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A PRACTICAL APPROACH TO THE DETERMINATION OF REPRODUCIBILITY PRECISION (σ_{TARGET}) IN THE FIELD OF SOUND ABSORPTION MEASUREMENTS: EVALUATION OF PROFICIENCY TESTING DATA ACCORDING TO ISO 354:2003

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ABSTRACT

ISO 354:2003 specifies a method of measuring the sound absorption coefficient of acoustical materials used as wall or ceiling treatments. The measured values in one-third octave bands of the sound absorption coefficient are converted to values in the corresponding octaves (practical and weighted sound absorption coefficients - ISO 11654). The adequacy of proficiency tests is guaranteed by means of the assessment of global precision criteria in compliance with the scope stipulated by the normative references in order to determine the reproducibility limits in a regulated measurement method. Unfortunately, the latest revision and endorsement of ISO 354 standard in 2024 does not include any information related precision data. From the experience acquired after seven rounds of the international interlaboratory comparison schemes for sound absorption measurements managed by RPS-Qualitas between 2012 and 2024, according to the methods specified in ISO 354:2003, and in this scenario, a practical approach is proposed to the determination of the reproducibility precision (σ_{target}) in the field of sound absorption measurements by means of the historical records evaluation of the relevant proficiency testing data obtained according to ISO 354:2003

The aim is to provide not only a reliable but also up-to-date criteria for the evaluation of repeatability and reproducibility limits in this field, particularly where there is not at all or very poor normative reference.

Keywords: *sound absorption tests, iso 354, target reproducibility precision. proficiency test.*

1. INTRODUCTION

The standard ISO 354 ‘‘Acoustics. Measurement of sound absorption in a reverberation room’’ [1] specifies a method of measuring the sound absorption coefficient of acoustical materials used as wall or ceiling treatments, or the equivalent sound absorption area of objects, such as furniture, persons or space absorbers, in a reverberation room. The measured values in one-third octave bands of the sound absorption coefficient are converted to values in the corresponding octaves (practical and weighted sound absorption coefficients - ISO 11654) [2].

Since ISO/IEC 17025 [3] requires testing laboratories to put in place external quality control procedures for monitoring the reliability of their measurements, the participation in proficiency testing schemes is the main mechanism for assessing compliance.

In this context, RPS-Qualitas, as an independent consulting and technical advisory company, associated with the Universidad Politécnica de Madrid, has launched since 2012 a project called AQUS, with the aim of providing a

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tool for the objective verification of technical competence, through the development of a biannual proficiency testing scheme in the field of acoustic absorption measurements, according to ISO 354 standard, in order to provide participating laboratories with a powerful tool to know the degree of adequacy in the said tests.

2. METHODOLOGY AND LIMITATIONS OF THE STANDARD

2.1 Proficiency test scheme

In order to satisfy this requirement, seven rounds of this proficiency testing scheme for sound absorption measurements have been conducted by RPS-Qualitas between 2012 and 2024, according to the methods specified in ISO 354 at international level. Since it is a proficiency test, the laboratories that were admitted had both a reverberation chamber and an alpha cabin, and the performance of the participating laboratories was also obtained from the results of measurements of the sound absorption coefficient in one-third octave bands. On the other hand, practical sound absorption coefficients were calculated in octaves and single weighted evaluation index was obtained according to the UNE - EN ISO 11654. All participating laboratories are accredited by ISO 17025. On the other hand, we would like to underline that in terms of the design of this proficiency testing programme, both the homogeneity and the stability of the samples have been duly checked throughout the proficiency test. Thus, we have achieved the goal of obtaining globally accurate results of high quality, so the requirements of ISO 17043 [4] have been taken into account from the outset and during the testing and data processing.

2.2 Stability and homogeneity of test item

In the AQUS project, the description of the proficiency testing (PT) scheme is well documented, considering a series of planned stages related to the monitoring, follow-up and control of the measurement items. This monitoring phase was designed to ensure both the stability and the homogeneity of the test item, which was evaluated and monitored by an accredited laboratory as a mandatory rule, allowing to declare that test item condition remain unchanged over time. It is important to mention that in each PT round, either a different type of material or a certain material with a range of thickness values were evaluated, with different absorption characteristics. These aspects are fully evaluated in order to guarantee the adequacy of the interlaboratory comparison through the evaluation of certain global precision guidelines in accordance with the current scope, since there are no regulatory or prescribed values for reproducibility verification in this scope.

2.3 Reproducibility precision

The precision goodness of the PT cannot be estimated via calculation of by the reproducibility of the test (measurement of acoustic absorption in reverberant chamber, according to ISO 354 standard), since there are no published data on this parameter in the corresponding standard. This standard has been recently revised and confirmed as unchanged until 2024. We have only been able to compare with previous data. Once the reproducibility data (SD_R of the revised ISO 354 standard) are available, these values will be selected as the appropriate SD_R value (σ_{target}) of the standardised test method for performance evaluation, adapted to the intended use of the participants.
This is the reason why the main objective of this paper is to propose a practical approach for the determination of the reproducibility precision (σtarget) in the field of sound absorption measurements by means of a proper evaluation of the experimental data obtained in the different proficiency test PT rounds.

3. STATISTICAL DESIGN AND PERFORMANCE EVALUATION

3.1 Statistical procedure

The protocol conducted in these proficiency test schemes outlines a statistical design not only intended for the analysis of the data but also for the evaluation of the proficiency testing results according to the standard ISO 5725-2, that describes the determination of the repeatability and reproducibility in a regulated measurement procedure using classical statistical methods with outlier elimination [5]. As regards the implementation of the PT scheme AQUS, the statistical parameters published for the

magnitudes object of study in the scope of the program are the following:
• assigned value (αs - sound absorption coefficient) in each frequency as consensus value from participants in the frequency range 100 - 5000 Hz
• estimate of the precision of the PT results in terms of repeatability and reproducibility limits
• standardized z-score taken as an assessment of the performance of the participation by each laboratory.
As for the determination of the assigned value, once discarded the outlier results, it is performed in accordance with the established protocol by first calculating the arithmetical average of the four results reported by each laboratory participants, taken as the consensus value for the number of non-excluded participants in each magnitude. This makes it possible to get the most appropriate measure of central tendency based on the distribution of the data of the participants, once verified the normality of them as mandatory previous rule. This condition of statistical normality of the test results allowed us to verify the results obtained with the ISO 13528 standard (robust statistical methods). Interestingly, they were quite similar and consistent in terms of the assigned value and reproducibility of the proficiency test that had been verified since the first round of the AQUS PT programme.Then, in order to define the variability of the proficiency test results, it is first necessary to estimate the values of both the standard deviation under conditions of repeatability (Sr) and the one under conditions of reproducibility (SD_R). These are applied to calculate the related parameters r and R according to ISO 5725-2.

$$r = 2,8\ S_r \qquad (1)$$

$$R = 2,8\ S_R \qquad (2)$$

The parameters r and R may be called ‘‘critical differences’’ or ‘‘limits,’’ as they describe the maximum difference of a pair of test results at which these can be considered equivalent at a probability level of 95 %.

3.2 Performance evaluation

The performance of each participant is evaluated by calculating the corresponding z-score, determined in accordance with:

$$z = (x_i - X_{PT})/\sigma_{PT} \qquad (3)$$

where x_i is the laboratory result, X_{PT} is the assigned reference value and σ_{PT} is the estimate of the standard deviation of the proficiency test results. In this way, results with a value $|z| \leq 2$ are considered as satisfactory; results with $|z| \geq 3$ are unsatisfactory; results with $2 < |z| < 3$ are considered questionable.

4. PITFALLS TO ESTABLISH PRECISION GUIDELINES

4.1 Scope and purpose

Regarding the evaluation of the precision criteria for the proficiency test according to the recently revised ISO 354 standard, unfortunately there are no regulatory values available that can be used as a prescribed reference, unlike what happens in other standards in the field of acoustics tests. Therefore, it has not been possible to verify whether the reproducibility values obtained during these interlaboratory PT round comparisons following ISO 354 correspond to a normative reference in terms of significant differences.
In addition to the aim of supporting the participants in all proficiency tests conducted, we would like to broaden the understanding of the state-of-the-art regarding the precision of the results obtained with this method. Therefore, once the PT rounds have been completed and with the knowledge acquired during their development, our proposal is to provide some practical data guidance on the precision. Furthemore, these data will be specific for the application of this standard within the considered scope.
A practical approach has been applied to determine the reproducibility precision (σ_{target}) in the field of sound absorption measurements by evaluating historical records of the relevant proficiency test data according to ISO 354, by means of performing some operational steps leading to the prescription/formulation of provisional values of reproducibility precision. A similar approach has been proposed for the assessment of precision criteria in relation to the ISO 140-5 standard in 2015. [7]. The aim is to provide not only a reliable but also up-to-date criteria for the evaluation of repeatability and reproducibility limits in this field, particularly where there is not at all or very poor normative reference.

Table 1. Reproducibility Precision (SD$_R$), assigned values (AV) of sound absorption coefficient (αs) from AQUS-2012 – AQUS-2004 and values obtained for SD$_R$ "pooled" (right column).

Frequency	AQUS-1- 2012 p = 14		AQUS-2 - 2015 p = 13		AQUS-3 - 2018 p = 17		AQUS-4 - 2020 p = 15		AQUS-5 - 2021 p = 14		AQUS-6 - 2022 p = 16		AQUS-7 - 2024 p = 15		
(Hz)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$	AV(α_S)	SD$_R$ "pooled"
100	0,027	0,10	0,022	0,04	0,028	0,06	0,024	0,12	0,018	0,03	0,026	0,06	0,014	0,04	**0,023**
125	0,067	0,19	0,024	0,07	0,033	0,09	0,038	0,20	0,018	0,05	0,024	0,07	0,019	0,05	**0,035**
160	0,068	0,33	0,021	0,10	0,025	0,11	0,026	0,29	0,020	0,08	0,022	0,11	0,016	0,08	**0,032**
200	0,053	0,52	0,024	0,14	0,032	0,16	0,037	0,39	0,022	0,15	0,023	0,14	0,025	0,13	**0,032**
250	0,075	0,76	0,020	0,20	0,041	0,22	0,045	0,49	0,022	0,23	0,018	0,17	0,033	0,19	**0,040**
315	0,079	0,89	0,030	0,30	0,035	0,31	0,040	0,59	0,025	0,36	0,029	0,24	0,048	0,28	**0,044**
400	0,095	0,99	0,044	0,48	0,049	0,42	0,044	0,67	0,034	0,51	0,049	0,30	0,081	0,40	**0,059**
500	0,060	1,06	0,054	0,63	0,039	0,55	0,037	0,76	0,037	0,69	0,034	0,38	0,075	0,61	**0,050**
630	0,074	1,09	0,051	0,74	0,052	0,67	0,043	0,82	0,049	0,83	0,047	0,47	0,078	0,83	**0,058**
800	0,062	1,07	0,051	0,84	0,049	0,76	0,050	0,85	0,062	0,92	0,036	0,56	0,060	1,00	**0,053**
1000	0,056	1,07	0,075	0,90	0,062	0,83	0,059	0,87	0,081	0,99	0,051	0,64	0,048	1,03	**0,062**
1250	0,055	1,03	0,063	0,94	0,055	0,86	0,048	0,87	0,075	0,98	0,065	0,70	0,045	0,96	**0,059**
1600	0,053	1,02	0,060	0,96	0,057	0,90	0,038	0,85	0,073	1,00	0,066	0,74	0,054	0,90	**0,058**
2000	0,057	1,01	0,052	0,97	0,043	0,90	0,052	0,85	0,079	1,01	0,070	0,79	0,056	0,87	**0,059**
2500	0,055	1,00	0,061	0,98	0,056	0,92	0,054	0,87	0,061	1,02	0,066	0,83	0,057	0,84	**0,059**
3150	0,055	0,99	0,064	0,98	0,059	0,93	0,076	0,89	0,057	1,01	0,057	0,86	0,061	0,84	**0,062**
4000	0,062	1,00	0,073	0,97	0,063	0,94	0,064	0,96	0,056	0,99	0,061	0,88	0,100	0,86	**0,070**
5000	0,073	0,99	0,076	0,97	0,066	0,96	0,047	1,00	0,075	1,01	0,061	0,89	0,061	0,87	**0,066**

5. RESULTS AND DISCUSSION

Once the seven rounds have been carried out (see Tab. 1), the assigned values obtained from the consensus of the participants, after rejection of the outliers, are presented for each frequency and each round, together with the corresponding standard deviation of reproducibility (SD$_R$), which shows a high consistency between the values of the measurable parameter over time. However, it should be noted that the sound absorption coefficient and the reproducibility precision seem to be strongly dependent on the type of material used as the PT test piece.

Therefore, after applying the statistical protocol for the calculation of PT results, the corresponding SD$_R$ values were calculated, taken as an indication of the reliability of the interlaboratory comparison. A comparison of these SD$_R$ values obtained at each measurement frequency for each PT round is presented to facilitate a graphical comparison over time (see Fig.1) with the estimated value of reproducibility precision (σ_{target}). The estimated value of reproducibility precision (σ_{target}) was calculated as a pooled standard deviation (SD$_R$" pooled") from the individual values of each independent PT round taking into account the number of participants (degrees of freedom) (see Tab.1) [8-9]. In addition, it is interesting to note that the SD$_R$ values in the first (2012) and last (2024) round are more scattered at low and high frequencies compared to the majority of values in the remaining rounds, which are below the estimated target SD$_R$ value (dark blue line). The causes of these higher SD$_R$ values in the first PT Round (AQUS-1_2012) could be due to:

- Damage of PT ítems during transport
- Some participants did not fully comply with the instructions, in particular regarding the mounting of the sample in the reverberation room: the perimeter edge of the sample shall be sealed or covered with a acoustic reflective frame of rigid material according to Annex B point B.2 Type A mounting.

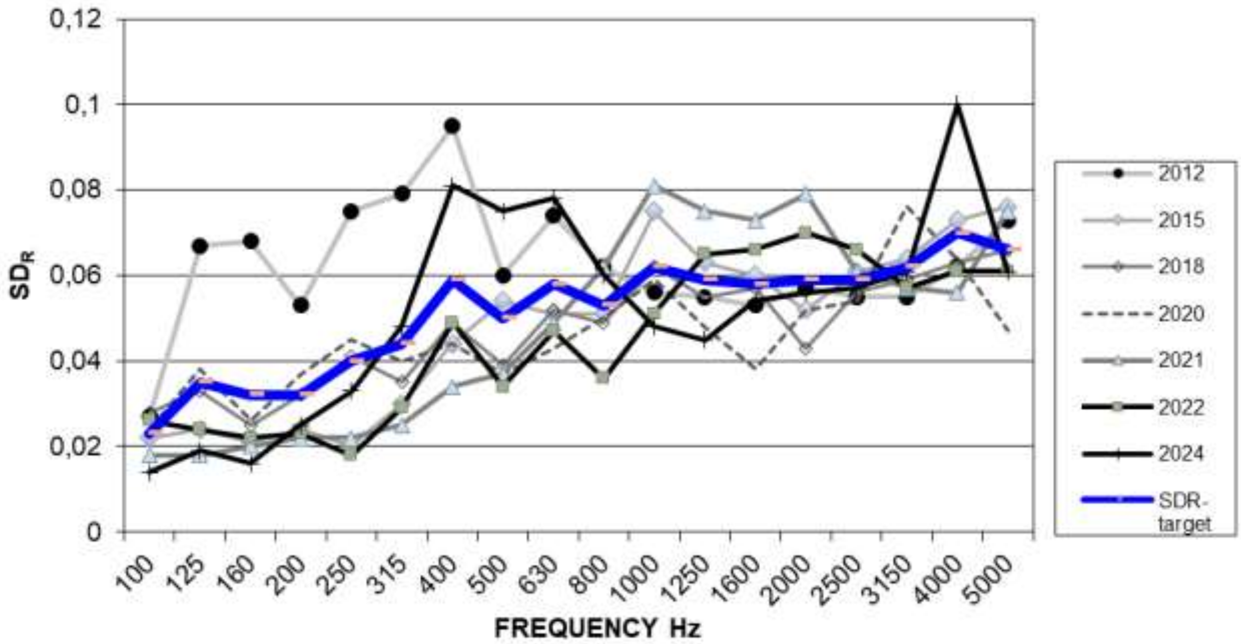

Figure 1. Comparison of standard deviation of reproducibility SD_R obtained in AQUS PT schemes (years 2012–2024) versus SD_R target (dark blue line)

The causes of these higher SD_R values in the last PT Round (AQUS-7_2024) could be due to:

- The material shows maximum absorption between the thirds of 630 and 1000 Hz. These absorption peaks are located differently by different laboratories and consequently there is maximum dispersion in this frequency range.
- Similarly, the material again shows a second absorption maximum around the 4000 Hz third, but not all laboratories clearly define this absorption peak. As a result, the dispersion in this octave third is very high. Some reverberation rooms, even if they meet the requirements of the standard, may lose sensitivity when measuring coefficient at high frequency.
- On the other hand, a slight permanent deformation may occur during transport due to crushing of the PT sample material plates. This crushing slightly alters the structure factor of the material, resulting in a slight change in the frequencies of maximum absorption in the range between 630 and 1000 Hz, and also at 4 kHz. This partly explains the higher dispersion of the SD_R values in the octave thirds shown.

6. CONCLUSIONS, PROPOSAL AND FUTURE OBJECTIVES

The next steps for the completion of the activities related to the present project should focus on developing of a collaborative study to assess the performance of the measurement method. This will allow for the establishment of precision guidelines based on the experience gained from measurements conducted according to ISO 354. It is expected that the study will enable to assess if the proposed reproducibility values for each frequency (σ_{target}) are suitable in terms of minimum precision level to determine the standard deviation for proficiency assessment.

Furthermore, these prescribed values of precision should be verified regularly, as well as monitoring the practical conditions of application in such a way that the reproducibility values may also be used to verify the proper operation of test procedures of any laboratory involved in this scope of acoustic measurement.

Therefore, in this paper, we propose a practical approach to determine the reproducibility precision (σ_{target}) in the field of sound absorption measurements by evaluating historically relevant proficiency testing data according to ISO 354. Some points of interest that must be foreseen are related to both the applicability and practicability of the method since a collaborative trial requires substantial effort and should only be applied to methods that have received adequate prior testing. These values of the reproducibility precision (σ_{target}) will be used to assess the performance of participants in the next proficiency test AQUS-8 in 2026 for proving the goodness of this proposal.

It is honestly believed that this challenge is quite difficult to achieve, mainly because there are a large number of materials for acoustic testing with quite different characteristics and values of sound absorption coefficient (αs), without being able to make a suitable catalogue of SD_R target for each one. However, to the best of our knowledge, this is the first attempt to determine the reproducibility precision (σ_{target}) using a large experimental weight of data collected over a decade from 2012 to 2024.

The aim is to provide not only a reliable but also up-to-date criteria for the evaluation of repeatability and reproducibility limits in this field, particularly where there is not at all or very poor normative reference. In this way, future participants could have some kind of reference values for the evaluation of precision criteria in this field.

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