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On the revision of ISO 354, measurement of the sound absorption in the reverberation room

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ABSTRACT

The measurement method for diffuse field sound absorption (ISO 354) is troubled with low reproducibility, far worse than can be accepted in respect to design of spaces, control of quality and legal security. This is caused by deviations from the basic assumption for the relation between sound absorption and reverberation time: the presence of a homogeneous and isotropic sound field. Research has been done to increase and quantify the diffusivity of the sound field in the room.

It was found that indeed it is possible to improve the diffusivity but the only reliable indicator of the diffusivity is the sound absorption of the sample itself. Only improving the room will not take away the differences between laboratories. An ISO working group has made a working draft for the revision of ISO 354, that contains a qualification of the room with a minimum sound absorption of a reference absorber and correction of the outcome of every sample, based on the measurement result of the reference absorber.

This working draft was circulated and commented. A basic outline of the method is presented as well as a summary of the comments given.

Keywords: Sound absorption, ISO 354, Reverberation

1. INTRODUCTION

The measurement method for diffuse field sound absorption, ISO 354 (1) has some drawbacks, the most important one is the low reproducibility , far worse than can be accepted in respect to design of spaces, control of quality and legal security (2). The difference of measured α_w of a specific product measured in two laboratories can be up to 0.1, which is equal to the difference between sound absorption classes A and B according to ISO 11654. This low reproducibility is caused by deviations from the basic assumption for the relation between sound absorption, volume and reverberation time (Sabine’s equation): the presence of a homogeneous and isotropic sound field. Research has been done to increase and quantify the diffusivity of the sound field in the room (2,5,6,7).

It was concluded that qualification of a room should be done based on a minimum absorption of a reference sample and that a correction procedure would be needed based on the absorption of this reference sample. This is the basic outline of the a revision of ISO 354, a working draft (WD) has been circulated in 2018. In this paper we will present the main changes in this revision, as well as the main comments given on this draft.

2. USING A REFENCE ABSORBER

2.1 Qualification of the reverberation chamber

An important step in reducing the inter-laboratory spread is standardizing an qualifying the reverberation chamber. The current standard contains a method of increasing the diffusers in the room until a maximum is reached. But by doing that a part of the volume can be decoupled (2) and rearranging the same number of diffusers may even further increase the absorption. Attempts were made to qualify the diffusivity of the sound field (3,5,6) but the conclusion was that the measurement of the sound absorption itself was the only good indicator (5,6). So the draft ISO 354 has a minimum requirement for the absorption of a reference absorber.

This reference absorber was developed, based on the requirement of a sound absorption close to 1.0

for all frequencies. The reason for this is that for such a high sound absorption small differences the properties (like weight, thickness, air flo resistivity) have minor impact on the sound absorption. It was decided to choose a 200 mm (2x100) thick glass wool sample (8, 9). Although attempts have been made to derive the theoretical correct ("true") absorption value, it is hardly possible to do so, mainly because of the unknowns in the edge effect (8). So the absorption of this reference absorber needed to be stated, see table 1. To equal out variations in (low) frequency third octave bands, the requirements are set in octave bands.

Table 1 - Required absorption of the reference absorber (10.8 m^2)

Octave band frequency [Hz]	125	250	500	1000	2000	4000
A_{req} [m^2]	10,3	10,6	10,9	11,1	11,1	11,1

2.2 Absorption correction factor γ

After this minimum absorption value has been obtained, by increasing the sound diffusion in the chamber, a minimum diffusivity of the sound field is obtained. However, still differences between laboratories can occur, which might be frequency dependant as well. To level out these differences between laboratories the new standard contains a method to correct the measured absorption of test object by correcting for this excess of absorption:

$$A_T = \gamma(A_2 - A_1) = 55{,}3\gamma\left(\frac{V_2}{c_2T_2} - \frac{V_1}{c_1T_1}\right) - 4\gamma(V_2m_2 - V_1m_1) \quad (1)$$

Where subscript 1=without sample, 2=with sample, V=Volume [m^3], A=Absorption [m^2], m=power attenuation coefficient [m^{-1}], T=reverberation time [s] and γ is the absorption correction factor, based on the ratio of required absorption according to the measured absorption with the reference absorber $A_{s,ref}$:

$$\gamma = A_{req} / A_{s,ref} \quad (2)$$

The qualification of the room is done for the standard position on the floor. Since there is a minimum requirement to the absorption (table 1), it follows that $\gamma \leq 1$ at this position. For other positions in the room, like for the wall (for example for measuring curtains), the reference value of the absorption with the reference absorber has also to measured. But for those positions there is not a minimum requirement. The absorption can be higher or lower than the values in table 1, resulting in a γ that can be lower, equal or higher than 1.

From a round robin investigation with several samples, one of these being used as reference absorber, the reproducibility standard deviation was measured (2). Using the method shown in ISO 12999-2 (10), the uncertainty for a sample with α=1 was derived, after aplication of the correction method with formula (1) and (2), see table 2 and figure 1. The data on the 2003 version of ISO 354 are from (10).

Table 2 - . Indication of the uncertainty under reproducibility conditions for absorptive materials with $\alpha_s \approx 1$

frequency [Hz]	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k
ISO 354:2003 [1)]	0,255	0,195	0,155	0,125	0,105	0,09	0,075	0,065	0,06	0,055	0,055	0,056	0,055	0,056	0,057	0,062	0,07	0,086
ISO 354:2018 [2)]	0,267	0,142	0,124	0,076	0,063	0,029	0,041	0,028	0,037	0,029	0,031	0,023	0,024	0,028	0,029	0,025	0,047	0,015

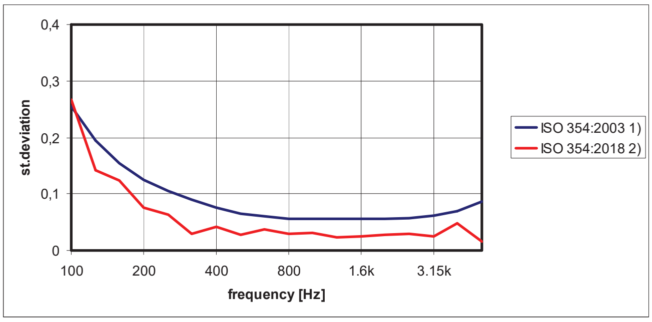

Figure 1 - Indication of the uncertainty under reproducibility conditions for absorptive materials with $\alpha_s \approx 1$

These results show that significant improvements in inter-laboratory variation are possible. Of course large scale studies are needed to obtain more reliable data on the reproducibility standard deviation.

3. OTHER CHANGES IN ISO 354/WD

3.1 Improvements regarding the reverberation chamber and test setup

3.1.1 Linearity of the decay

The diffusion of the reverberation chamber can be impoved by diffusing elements, either freely suspended or attached to ceiling and walls. In the latter case there is no doubt on the volume of the room, in the first case there is a risk that the volume behind the diffuser is decoupled. There are two requirements in the WD that intend to improve the diffusivity. First requirement is the already mentioned minimum absorption of the reference sample on the standard position, the second is a requirement regarding the linearity of the decay.

Non linear decays may be caused by:

- unbalanced damping modes within an third-octave band at low frequencies,
- presence of (de)coupled spaces, for example behind diffusers,
- insufficient diffusivity, resulting in different decays for horizontal and vertical sound fields,
- influence of background noise in the last part of the decay,
- incorrect ensemble averaging.

The “double decay” or “curvature” C_m is determined by splitting the evaluation range of 30 dB into a top part (T_t) and a bottom part (T_b) of 15 dB:

$$C_m = 100\left(\frac{T_b}{T_t} - 1\right) \ [\%] \tag{3}$$

The average curvature should be less than can be expected based on the theoretical variation of the curvature, resulting from the statistical variation of the reverberation time (11):

$$\left|\overline{C}_m\right| < \frac{294}{\sqrt{fT}} \tag{4}$$

3.1.2 Sample size, maximum absorption, and volume

The sound absorption, especially for highly absorptive samples, is influenced by the edge-effect (or “area-effect”). That means that the sound absorption and sound absorption coefficient is dependant on the size and shape of a sample. For a good reproducibility the size of the sample should be fixed as much as possible. In the new standard the sample size of 10-12 m^2 is maintained, but the correction of the upper limit in case of a larger chamber is removed. Also the correction for the maximum absorption in the empty room for larger room volumes is removed. Consequently a maximum of 300 m^3 is introduced for the room size. The minimum recommended volume of 200 m^3 is used as minimum, in view of the low frequency behaviour. A room volume between 200 and 250 m^3 is recommended.

3.1.3 Damping the room

The bandwidth of room modes relates to the damping of the room mode. Damping the room modes will increasing the bandwidth, improve the overlap, resulting in a lower Schroeder frequency and better diffusivity at these frequencies. Especially considering the large standard variation at low frequencies (see figure 1) it is recommended in the WD to increase the sound absorption in the empty room until just below the maximum absorption values required in the standard. This can be done with tuned and damped plate absorbers.

3.1.4 Sound sources

Excitation of low frequency room modes can best be done from the corner. This prevents unbalanced room modes. Requirements for loudspeaker positions and uniform radiation are in a new Annex H.

3.2 Improvements in the measurement procedures

3.2.1 Evaluation range

The statistical variation of individual decays and therefore also the variation of the average reverberation time depends on the evaluation range *D*. For 20 and 30 dB range, and third octave bands with center frequency *f*, the expected spatial variance σ^2 (for different source-mic positions, not including the effect of ensemble variation) is (12):

$$D{=}20\text{ dB:}\quad \sigma_s^2(T) = 2{,}8\,T/f \tag{5a}$$

$$D{=}30\text{ dB:}\quad \sigma_s^2(T) = 1{,}09\,T/f \tag{5b}$$

Because of the significantly lower variance, the evaluation range is increased from 20 to 30 dB.

3.2.2 Interrupted noise

The statistical fluctuating character of noise adds to the variance of the decays, this significantly contributes to the total variance of the average reverberation time, for 30 dB range (12):

$$\overline{\sigma}^2(T) = T\,\frac{1{,}09 + 1{,}65/n}{Nf} \tag{6}$$

Where N=number of source-mic combinations and n=number of ensemble averages per source-mic position. The number of ensemble averages for interrupted noise method is increased from 3 to 6.

The ensemble variation is further optimized by prescribing a time constant and ensemble averaging. The time constant of an exponential or linear averaging device should be close to T/20, thus maximising averaging in time domain, while still having sufficient samples for least square fitting. This frequency dependent time constant can be realised by post-processing.

Ensemble averaging is done by averaging in time domain. This requires exact timing for the switch off point of the noise, otherwise a S-shape curve will appear.

3.2.3 Integrated impulse

The required backward (Schroeder) integration of the squared impulse response has a drawback: The tail of the decay is dominated by noise, and starting the backward integration at the start (end) of the slope truncates a relevant, triangular, energy part. The backward integration can be described by (13):

$$E(t) = \int_{t_2}^{t} p^2(\tau)\,d(-\tau) + C \tag{7}$$

where *C* is the truncated energy after t_2. *C* can be calculated from the estimated reverberation time $\hat{T}$ and the sound level L_{t2} of the signal at time t_2:

$$C = 10^{L_{t2}/10}\,\frac{\hat{T}}{13{,}82} \tag{8}$$

The estimated reverberation time can be derived from a first linear fit of the non integrated data.

3.2.4 volume of the sample

The sample can take up a significant part of the volume of the chamber. A correction will be applied in case of samples larger than 2 m^3, which corresponds roughly to a height of 20 cm.

3.2.5 Temperature and humidity

Temperature and humidity can have influence on the reproducibility, as shown by (14). Increasing the lower limit for the humidity from 30% to 50% could be an option, but the risk is that with different conditions in the room and the environment short term fluctuations due to opening of doors can have a strong negative impact. Rather than setting a lower limit to humidity, a requirement was added to limit the influence of environment conditions before and after the test to 3%:

$$4V(m_2 - m_1)/S < 0{,}03 \quad (9)$$

3.3 Non normative annexes

The new Annex A contains a recommendation that the measured statistical variation of the reverberation time, averaged over the frequency range from 250 to 3150 Hz, should not be more than the theoretical variation. The statistical variation is not a precise instrument for qualification of the diffusivity of the room, but it turns out to be a valuable tool to verify the accuracy of the chain.

Though this may surprise, the sound absorption coefficient relates to sample size, as indicated in 3.1.2. Annex D presents a method to estimate the sound absorption coefficient for other dimensions than measured in the laboratory, derived from (15) and described in (4).

Optimal situation would be exactly to prescribe the measurement instrument: size, shape and materials of the reverberation chamber. Due to the existence of many rooms and investment costs related to changing these rooms, this is not feasible. Also there is no clear view on what the "perfect" shape of a reverberation room should be. So we have to settle with some design guidelines for new (and existing) rooms, that are given in Annex E of the WD.

Annex F gives a method to estimate the repeatability standard deviation (so within the laboratory) based on the variance of the measured reverberation times. Without doing additional measurements, an impression on the actual uncertainty can be obtained. This can be helpful as quality check, especially for low absorbing materials.

4. COMMENTS ON THE ISO 354/WD AND DISCUSSION

The WD was circulated and 103 comments were received. Several comments expressed support for the concept with a reference absorber. Nevertheless, the concept is new and quite different from the existing standard, so also questions arise, partly due to lack of knowledge of the underlying research. Also comments were received that are very usefull for further improvement of the document.

Some of the most relevant comments are summarized below (rephrased). In *italics* the response or discussion on the comment is presented.

- Is this the best possible absorber in terms of stability of material properties and in terms of acoustics ? *The material is very stable, there is no other product proposed that fulfils the other criteria, with the same or better claim regarding stability. The high absorption ensures low sensitivity to small changes in product properties, see par. 2.1 and (8).*
- Is future delivery guaranteed ? *There is no 100% guarantee, but the product already exists over 20 years and continuation is very likely.*
- Shouldn't we have also an "half-way" range absorber ? *A "half-way" absorber has larger uncertainties regarding the "true" absorption value. Furthermore: the method with the reference absorber based on α=1 already gives an important, first order improvement of the results. Adding a "half-way" absorber would, at best, add a second order improvement.*
- The required "correction" is expected to be more for strongly absorbing samples, that influence the sound field, than for low absorbing samples. *The correction is also relative: it gets smaller for low absorptive samples.*
- Could we use the absorber as reference for every measurement, in stead of the empty room ? *That is an interesting option, in stead of comparing to a surface with $\alpha \approx 0$ a comparison is made with a surface $\alpha \approx 1$. It will introduce significantly more effort though, since the measurement with the reference absorber need to be done directly before and/or after measuring the test object. For the moment it is decided not to follow this route.*
- What is a good frequency to verify the absorption of the reference absorber ? Once a year seems too little. *This seems a relevant point. It still has to be decided what could be a good interval. There is also the question on how to deal with the variation of consecutive measurements of the reference absorber.*
- Procedural comment: A round robin is requested which does not fit into the time line so a delay is requested. *This idea is supported by the working group. At this moment there is an Italian round*

robin going on, that might give useful results for further progress with this standard.

- The new ISO 354 will give other results than the 2003 version, some comments address that as a problem. *This seems to be a logical result of changing a standard. However there is no systematic change expected. A possible disadvantage of a different outcome from testing a sample based on the new standard, is to be considered less important as the advantage of obtaining results that are much less depending from the actual laboratory where the measurements took place. Nevertheless, it will be allowed that additionally the results without correction γ will be reported by the laboratory.*
- Since $\gamma \leq 1$ for the standard position, it is feared that future data will be systematically lower than the existing. *This argumentation overlooks the fact that the required minimum absorption of the reference absorber (chamber qualification) pushes laboratories to improve the diffusivity in the room and get higher absorption values. So this is an upward drive for the measured sound absorption. So future data of products in specific laboratories may be either higher or lower than the exisiting data.*
- A fixed design for the reverberation room was requested (normative for new labs). *This is an interesting suggestion and it would be good to do that, the main thing preventing us from doing so right know is not knowing what the best shape would be.*
- A considerable number of existing rooms are just outside the new range of 200-300 m^3, these would be excluded in the new standard. *It was decided to extend the range to 190-350 m^3.*
- When adding low frequency absorption in the empty room, to arrive close to the maximum of 6,5 m^2 of absorption, the measurement accuracy for low absorbing samples is reduced (determination of the difference of two large numbers). *Adding low frequency absorption improves the diffusivity of the chamber, this is expected to be more important than the numerical advantage of having a low absorption in the empty chamber.*
- There is a clear requirement on the temperature and humidity variation but measurement is only done before and after the series. This variation could also occur during measurements. *A method is added to monitor the conditions during testing and a criterion will be added in that respect (1% deviation from the average of the series).*
- Some laboratories are afraid for the increased evaluation range of 30 dB, in respect to background noise. *With normal, low background noise levels, proper sound profing of access doors and proper equipment this is should certainly not be a problem.*
- The calculation of the curvature is not available in commercial software. *Not only this but also other steps in the procedure, such as the required time constant, ensemble averaging and truncation correction might not be available. This however can not be a reason not to improve the standard. After the standard is published, it is fair to assume that commercial software will follow.*
- The mentioning of the supplier of the reference absorber is undesirable. *The product is described as much as possible by it specifications (partly even non-standardized properties). To limit the risk that, even with these specified properties, there will be differences in reference absorbers, the name of a supplier is mentioned in a note.*
- The normal incidence sound absorption of the reference absorber is given but there were comments on its values. *More measurements will be done for verification, an average value will be incorporated.*
- Annex G, on the determination of the decay curve from the impulse response measurement corresponds largely to ISO 3382-2. Why is this annex needed ? *The determination of t2 (end of slope-start of noise) an the truncation correction C are not clearly described in ISO 3382-2.*
- The new source position in the corner, is this needed ? Isn't it possible to use the same loudspeakers as for sound insulation measurements ? Should it be 1 or 3 loudspeakers ? *The positioning in the corner is needed for equal excitation of room modes. The 1 or 3 loudspeakers is just an example. The determining criterion is the uniform radiation.*

5. CONCLUSIONS

This paper describes the basic outline of the working draft of the new ISO 354. The main change is the use of a reference absorber. Preliminary investigations show that a significant improvement of the reproducibility standard deviation is possible. Further improvements will be made, based on the comments received and round robin data to be expected shortly.

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