit, Room 3 exceeds the limits at some frequencies, and Room 1 is far beyond. Room 1 has some features different from all other rooms: The floor is fitted with a floating screed, the brickwork walls are not painted, and an opening to accommodate windows or glazings is covered with a chipboard laminated with lead. Room 2 and Room 3 are source and receiving room of a building acoustics test stand where a plastered lime brick wall (440 kg m²) was installed in the test opening. It could not be clarified why Room 3 has a significantly higher A_1. It was decided to nevertheless include all 5 rooms in the round robin for the moment to see if the results show noticeable deviations.

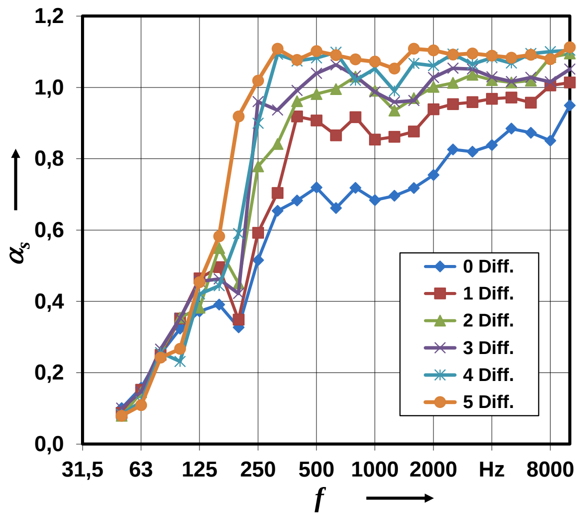

Figure 2. Example of a diffusivity test.

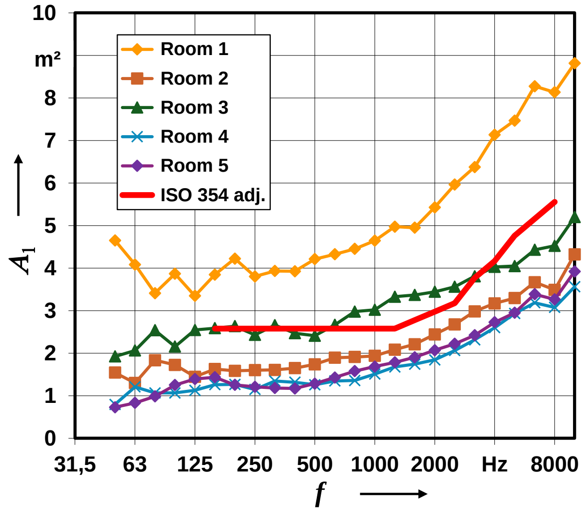

Figure 3. Equivalent absorption areas of empty rooms. ISO 354 specification adjusted for V = 50 m³.

2.4 Measurement results

The participants were requested to observe the specifications of ISO 354 as close as possible. In some cases, compromises were necessary due to the smaller room volume. Fig. 4 – Fig. 7 show some examples of the results.

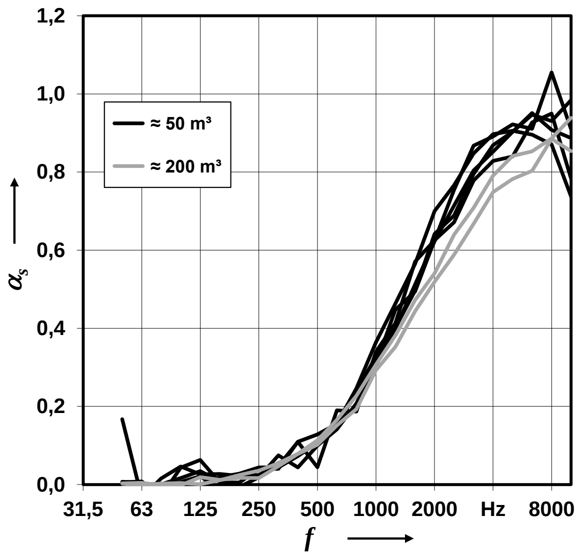

Figure 4. Absorption coefficients of carpet floor sample.

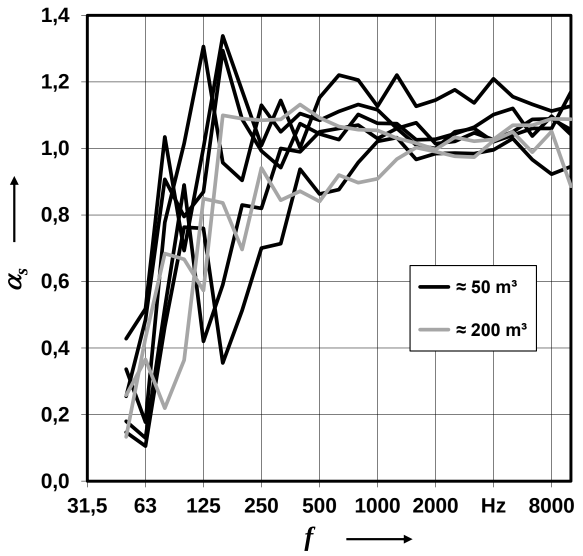

Figure 5. Absorption coefficients of 200 mm mineral wool absorber (“WG 35”).

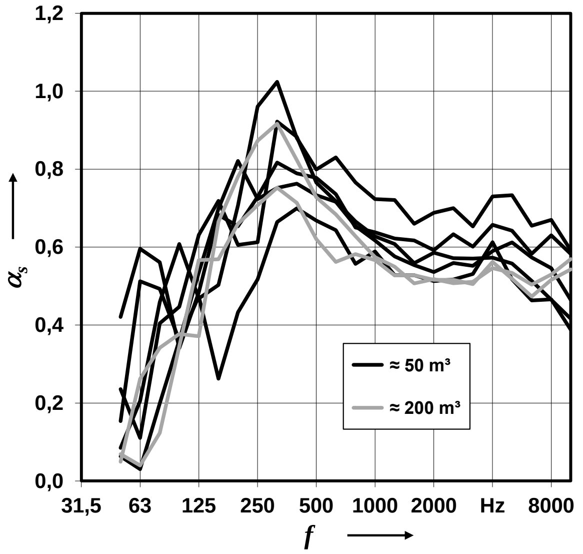

Figure 6. Absorption coefficients of Poly 2 sample.

It turned out that Room 1 delivered outlying results for the setups with individual elements (“Poly 4” – “Poly 6”). It was decided to not include these results for the statistical evaluation of the uncertainty coefficients, but to keep the data of the other absorber setups, because the data base is poor anyway.

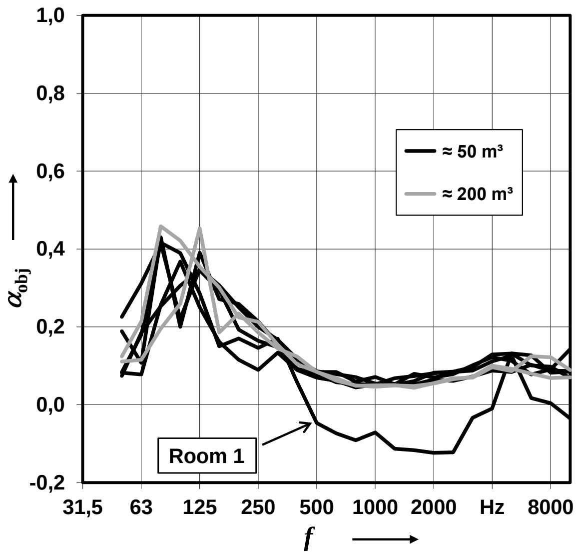

Figure 7. Absorption coefficients of Poly 6 sample.

3. EVALUATION OF RESULTS

3.1 Determination of coefficients *m* and *n*

The determination of the uncertainty coefficients follows the procedure described in [3], although the data base is much smaller. The average values for the individual samples and the respective standard deviations have been calculated and are shown in Fig. 8 and Fig. 9.

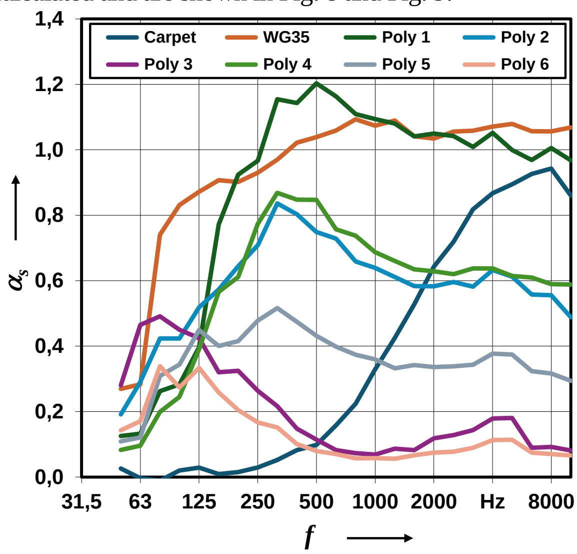

Figure 8. Average Absorption coefficients of individual samples.

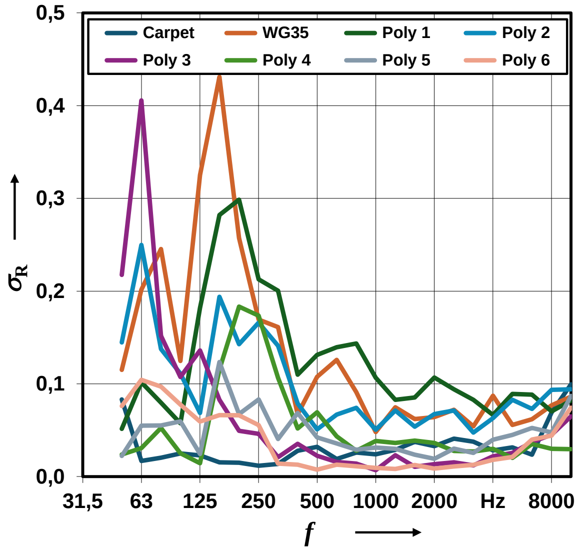

Figure 9. Standard deviation of reproducibility.

With this input data, it is now possible to determine the coefficients *m* and *n* from Eqn. (1) by linear regression. Fig. 10 gives an example for two one-third octave bands. For 125 Hz the correlation is quite low, as was to be expected regarding the small room volume and the low number of input data. For 1 kHz the correlation is much better. Finally, Fig. 11 and Fig. 12 show the coefficients obtained by the round robin data compared with those from [3], both in original form and shifted upwards by two one-third octave bands over the entire frequency range.

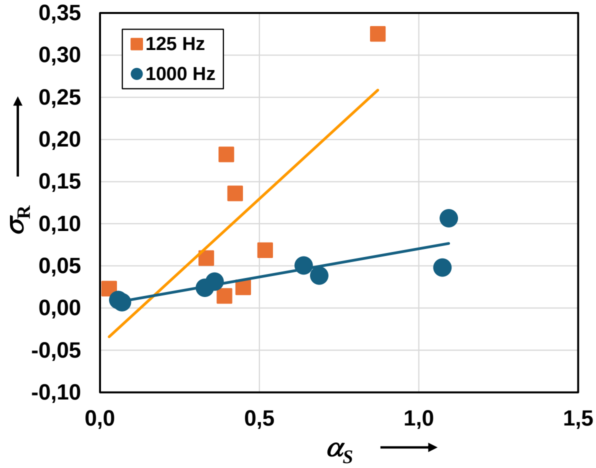

Figure 10. Obtaining *m* and *n* by linear regression.

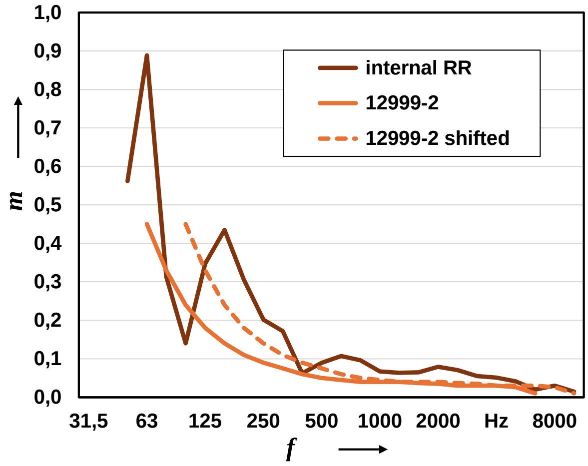

Figure 11. Results for coefficient *m*.

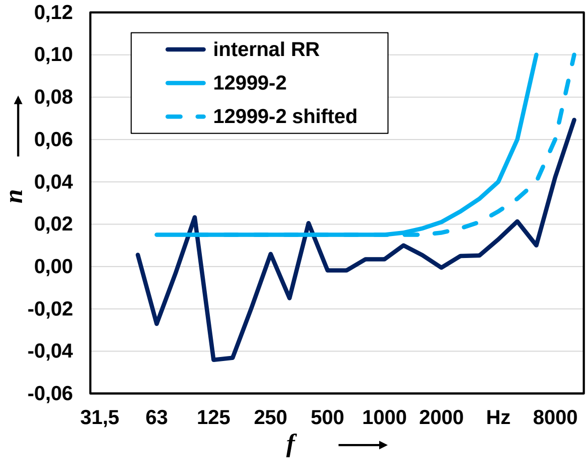

Figure 12. Results for coefficient *n*.

Regarding the low number of measurements considered, it seems to be reasonable to shift the values *m* and *n* from [3] by two one-third octave bands for a room size of 50 m³.

3.2 Combining results from different room volumes.

If the shifted values for *m* and *n* reasonably reflect the uncertainty for 50 m³ rooms, it should be possible to reduce the uncertainty by combining the results from two rooms of different size. In the frequency range where the original uncertainty $\sigma_{R,200}$ and the shifted uncertainty $\sigma_{R,50}$ are overlapping, the combined uncertainty is

$$\sigma_{R,\text{comb}} = \frac{\sqrt{\sigma_{R,200}{}^2 + \sigma_{R,50}{}^2}}{2}. \qquad (7)$$

This would be possible at the one-third octave bands from 100 Hz to 6300 Hz. In the case that both individual uncertainties $\sigma_{R,200}$ and $\sigma_{R,50}$ are equal, $\sigma_{R,\text{comb}}$ will be smaller than $\sigma_{R,200}$ and $\sigma_{R,50}$ by a factor of about 0,71 according to Eqn. (7). Fig. 13 and Fig. 14 illustrate the combination process. Fig. 13 shows the absorption coefficients for the "WG35" sample measured in both a "200 m³" room and a "50 m³" room, and the resulting average. The influence of the edge effect resulting from different sample sizes was not taken into account but should be considered in future research. The resulting uncertainties for the individual measurements and the combined uncertainty are shown in Fig. 14. For the calculation, the coefficients *m* and *n* from ISO 12999-2 were used shifted by two one-third octave bands for the 50 m³ room.

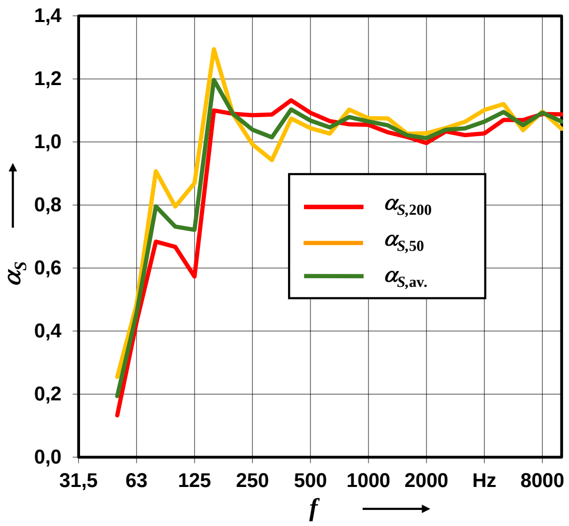

Figure 13: Example for individual and averaged absorption coefficient of "WG35" sample.

This example shows that for most one-third octave bands, the uncertainty of the reverberation room measurement is reduced. To get an idea of how the combination of uncertainties affects the overall uncertainty for all samples and room combinations, a stepwise evaluation procedure has been carried out. In a first step, for each sample the combined uncertainty was calculated for all ten possible combinations of "200 m³" and "50 m³" rooms (eight for the individual objects) using Eqn. (7), displayed in Fig. 15 as grey curves for the "WG35" sample.

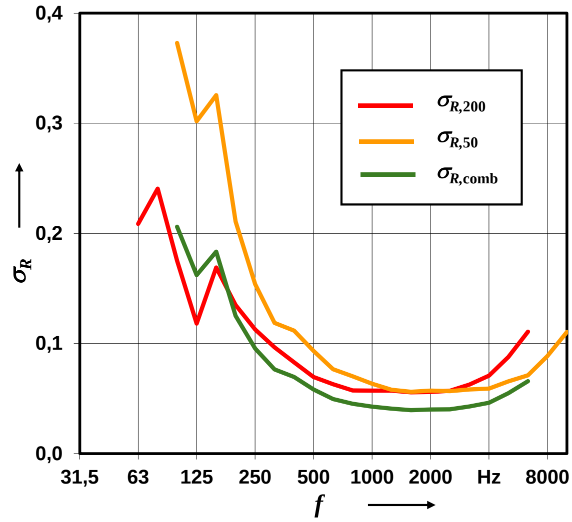

Figure 14: Respective individual and combined uncertainties for the absorption coefficients shown in Fig. 13.

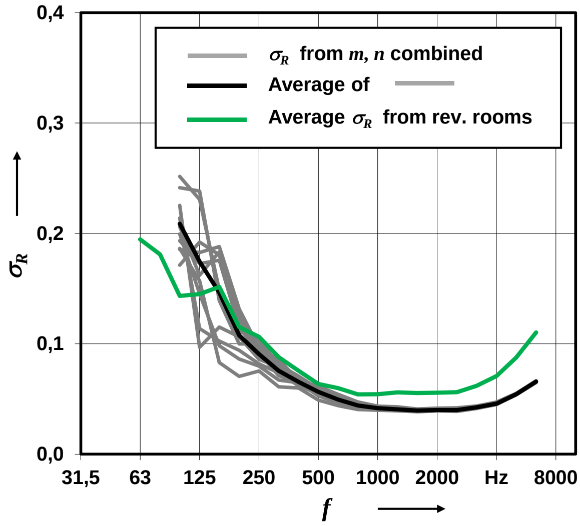

Figure 15: Combined uncertainties for "WG35" sample and average uncertainty of reverberation room measurements.

From these values the root mean square (black curve) was calculated, representing the average uncertainty $\sigma_{R,\text{comb}}$ that can be achieved by combining the different room volumes.

The green curve shows the root mean square of the uncertainties $\sigma_{R,\text{rev rooms}}$ from the two reverberation room measurements which is our best estimate of the uncertainty of a single measurement in a reverberation room.

As a result, the ratio of $\sigma_{R,\text{comb}}$ to $\sigma_{R,\text{rev rooms}}$ expresses the average reduction (if < 1) or increase (if > 1) of the uncertainty that results from the combination of absorption coefficient measurements in two different (nominal 200 m³ and 50 m³) room volumes in relation to a single measurement in a standardized reverberation room. This is displayed in Fig. 16 for all eight samples.

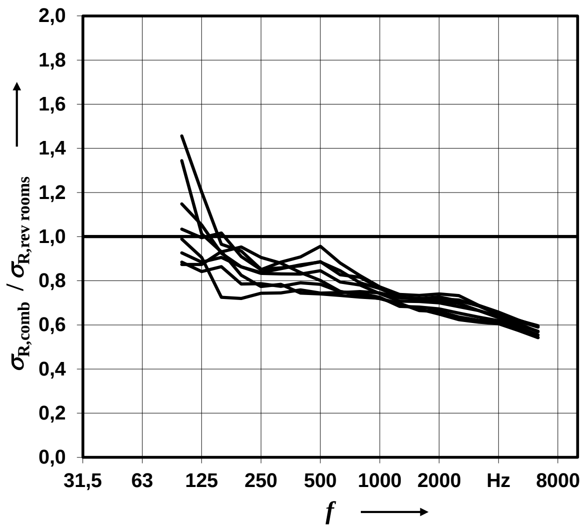

Figure 16: Ratio of $\sigma_{R,\text{comb}}$ to $\sigma_{R,\text{rev rooms}}$ for all samples.

A general reduction of the uncertainty is observed for all samples for all frequencies above 160 Hz. Above 1 kHz the results are quite uniform. A significant reduction of about a factor of 0,6 can be achieved at 6,3 kHz. Above this frequency, the combination is not possible because the coefficients *m* and *n* are not available. It should be mentioned again that of course all these considerations are based on a very small set of data, and further research on the topic is necessary.

4. CONCLUSION

An internal round robin conducted at PTB showed that measurement rooms with a volume in the range of 50 m³ deliver reasonable results for the absorption coefficient α_s, provided that the diffusivity of the rooms is adjusted properly. It was further shown that a combination of the results from the "50 m³" rooms with results from standardized reverberation rooms leads to a reduced uncertainty with respect to a single measurement in a reverberation room, especially at higher frequencies. However, given the very small amount of data this research is based on, further investigations are necessary to verify the presented findings. This also applies to the influence of the edge effect when results from different room sizes are compared.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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