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A suggestion to repeatability assessment in random incidence sound absorption measurements

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In recent years, efforts to increase comparability in random incidence sound absorption measurements have been studied in relation to updating of ISO 354. New and faster measurement setups have improved efficiency in laboratories. These setups also give the possibility to make more measurements on the same sample without much more effort. The uncertainty related to the repeatability in laboratories can hereby potentially be improved. Using combinations of multiple empty room measurements and multiple measurements with a sample, a range of results for α_s, α_p, and α_w for exactly the same sample can be reached. This holds a potential in research for dealing with the influence from pure measurement randomness. A look into this is presented.

1 Introduction

The standard for random incidence sound absorption measurements in Europa is ISO 354:2003, which currently is under revision. The standard has a range of problems relate the trustworthiness of the result. Some relates to comparisons between laboratories, some to uncertainty related to test method. A standard for evaluation of uncertainty is currently under developed in ISO on the basis of a number of interlaboratory round robin. It is called ISO/DIS 12999-2 [1]

The uncertainties of ISO/DIS 12999-2 are based on a single measurement run, which includes reverberation measurements in the same reverberation room for a reference case without sample and sampling case with sample. A minimum of twelve combination of speaker and microphone positions are used in each case and positions are chosen according to a number of requirements for distance from room surface and sample.

With the introduction of modern software based measurement setup, measurements of the twelve combinations of speaker and microphone positions can be made under 5 minutes. This is off cause a potential for the laboratories for greater efficiency, but it also holds a potential for dealing with the uncertainties relates to repeatability in laboratories. Especially in research or comparisons studies in the same laboratory a lower uncertainty related to the repeatability would increase the knowledge gained.

A study of this potential was made at ROCKWOOL International Acoustic Laboratory in Denmark. The first section describes the design of the reverberation room and its shortcomings. The second section is a description of the study and an overview of the results. The last section makes conclusions and an outlook.

2 Reverberation room at ROCKWOOL International A/S

2.1 Room design and measurement setup

The reverberations room at ROCKWOOL International Acoustic Laboratory is L-shaped room with a volume of 194 m^3. The room is fitted with diffusers of heavy and thick plastic. The room surfaces are heavy concrete floors, plastered brick walls, and approximately 60 m^2 of concrete ceiling and 20 m^2 of trapezoidal metal ceiling.

The tests are to the most possible extant performed according the ISO 354:2003 and EN 16487:2014. The test sample is placed near the corner in the L-shaped reverberation room as sketched in Fig. 1. The test object is placed with an approximate distance of 0.3 m to the nearest wall and minimum 1 m to the nearest diffusing element. The test sample is placed so that it is not parallel with any walls of the room. The test mountings used is in accordance with ISO 354:2003 and 16487:2014 including taping of all connections between frame and floor and frame and sample.

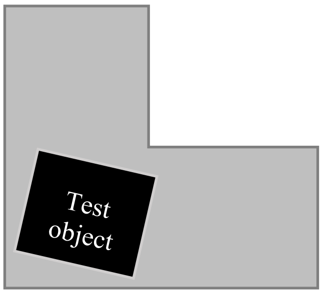

Figure 1: Sketch of reverberation room including approximate position of the test sample.

2.2 Measurement procedure and test mounting

The measurements are performed in accordance with ISO 354:2003 using the NOR850 software from Norsonic AS with an automated setup. It consists of three fixed speaker positions and fixed four microphone positions. The speakers are turned on in succession, one after the other, and five decays are carried out, before shifting to the next speaker. The four microphones measure the decays simultaneously, resulting in 20 measurement of reverberation time in less than 2 minutes. The duration of one automated measurement run is less than 5 minutes.

As a preference, the T30 reverberation times are used, but if the T20 reverberation times are found to be a better fit to the decay curve, this is used instead. If one measurement position is rejected, e.g. due to high background noise level, all four decays associated with the rejected decay, are deleted and a new set of four decays are for speaker position of interest. The reported reverberation time from one test is found using the real average over all 60 reverberation time measurements for each 1/3rd octave band..

3 Study and results

3.1 Uncertainty and repeatability of random incidence sound absorption

Uncertainty of a measurement can be related to both reproducibility and repeatability. In ISO/DIS 12999-2 [1] the repeatability condition is described as:

"condition of measurement that includes the same measurement procedure, same operator, same measuring system, same location (laboratory or usual building), and replicate measurements on the same objects over a short period of time"

and reproducibility condition is described as

"condition of measurement that includes the different laboratory, operators, measuring systems, and replicate measurements on the same or similar objects"

This study is only concerned with gaining more solid results within one laboratory, e.g. for comparisons studies and for this reason only repeatability is considered. To find the uncertainty due to randomness of a measurement result the standard deviation can be used. The expanded uncertainty U is related to a confidence interval, often 68%, 95% or 99%, using a covering factor, k. E.g. for a 95% confidence interval this covering factor k is 1.96. The expanded uncertainty U is found by

$$U = k \cdot \sigma_r \tag{1}$$

The repeatability standard deviation σ_r for one measurement of random incidence sound absorption is in [1] found using table values and the measured sound absorption coefficients as an input. The same is possible for the α_p's and α_w from ISO 11654:1997. The standard deviation of a mean value of x is found using

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}, \tag{2}$$

where σ_x is the standard deviation of the values $x_1, x_2 \ldots x_N$ and N is the number of measurements. [2] If the α_s value is a mean from a number tests then $\sigma_r = \sigma_{\bar{x}}$.

One measurement of α_s's includes a reference measurement without the sample in the reverberation room and one with the sample. By performing two or three instead only one of each of these measurements, one gains actual 4 or 9 results of α_s's, respectively, by cross comparisons. This leads to that using mean values instead of only one measurement the standard deviation and the expanded uncertainty can be lower by a factor or 2 or 3, respectively. Actually one cannot get a standard deviation from a single measurement, why this value and the expanded uncertainty must in this be reach from table values like in [1].

To find the uncertainty of the mean of α_w according to ISO 11654:1997, simple rules for sum combinations of independent uncertainties can be used. In short, the uncertainty of $\overline{\alpha_w}$ are found as the quadratic sum of standard deviations for frequencies from 200 Hz to 5 kHz times a covering factor and divided by the square root of the number of measurements. Equation (3) puts it all together

$$U_{\overline{\alpha_w}} = k \cdot \frac{1}{\sqrt{N}} \cdot \sqrt{\sum_{i=200\ Hz}^{5\ kHz} \sigma_i{}^2}, \tag{3}$$

where i is the 1/3 octave bands and σ_i is the standard deviation of i^{th} band coming from the N measurement.

3.2 Description of samples and study

Four stone wool based samples were selected for testing in the ROCKWOOL International Acoustic Laboratory reverberation room. The samples are described in Table 1.

Table 1: Overview of samples for case study

Sample	Approx. thickness	Norminal density	Mounting (ISO 354)
A	20 mm	150 kg/m^3	A mounting
B	100 mm	50 kg/m^3	A mounting
C	20 mm	150 kg/m^3	E200
D	20 mm	150 kg/m^3	E200

Reverberation room results as described in section 2.2 was measured 3 times for each sample. In connection to these tests also an empty room result was found 3 times. All in all nine evaluations leading to nine results of α_s's, α_p's and α_w were found for each sample.

3.3 Results

In the following pages results expressed as α_s according to ISO 354:2003 and α_p and α_w, according to ISO 11654:1997 are presented as means of nine test. Also σ_r according to ISO/DIS 12999-2:2019 and equation (2) and related expanded uncertainties U are visualized.

3.3.1 Random incidence, practical and weighted sound absorption

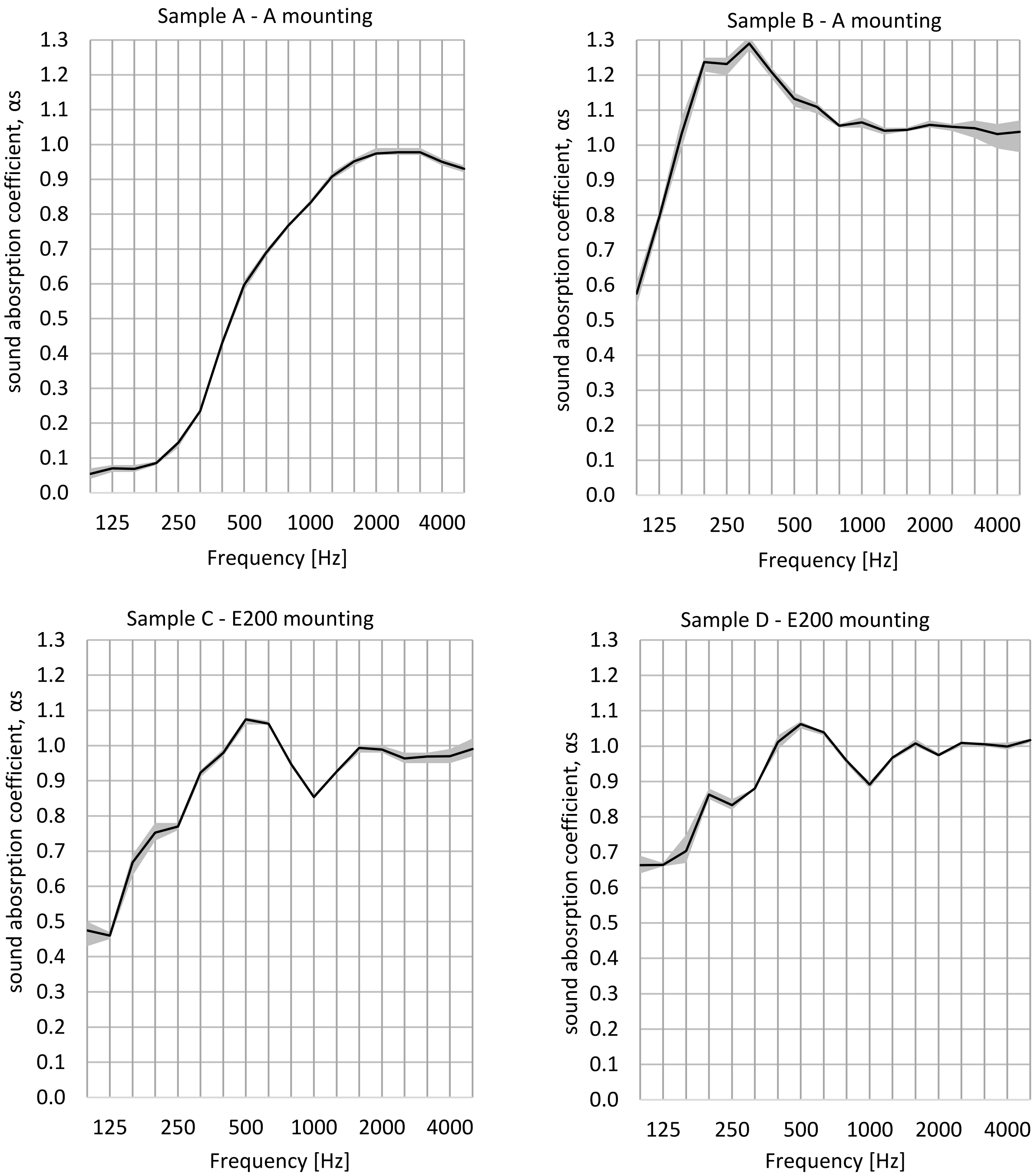

Figure 2: Averages of nine random incidence sound absorption results gain for 3 by 3 measurements of reverberation time with and without sample. The grey shadows mark the maximum and minimum results of all nine evaluations.

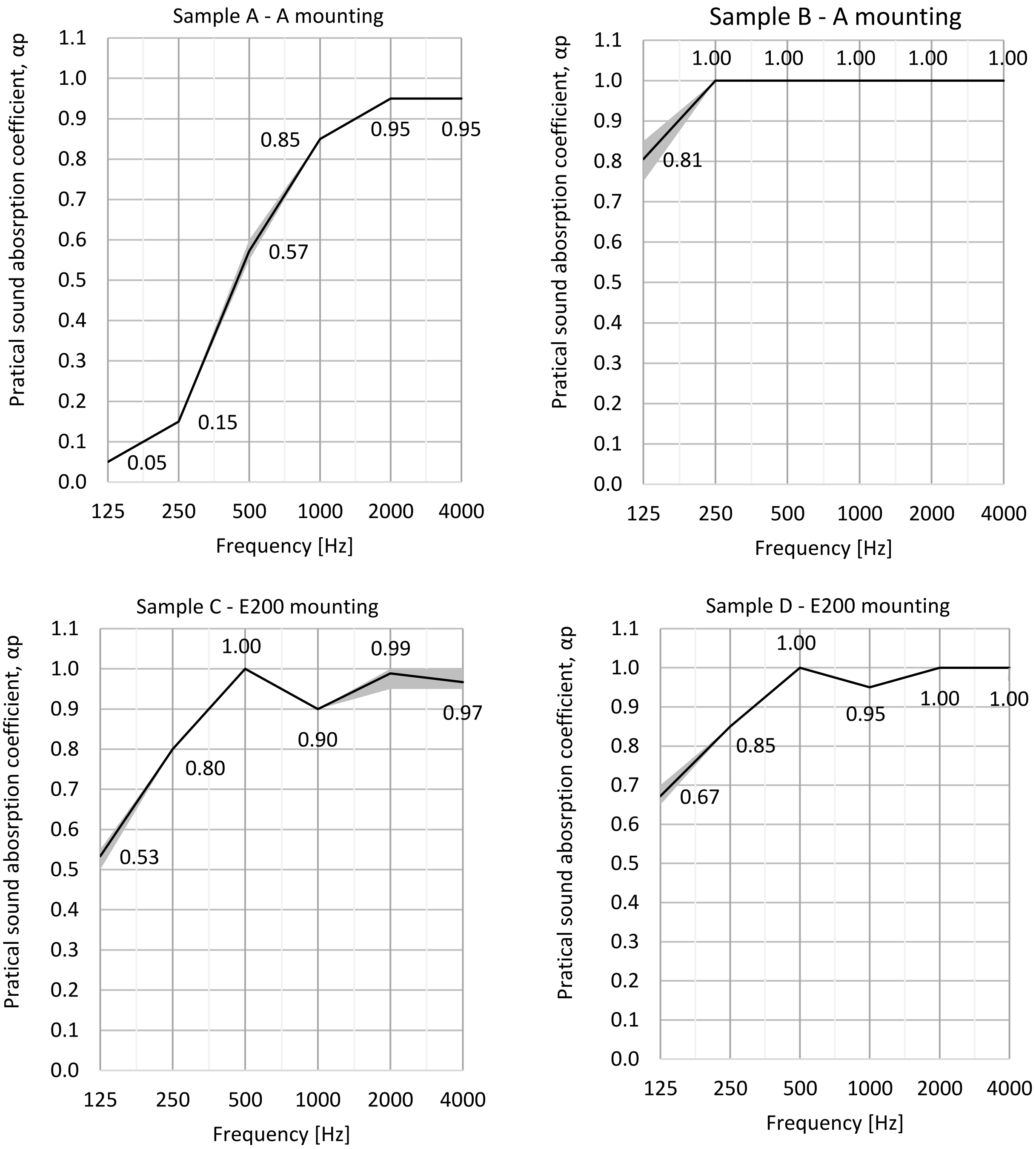

Figure 3: Averages of nine practical sound absorption results gain for 3 by 3 measurements of reverberation time with and without sample. The grey shadows mark the maximum and minimum results of all nine evaluations.

Table 2: Mean of α_w from nine test of random incidence sound absorption and evaluation of α_p. Cf. figures 2 and 3. Uncertainty ranges are expanded uncertainties using a 95% confidence level (k = 1.96) under repeatability conditions.

	Sample A	Sample B	Sample C	Sample D
Mean of α_w from nine test, $\overline{\alpha_w}$	0.45 ± 0.01	1.00 ± 0.04	0.99 ± 0.02	1.00 ± 0.02

3.3.2 Standard deviations and expanded uncertainties

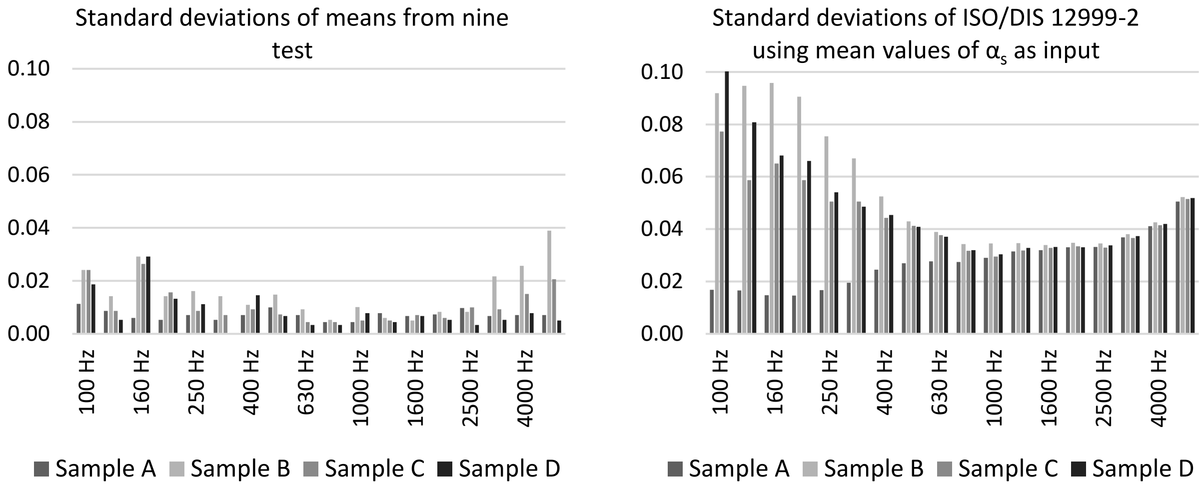

Figure 4: Left subfigure: Standard deviations of means from nine test on the four samples under repeatability conditions. Right subfigure: Calculated standard deviations for test on the four samples under repeatability conditions using ISO/DIS 12999-2 and the mean α_s's as input.

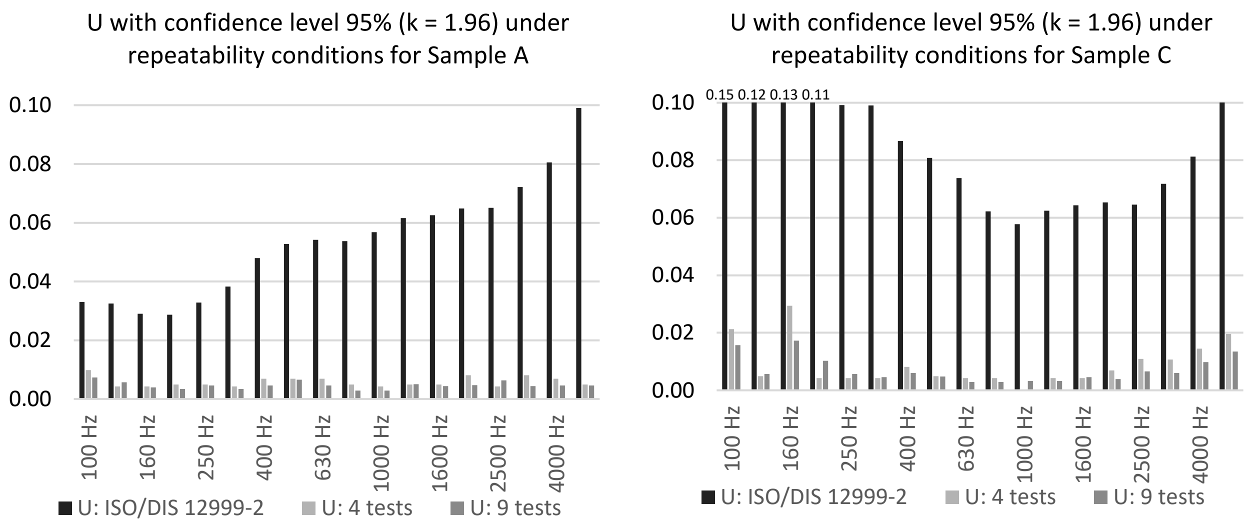

Figure 5: Expanded uncertainty, U, with confidence level 95% (k = 1.96) under repeatability conditions for Sample A and C according to ISO/DIS 12999-2, using four and nine results of studies, respectively. Calculated standard deviations according to ISO/DIS 12999-2 is based on the mean α_s's as input.

3.4 Conclusions and outlook

Comparisons of the standard deviations and expanded uncertainty based on the ISO/DIS 12999-2 and the measurements of under repeatability conditions point to that these values are hugely overestimated in ISO/DIS 12999-2 for this particular reverberation room. E.g. using only one measurement result and ISO/DIS 12999-2's prediction of uncertainty, one could risk falsely concluded that results of Samples C and D are not distinguishable.

On the other hand, the suggested approach of equation (3) do not seem like a fitting approach for finding uncertainty of $\overline{\alpha_w}$, since sample B, which in this study have all α_s's in the evaluation frequency range above 1.00. A better way could be to give a probability associated with the $\overline{\alpha_w}$ being within a fixed range, $\pm$E. E.g. the result would be $\overline{\alpha_w} \pm$ E with a certainty of X %. A fitting E could be 0.02, since this would tell whether the probability of jumping a step in α_w would be small or large.

Anyway, using means to express α_p and α_w do seem beneficial for comparisons study since a better sense of whether the results is close to reaching a lower or higher value is directly expressed from the result.

The considerable uncertainties under reproducibility conditions introduced in ISO 12999-2, points to the fact that not much is gained from multiple measurements, when documenting absorption values of products. At least this is true with the current version of ISO 354.

References

[1] ISO, ISO/DIS 12999-2, 2019

[2] J.R. Taylor, An introduction to Error Analysis, 2nd edition, 1997.