PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Some comments on using a reference absorber for absorption measurements in reverberation rooms

Volker WITTSTOCK[1]; Heinrich BIETZ[1]; Sylvia STANGE-KÖLLING

[1] Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

ABSTRACT

The uncertainty of absorption measurements in reverberation rooms is considered to be unacceptably large for certain applications. A long-discussed possibility to reduce the uncertainty is to measure the absorption relative to the known or defined absorption of a reference absorber. To check this approach, measured absorption coefficients from a large data base with round robin results are explored. This check is possible because several different specimens have been measured in the same set of reverberation rooms in some of the round robins. Furthermore, a special reference absorber has been proposed recently. This material was used for a comparison measurement at PTB. About 10 different laboratories measured the sound absorption of the proposed reference absorber, using their own measurement equipment and data analysis, in one of PTB's reverberation rooms. Additional investigations involved measurements of the reference absorber and some other specimens in two different reverberation rooms at PTB. Measurement and analysis results are presented and discussed in view of the current proposals for the revision of ISO 354.

Keywords: Sound absorption, reverberation room

1. INTRODUCTION

The uncertainty of absorption measurements in reverberation rooms can be estimated according to (1 and 2). There, many round robins are statistically analysed, and the results are compressed into a simple numerical estimate for the standard deviation of reproducibility and repeatability. It is planned to incorporate this method in a possible future international standard ISO 12999-2, which is now under development. Nevertheless, this is a mere description of the current situation and there is no possibility to reduce the uncertainty which could be deduced from (1 or 2).

One proposal for reducing the uncertainty is the application of an appropriate reference absorber. This could be used for at least two different purposes. The first is to adjust a reverberation room in a certain manner. In the current ISO 354 (3), such a procedure is prescribed. A highly absorbing specimen is to be placed in the reverberation room and its absorption is to be measured with an increasing number of diffusors. The number of diffusors required for a maximum measured absorption is then to be used for all other specimens. A current proposal for revising ISO 354 is to prescribe one particular reference absorber, and to require that reverberation rooms are adjusted to yield a given minimum absorption. This is a much stronger requirement than in the current standard which is hoped to reduce the overall spread of measured sound absorptions.

Another application of a reference absorber would be to generally refer all measured absorption coefficients to the measurement results obtained with the reference absorber individually in each laboratory. This would reduce the spread of the measurement results if the uncertainty of the correction is sufficiently small. This is checked in this contribution in chapter 2 using existing round robin data.

To gain experience with the proposed reference absorber, PTB included sound absorption measurements into the comparison measurements. The participation in these measurements is compulsory for laboratories recognised by DIBt – the highest German building authority. A list of these laboratories is found under https://www.schall-pruefstellen.de. Usually, there are further companies and institutions with own laboratories, which voluntarily take part in the comparison measurements. So, different teams come to PTB's reverberation room and measure the sound absorption of the identical reference absorber using their own equipment. Results from these measurements are reported in chapter 3.

[1] volker.wittstock@ptb.de

Finally, absorption measurements in two different reverberation rooms at PTB were performed with the proposed reference absorber and several other absorbers. Results from these measurements are reported in chapter 4.

2. ANALYSIS OF EXISTING ROUND ROBIN DATA

2.1 Existing data sets

To check whether a reference absorber may be useful, only the round robin data where more than one product was measured in the same set of reverberation rooms can be used. An overview on such data sets is given in table 1. It is a subset of data from earlier investigations (1 and 2). It is considered that all these measurement results were obtained applying the procedure of ISO 354 (3). Measurement results from (7) were obtained following ASTM C 423 (8), nevertheless, in terms of uncertainty these results matched the ISO-results quite well (1). Therefore, this data set is also included in the analysis.

Table 1 – Round robins with more than one test object measured in the same set of reverberation rooms

Year	Object	Number of rev. rooms	Organisation
2011	15 mm wetfelt panel (*x*)	22	CEN TC 126 WG 11 (4)
	50 mm glass wool panel	22	
	12,5 mm perforated plaster board panel	22	
2009	100 mm mineral wool (*x*)	13	PEUTZ (5)
	„Dam board“ plywood/mineral wool	13	
	18 mm plywood on 100 mm mineral wool	13	
	33 mm Foam	13	
2006	Ceiling system, Mounting Type A (*x*)	16	ASTM (6)
	Ceiling system, Mounting Type E400	12	
1974	10 Baffles of mineral wool	11	Nord-Test (7)
	50 mm mineral wool (*x*)	12	
	50 mm mineral wool on battens	12	
	6 mm hardboard on battens	11	
	perforated gypsum board	12	

2.2 Correlation analysis

For a first check, possible correlations were explored by plotting the measured sound absorption for one specimen as a function of the sound absorption for another specimen. Some examples are shown in Figure 1 and 2. In these graphs, each data point represents one specific laboratory which performed measurements with the two mentioned specimens. When all points would be in a straight line, strong correlation would occur between the measured absorption coefficients for different specimens. This would mean that each laboratory would always measure with a certain offset which could be compensated for e.g. by using a reference specimen.

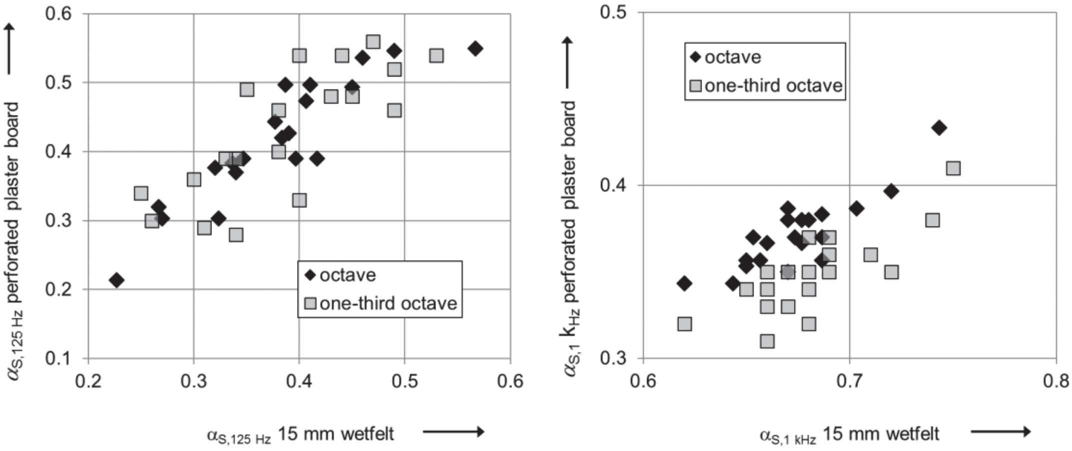

Figure 1 – Scatter plot between absorption coefficients of the wetfelt and the perforated plaster board from [4], measured in different reverberation rooms, left graph: 125 Hz, right graph: 1 kHz

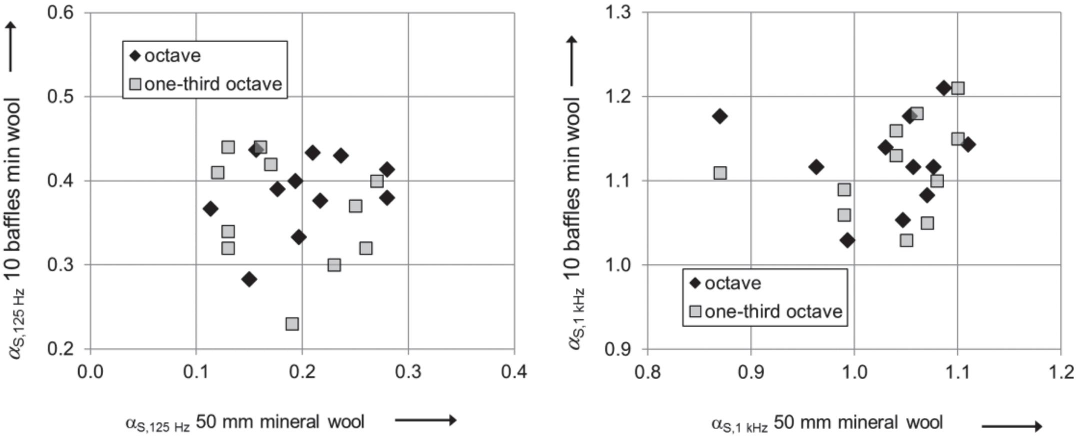

Figure 2 – Scatter plot between absorption coefficients of the 50 mm mineral wool and the mineral wool baffles from [7], measured in different reverberation rooms, left graph: 125 Hz, right graph: 1 kHz

Measurement results are available in one-third octave bands. The visual correlation analysis was performed in octave and one-third octave bands where the former was calculated by linearly averaging the three one-third octave band sound absorption coefficients which belong to the corresponding octave band.

Observed correlations cover a large spread. Many graphs show a considerable degree of correlation like presented in Figure 1. There are other examples where there is no correlation at all like presented in Figure 2. Correlations are detected for the octave band and for the one-third octave band values.

A statistical descriptor for the correlation is the correlation coefficient

$$r = \frac{\sum(x-\bar{x})\,(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\,\sum(y-\bar{y})^2}} \tag{1}$$

which was calculated for all cases of table 1. The test specimen chosen as the independent variable x is marked in table 1 by (x). Observed correlation coefficients are sometimes negative or close to zero (Figure 3), but many of them indicate a significant degree of correlation. Performing the analysis in octave bands smoothens the curves considerably and it increases the correlation coefficient in most cases.

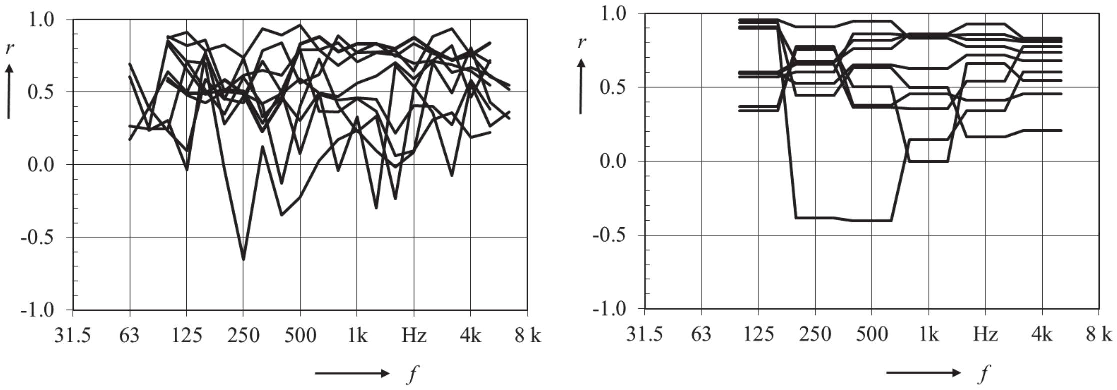

Figure 3 – Correlation coefficients calculated from measured absorption coefficients for all data from table 1, left hand side: one-third octave band values, right hand side: octave band values

2.3 Application of a reference absorber correction

A correction of the measured absorption coefficients would reduce the spread of the results if the correlation as described in clause 2.2 would be sufficiently large. This is tested by applying the correction

$$\alpha_{\text{spec},i,\text{ref}} = \frac{\alpha_{\text{spec},i}}{\alpha_{\text{ref},i}} \overline{\alpha_{\text{ref}}} \tag{2}$$

where $\alpha_{\text{spec},i}$ is the absorption coefficient of a certain specimen measured in laboratory i, $\alpha_{\text{ref},i}$ is the absorption coefficient of the reference specimen measured in laboratory i and $\overline{\alpha_{\text{ref}}}$ is the reference value for the absorption coefficient. For the analysis, the latter is chosen to be the mean value from all laboratories in the round robin. The reference specimens are those marked by (x) in table 1.

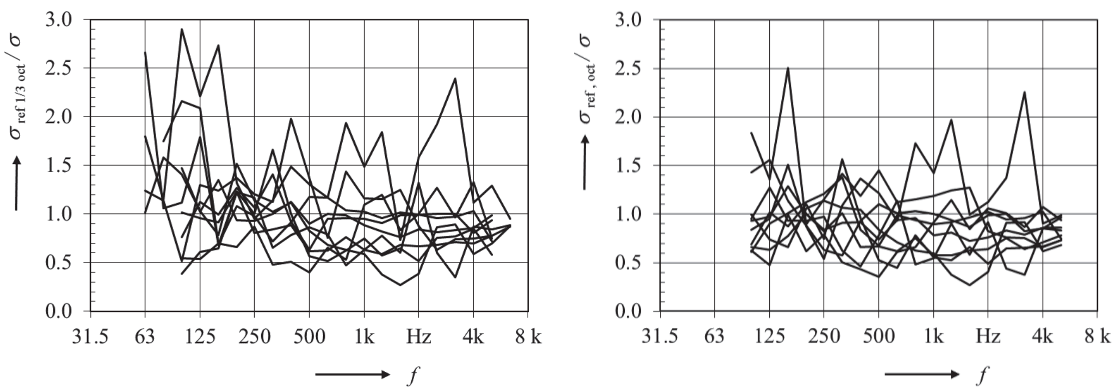

Figure 4 – Ratio between standard deviations of the corrected sound absorption coefficients to the standard deviation of the direct measurement results, left hand side: correction with one-third octave bands, right hand side: correction with octave band values for the reference absorber

The correction according to eq. (2) was applied, and the standard deviation of the corrected absorption coefficients was calculated. This standard deviation was divided by the standard deviation of the uncorrected absorption coefficients to see the change. When the whole calculation is performed in one-third octave bands, there are many cases where the standard deviation is significantly reduced (Figure 4, left hand side). But there are other cases where it increases. Omitting the worst cases, the ratio of standard deviations is roughly between 0.5 and 2.0. Correcting the measured one-third octave band absorption coefficients $\alpha_{\text{spec},i}$ with octave band values for the reference absorber $\alpha_{\text{ref},i}$ and $\overline{\alpha_{\text{ref}}}$ gives a slightly smaller ratio of standard deviation, i.e. it improves the effect of the correction.

Since there is no general dependency on frequency observed, neither for the correlation coefficients (Figure 3) nor for the standard deviation ratio (Figure 4), it is rather interesting to explore which correlation coefficient is required for a reduction of the standard deviation. The corresponding graph (right hand side of Figure 5) shows that correlation coefficients above 0.8 guarantee a reduction of the standard deviation. For smaller correlation coefficients, increased or reduced standard deviations are observed.

Another interesting question is whether the reference absorber should have a similar absorption as the test specimen. From the right-hand graph of Figure 5, it can be seen that the largest reductions of the standard deviation indeed occur for an α-ratio of 1. Nevertheless, a similar absorption coefficient between the specimen under test and the reference absorber does not guarantee a reduction of the standard deviation.

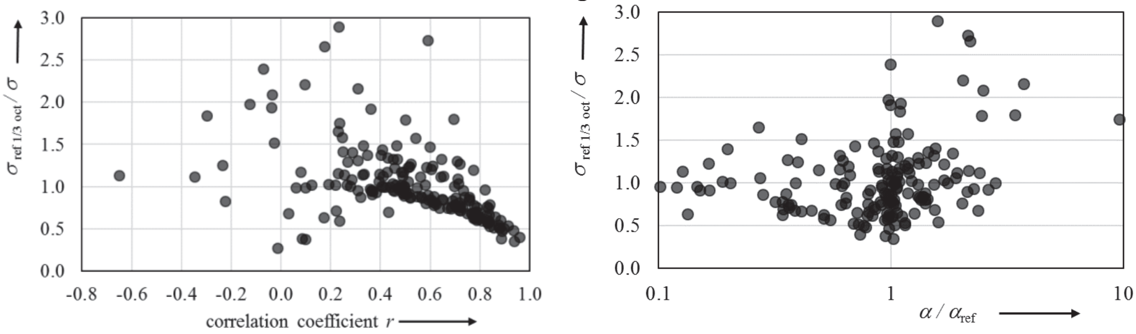

Figure 5 – Ratio between standard deviations of the corrected sound absorption coefficients to the standard deviation of the direct measurement results, left hand side: as a function of the correlation coefficient, right hand side: as a function of the ratio between the absorption coefficient and the absorption coefficient of the reference absorber

3. Comparison measurements at PTB

Measurements are performed in PTB's non-rectangular reverberation room. The room volume is 204 m³, the surface area is 210 m². The room is equipped with altogether 7 diffusors with a size of 2,4 m² (one-sided) which were arranged according to the procedure of ISO 354 (3). Furthermore, additional low-frequency damping was added to achieve sufficient modal overlap at low frequencies.

Each measurement team had the task to determine the absorption coefficient of a given test specimen according to ISO 354 (3). The arrangement of diffusors and additional absorption was not to be changed by the participants. Nevertheless, loudspeaker and microphone positions as well as the position of the test specimen had to be chosen by the participating acousticians. Each team used its own measurement equipment, i.e. loudspeaker, microphones and sound analysers. For test purposes, the frequency range of measurements was extended to one-third octave bands from 50 Hz to 10 kHz.

The test object is the currently proposed reference absorber. It consists of mineral wool panels of 1.2 m x 1.2 m x 0.1 m. These panels are to be installed by each measurement team on the floor of the reverberation room to give an absorbing element of 3.6 m x 3.0 m x 0.2 m. To reach these dimensions, some panels had to be cut which was done by PTB. All teams used the same set of panels. A 19 mm core board frame is provided by PTB so that the participants can cover the edges of the absorber.

The absorber is stored in the hall where the reverberation room is situated. Climatic conditions in this hall and in the reverberation room are very similar since there is no air-conditioning installed. All participants performed their own calculations based on their own measurement results. Only the volume of the reverberation room was provided since it is difficult to determine.

During the measurements, the static pressure was between 996 hPa and 1025 hPa, the temperature between 291 K and 296 °C and the relative humidity between 35 % and 49 %.

In general, measured absorption coefficients are within a relatively narrow range (Figure 6, left hand). At the lowest frequencies from 50 to 80 Hz, the scatter is surprisingly small whereas it is significantly larger at 100 Hz and 200 Hz. At 100 Hz, measured absorption coefficients cover the very large range between 0.35 and 0.85. For medium frequencies, the scatter range becomes narrower. Starting from about 4 kHz, it increases again, probably due to the air damping effect.

With the exception of 100 Hz and 200 Hz, the standard deviation of the measured absorption coefficients is much smaller than the standard deviation of reproducibility calculated by (1), see Figure 6, right hand. This result was expected, since the reproducibility standard deviation is considered to be caused mainly by the differences of the reverberation rooms. It is furthermore interesting to notice that the standard deviation from PTB's comparison measurement is very close to the repeatability standard deviation estimated from (1) with the mentioned exceptions. This indicates that the exact choice of microphone and loudspeaker positions as well as the measurement equipment and evaluation algorithms for the calculation of reverberation time are only of minor importance for the overall uncertainty. The main influence seems to be the reverberation room itself.

Another interesting question is how important the correction for air absorption is. To test this, the absorption coefficient was calculated from the directly reported reverberation times assuming the same environmental conditions for the measurement with and without the specimen in place. This is identical to the assumption of a constant air damping. The standard deviation of these absorption coefficients is identical to the one with air damping correction included (Figure 6, right graph).

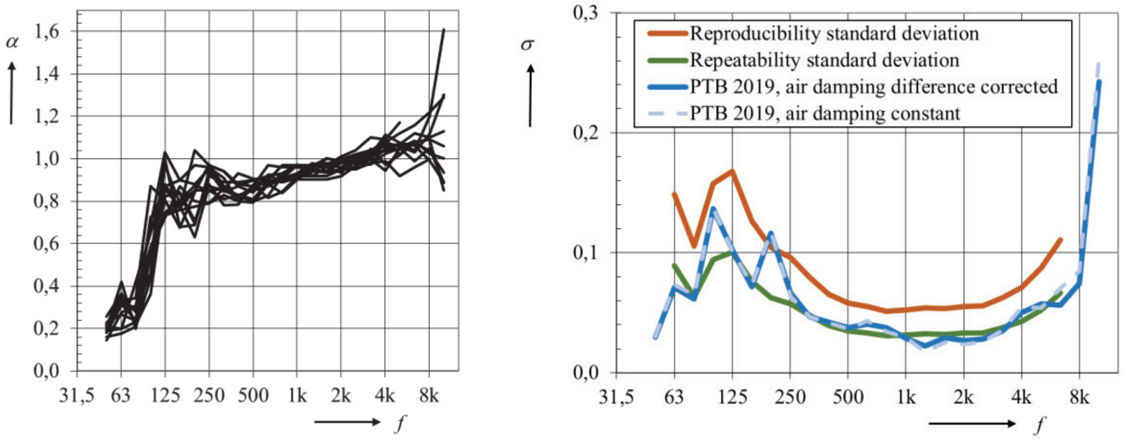

Figure 6 – Sound absorption coefficients measured by 12 independent teams in PTB's non-rectangular reverberation room (left hand side) and standard deviation of the results compared to the standard deviation of reproducibility and repeatability calculated by (1)

Figure 7 shows the total absorption area calculated from the mean reverberation times measured by all participants with and without the test specimen. Furthermore, the absorption areas corrected for air absorption A1 (without specimen) and A2 (with specimen) are shown as reported by the participants. The error bars indicate the standard deviation of the reported absorption areas. Since the difference of these two values has to be calculated, it is obvious that the result has a large uncertainty at high frequencies due to the large error bars in this range. The maximum absorption mentioned in ISO 354 (3) is also displayed. The additional low-frequency damping is adjusted to be close to that value to increase the modal overlap at low frequencies for the measurements without the specimen. Nevertheless, the equivalent absorption area A1 is below the maximum absorption area at all frequencies.

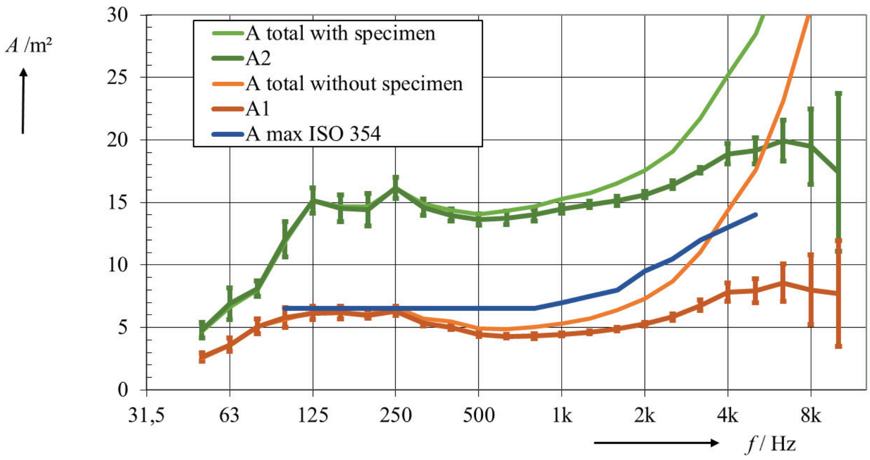

Figure 7 – Total equivalent absorption areas with and without specimen, equivalent absorption areas corrected for air absorption A1 (without specimen) and A2 (with specimen): mean values and standard deviation calculated from participant's data and maximum equivalent absorption area given in ISO 354 (3)

4. Additional measurements in two reverberation rooms at PTB

The measurements were performed in two different reverberation rooms at PTB. One is the non-rectangular reverberation room (NRR) described in clause 3.1. The other room is the rectangular reverberation room (RRR) with a volume of 237 m³ and a surface area of 246 m². The room is equipped with a rotating diffusor which rotates at 20 rpm during the measurements and has a surface area of 24 m² (both sides).

Test specimens are the reference absorber and additional specimens. One further specimen consisted of commercially available high density mineral wool panels. The nominal size of one panel is 600 mm x 600 mm x 15 mm. An array of 5 x 6 panels with a total surface of 10,6 m² was used. For a next set of tests, 12 specially designed absorbers were employed. These consist of a 1000 mm x 700 mm x 125 mm metal frame filled with a special polyester fleece material. One side is covered with a wooden panel of 16 mm (5 Absorbers) or 8 mm (7 Absorbers) thickness. In a first series, these absorbers were installed in a 4 x 3 array to create a plane absorber with a surface area of 8,6 m². The absorbers were arranged in three different configurations: 1.) All open sides facing upward; 2.) As a chequerboard pattern with 6 covered sides (all 8 mm panel) facing upward; 3.) All covered sides facing upward. In a second series, always two absorbers were placed together on edge (long side) to create six individual objects, which were distributed randomly in the reverberation room. Again, three different configurations were employed: 1.) all uncovered sides facing outward; 2.) Six covered sides (all 8 mm panels) facing outward; 3.) All covered sides facing out ward. For this series, the equivalent absorption area A and the absorption coefficient α_{obj} according to ISO 20189 (9) were calculated.

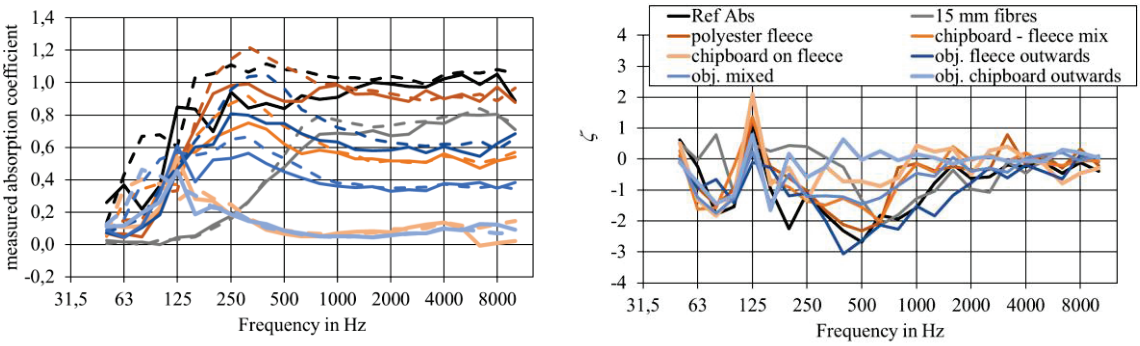

Figure 8 – Left-hand side: measured absorption coefficients, solid curves: non-rectangular reverberation room, dashed curves: rectangular reverberation room, colour code in the right graph, right-hand side: difference related to uncertainty for directly measured absorption coefficients

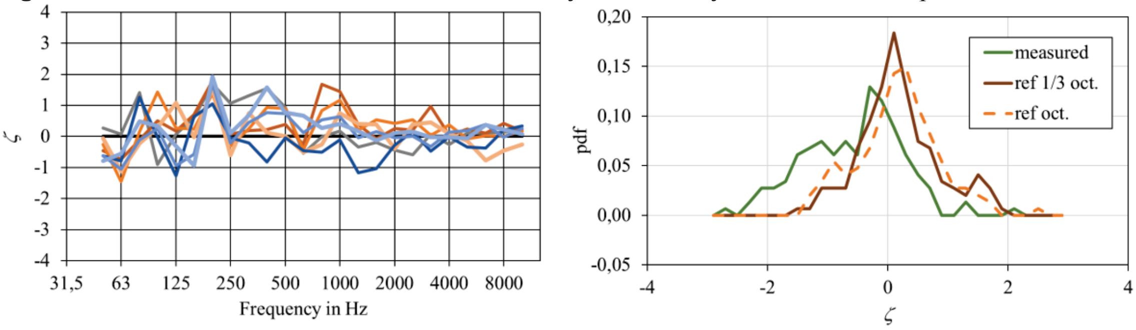

Figure 9 – Left-hand side: difference related to uncertainty for directly measured absorption coefficients, right-hand side: probability density functions of the differences related to uncertainty

Due to the variety of absorbers used, measurement results cover a large range of absorption coefficients (left graph of Figure 8). The difference of the measured absorption coefficients from both rooms was related to the uncertainties by

$$\zeta = \frac{\alpha_{\mathrm{NRR}} - \alpha_{\mathrm{RRR}}}{\sqrt{u^2(\alpha_{\mathrm{NRR}}) + u^2(\alpha_{\mathrm{RRR}})}} \tag{3}$$

where the uncertainties were estimated by the standard deviation of reproducibility from (1).

The results from both rooms clearly exhibit significant systematic deviations below 2 kHz (right graph of Figure 8). The rectangular reverberation room usually gives the larger results with the exception of the 125 Hz one-third octave band. Nevertheless, measured absorption coefficients are not really discrepant in view of the uncertainties. With the approach from eq. (3), about 95 % of the measurement results should be in the interval of ± 2,0. The observed percentage is 94 %.

Referring measured absorption coefficients to the absorption coefficients of the reference absorber in one-third octave bands introduces a positive shift to the results (left graph of Figure 9). An ideal result is obtained at 125 Hz. The systematic deviation between both rooms is eliminated by the correction at that frequency. At other frequencies, e.g. at 200 Hz, the systematic difference becomes larger by the correction. Since eq. (3) removes the main influences of frequency and magnitude of the absorption coefficient, results from all frequencies and test specimens were compressed into probability density functions (pdfs) for ζ (right graph of Figure 9). It can be seen from the pdfs that the mean value is shifted by referring the measured absorption coefficients to the reference absorber data in one-third octave bands from -0,6 to 0,2 whereas the standard deviation is reduced from 0,8 to 0,7. The effect of a correction with the octave band results of the reference absorber is nearly identical (also shown in the right graph of Figure 9). This demonstrates that the systematic difference between both rooms is significantly reduced whereas the statistical scatter is not changed significantly.

5. CONCLUSIONS

Round robin test results as well as additional measurements from two reverberation rooms at PTB suggest that the application of a reference absorber for correcting measured absorption coefficients may reduce systematic differences between laboratories. Further research has to show to which extent the uncertainty is decreased and whether the additional effort is justified.

Comparison measurements at PTB furthermore revealed that the spread of the measured absorption coefficients is relatively small when different measurement teams come to the same reverberation room and perform measurements without changing the room. This indicates that the exact choice of microphone and loudspeaker position as well as the algorithm for the calculation of reverberation time are only of minor importance.

ACKNOWLEDGEMENTS

The provision of the reference absorber by Ecophon is gratefully acknowledged. Furthermore, the authors thank the laboratories which participated in PTB's comparison measurement for the absorption coefficient in 2019.

REFERENCES

1. Wittstock, V.: Determination of measurement uncertainties in building acoustics by interlaboratory tests Part 2: Sound absorption measured in reverberation rooms. Acta Acustica united with Acustica: 104 (2018), 999 - 1008
2. Wittstock, V.: Uncertainty of sound absorption measurement in reverberation rooms: practical absorption coefficient and and single number value according to EN 1793-1. DAGA 2019, Rostock, 18.-21. März 2019
3. ISO 354, Acoustics -- Measurement of sound absorption in a reverberation room, 2003
4. A.-C. Thysell: *Test Codes for suspended ceilings. – Sound absorption RRT*. Tyrens AB project no. 224628, 2011
5. D. Tompson, M. Vercammen: *Round robin project*. PEUTZ B.V., 2009
6. Interlaboratory Study to establish precision statements for ASTM C423, Research Report E33-1010, ASTM, 2006
7. Internordisk Jämförelsemätning av Ljudabsorptionsfaktorn, SP-Rapp. 1974: 30
8. ASTM C423 - 09a Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method
9. ISO 20189:2018 Acoustics -- Screens, furniture and single objects intended for interior use -- Rating of sound absorption and sound reduction of elements based on laboratory measurements