VPS VIBRATIONS IN PHYSICAL SYSTEMS

DOI: 10.21008/j.0860-6897.2022.1.03
Vibrations in Physical Systems, 2022, 33(1), 2022103

Analysis of Factors Influencing the Measurement Result of the Reverberant Sound Absorption Coefficient Under Laboratory Conditions

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Abstract There are still discrepancies in the measurement results despite the standardized methods of measuring the sound absorption coefficient in the reverberation room. They appear especially in interlaboratory tests. The research used the method included in the EN-ISO 354: 2003 standard to determine the sound absorption coefficient. The subject of scientific research was to investigate the impact of measurement techniques (Maximum Length Sequence method and interrupted noise method for both T20 and T30 evaluation ranges), humidity in the test room, sample seasoning and sample fitting, and finally the influence of room variability on the measurement results. The tests were performed in two reverberation chambers. The study included two types of materials. Samples (1) made of identical pieces of mineral wool (ISOVER glass wool and ROCKWOOL rock wool) and (2) of fibreboard. Mineral wool was of different thicknesses. Among the measurement techniques, the smallest dispersion of the reverberation time results was obtained with the MLS -T30 method, and the highest differences in the results were caused by the test being performed in another room (reverberation chamber). There was no significant influence with the increase in humidity or the careful arrangement of the test sample from the components on the measurement result.

Keywords: sound absorption coefficient, reverberation room, reverberation time, MLS method.

1. Introduction

The parameter used to determine the sound absorption performance of a material or surface is the absorption coefficient. It is defined as the ratio of the acoustic energy absorbed by a given sample to the energy of the incident wave on its surface. The value of the absorption coefficient for a given material depends on the frequency and angle of incidence of the acoustic wave. From this point of view, the physical and reverberant absorption coefficients are distinguished. When the incident wave is plane and comes at a right angle to the tested surface, we speak of the physical absorption coefficient; in scattered field conditions, when the waves apply to the tested sample at every possible angle, the reverberant sound absorption coefficient is determined.

The measurement of the sound absorption coefficient is carried out in a reverberation chamber, by measuring the change in reverberation time in the chamber, caused by the presence of the tested material. Unified details of the reverberant absorption coefficient measuring system can be found in the international standard ISO 354: 2003 [1]. They include the parameters of the reverberation chamber, the diffusivity of the acoustic field present in it and the equivalent sound-absorbing surface area, on the other hand, the shape and surface of the sample related to the volume of the chamber. Special attention was paid to the method of mounting the sample in the chamber, depending on the type of sample tested. The standard also specifies the meteorological conditions of measurement: temperature, humidity, and the method of measuring the reverberation time necessary to determine the acoustic absorption of the chamber.

However, despite such detailed regulations on the standardization of measurement procedures, there are still large discrepancies in the results obtained, especially in terms of repeatability and reproducibility of the results [2-7].

In previous studies, you can find several works on the measurement of the reverberant sound absorption coefficient under reverberation conditions. As early as 1939, Hundt [8] drew attention to the

discrepancy in the results obtained in different laboratories. Warnock [7] indicated that the sources of errors in the measurements of the reverberant sound absorption coefficient are the loudspeaker, the position and arrangement of the material in the chamber, as well as the number and arrangement of the scattering elements in the reverberation chamber. It has been shown that the sound decay curve, and thus the absorption coefficient, strongly depends on the location of the microphone. This relationship was also found in the work of Mleczko and Wszołek [9], which showed a strong dependence of the reverberation time on the position of the microphone, especially in the low frequency range (125 Hz and 160 Hz). The reason for the large dispersion of the results is primarily the heterogeneity of the acoustic field, but despite the use of sound diffusers, it is not possible to achieve a satisfactory level in the entire bandwidth. One of the effective possibilities of reducing the impact of field inhomogeneity on the measurement result is increasing the number of microphone positions in the chamber space, as well as using at least two positions of the sound source, as demonstrated by Cops, Vanhaecht and Leppens in [6].

As part of this research, experimental tests were carried out on the sound absorption coefficient of samples made of hard fiberboard and mineral wool of various thicknesses, under changing conditions and different measurement techniques.

The main factors that may affect the result of measuring the sound absorption coefficient are: (1) methods and evaluation for the reverberation time measurement, (2) test room (reverberation chamber A and B), (3) different humidity during the measurement, (4) condition of samples installed in the chamber (storage in the chamber for 24 hours before and storage outdoor) and (5) neat fitting of pieces of the tested material sample in the reverberation chamber.

2. Laboratory tests

2.1. Samples

There were two types of materials tested:
(1) Hard fibreboard 20mm thick and (2) glass wool produced by Isover series: Super Mata +, 50 mm and 150 mm thick, density 26 kg/m^3.

A rectangular test sample with sides of 3 m long and 3.6 m with a total area of 10.8 m^2 was placed on the floor of the reverberation chamber (test rooms A and B). In the case of mineral wool specimens, its edges were framed by wooden boards and evenly levelled with the thickness of the specimen (Fig. 2-3). The fibreboard specimen was not framed (Fig. 1)

Figure 1. Reverberation chamber B. Sample - Fiberboard 20mm.

Figure 2. Reverberation chamber A. Sample - Isover Super Mata+ 150 mm.

Figure 3. Reverberation chamber A. Sample - Isover Super Mata+ 50 mm.

2.2. Test method and measuring equipment

The reverberant sound absorption coefficient is defined as the ratio of acoustic absorption (equivalent to the area of the tested sample) A_T to the area covered by the tested sample, S [1]:

$$a = \frac{A_T}{S}. \tag{1}$$

In the formula (1):

$$A_T = A_2 - A_1 = 55.3V\left|\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right)\right| - 4V(m_1 - m_2), \tag{2}$$

where A_1, A_2 are the sound absorption area; 1 – in an empty chamber, 2 – with test sample; V is volume of the test room, [m^3]; c_1, c_2 – speed of sound at temperatures t_1, t_2, $\left[\frac{\text{m}}{\text{s}}\right]$; T_1, T_2 – reverberation time; 1 – empty room, 2 - with sample, [s]; m_1, m_2 – power attenuation coefficient, $\left[\frac{1}{\text{m}}\right]$, for meteorological conditions in the test room (1 - empty room and 2 - with test sample), according to ISO 9613-1 [10].

In practice, all parameters according to Eq. (2), which could have an impact on the measurement result, were constant. Except for the intentionally changed humidity, which influenced the value of the parameters m_1 and m_2. Thus, the only variable parameter characterizing the amount of absorbed acoustic energy in the sample was the change in reverberation time (from T_1 to T_2) in the chamber, caused by the installation of the sample. Another factor that may affect the amount of energy absorbed is the state of the moisture, depending on the place where the sample is stored before it is placed in the chamber. Another parameter that we decided to test is the influence of the test room (chamber) in which the tests were performed, which in Eq. (2) is represented only by its volume V.

Experimental studies [11], considering the variants described above, were performed in a set of coupled reverberation chambers of the Department of Mechanics and Vibroacoustics of the AGH University of Science and Technology in Kraków. The laboratory is used primarily to measure the acoustic insulation of partitions, but the chambers can be used individually, for example, for tests of the reverberant sound absorption coefficient, according to the requirements of ISO 354 [1].

The measurement of the sound absorption coefficient α_s was performed in both reverberation chambers. The volumes of the rooms are the transmitting chamber A, V_A = 178.77 m^3 and the receiving chamber, marked as B, V_B = 176.9 m^3. Chamber B also has suspended ceiling acoustic diffusers. The view of the chambers, together with samples of the tested materials, is shown in the photos in Fig. 1-3.

The tests were performed in the measurement system shown in Fig. 4. The basis of the measurement system is the Norsonic Nor 840 two-channel analyser with a built-in noise generator and MLS (Maximum Length Sequence) signal generator with an automatic reverberation time measurement mode, both with noise excitation (intermittent pink noise) and with MLS excitation.

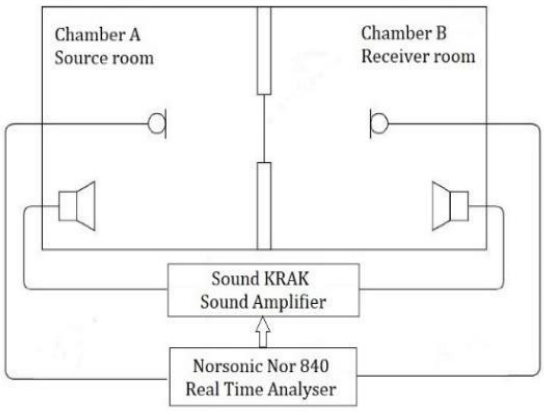

Figure 4. Measurement base diagram

Sound decay measurements were made at 10 microphone positions with two sound source settings. In the tests of each sample, 20 measurements of the decay curve were performed using both methods (intermittent noise and MLS) with two evaluation ranges to determine the reverberation time from the recorded decay curve, T20 and T30.

All measurements were made in 1/3-octave wide bands in the range from 100 Hz to 5 kHz. In each frequency band, the standard deviation was determined as a measure of the dispersion of the results (and the main component of the measurement uncertainty), which was illustrated in all graphs. Simultaneously with the acoustic measurements, environmental parameters were noted, such as the temperature, pressure, and relative humidity of the air and samples.

Basic tests with various methods of measuring the reverberation time (intermittent noise, MLS with evaluation range both T20 and T30) were carried out at a practically constant relative humidity of approx. 60%. The seasoned samples also had such humidity.

The following tests were performed for samples made of glass wool, Isover 50 and 150 and fibreboard both at 80% humidity and for samples in test room A and test room B. Only mineral wool samples were seasoned.

Independently there we carried out tests for two other samples: (1) RocksLab Acoustic 50 mm stone wool and (2) Isover Panel 100 mm board. Tests were carried out for the version with a neat and slapdash arrangement of slightly deformed sample components. Such tests were possible only in the case of samples made of panels with dimensions of 0.6 m x 1.2 m. The actual elements have imperfections. They are not perfectly flat and do not have even edges. It is difficult to position them and obtain a perfectly smooth surface over the entire sample.

2.3. Results

Graphs of the absorption coefficient α in 1/3 octave bands were used as a basis for the analysis of the results obtained, including the dispersion of the measured quantities in the frequency range. Some of the absorption coefficient results, especially in the mid-frequency bands, are greater than one. According to the algorithm of EN ISO 11654 [12], this value should be rounded to 1.0. The graphs were prepared so that it was possible to visually assess the changes in both the value of the absorption coefficient and the size of its dispersion, and they are presented in Fig.5-18.

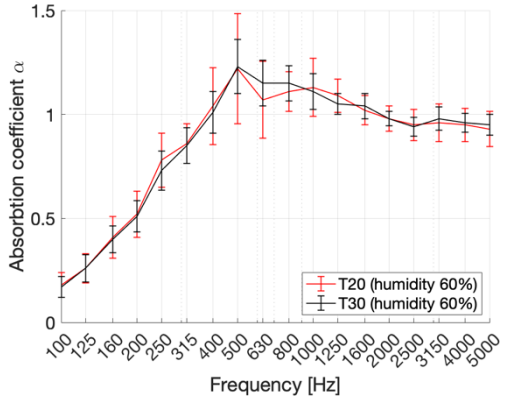

Figure 5. Evaluation range T20 vs. T30. Interrupted noise method. Sample - Is over 50 mm.

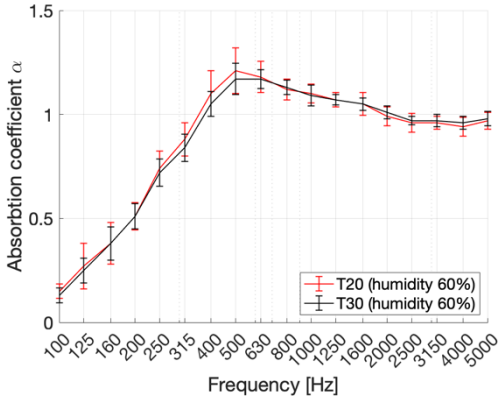

Figure 6. Evaluation range T20 vs. T30. MLS method. Sample - Isover 50 mm.

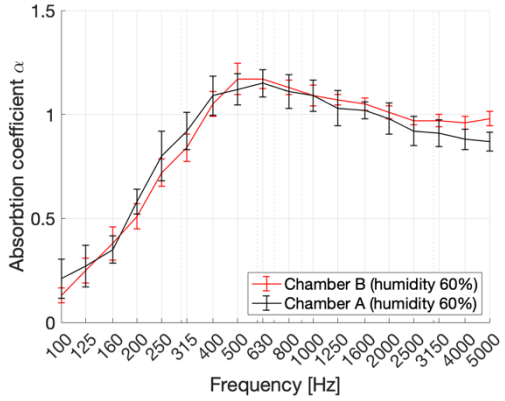

Figure 7. Chamber A vs. chamber B. MLS method. Evaluation range T30.Sample - Isover 50 mm.

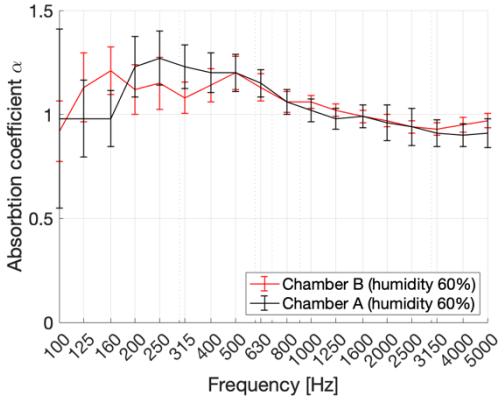

Figure 8. Chamber A vs. chamber B. MLS method. Evaluation range T30. Sample - Isover 150 mm.

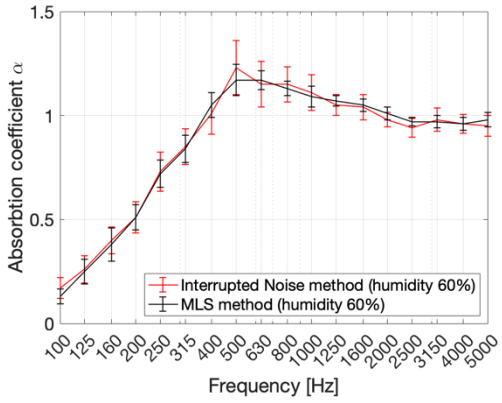

Figure 9. Interrupted noise method vs. MLS. Evaluation range T30. Sample - Isover 50 mm.

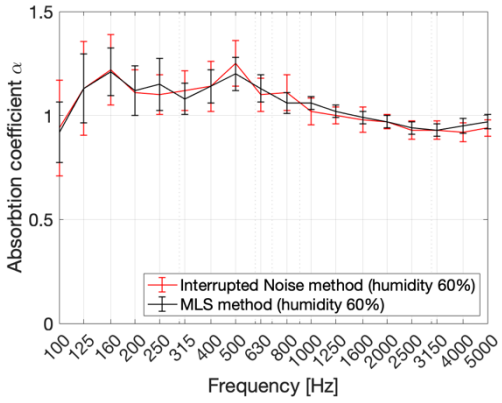

Figure 10. Interrupted noise method vs. MLS. Evaluation range T30. Sample - Isover 150 mm.

In this paper, to show the influence of the factors examined on the measurement result in the whole frequency range, unrounded values were left. The full uncertainty budget was not analysed for each sample separately, assuming that the measurement conditions were invariant for all samples during one session of measurements. It can be accepted that the uncertainty brought by them will be comparable, and the existence of a changing partial uncertainty will be the standard uncertainty (standard deviation) of the reverberation-time measurement.

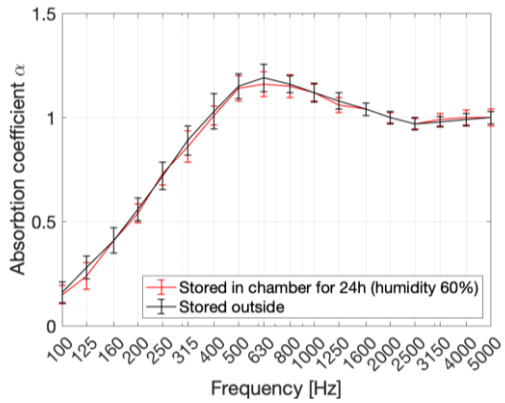

Figure 11. Stored outside (low humidity) vs. stored in a chamber for 24 h. MLS method. Evaluation range T30. Sample - Isover 50 mm.

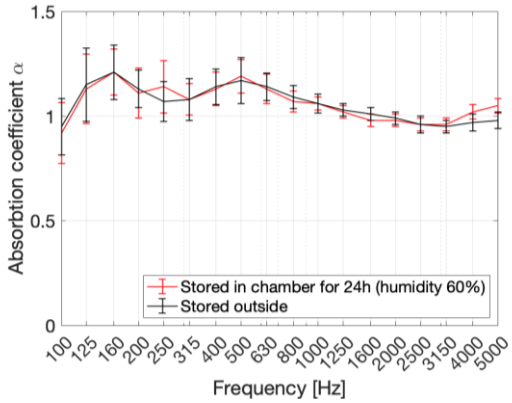

Figure 12. Stored outside (low humidity) vs. stored in a chamber for 24 h. MLS method. Evaluation range T30. Sample - Isover 150 mm.

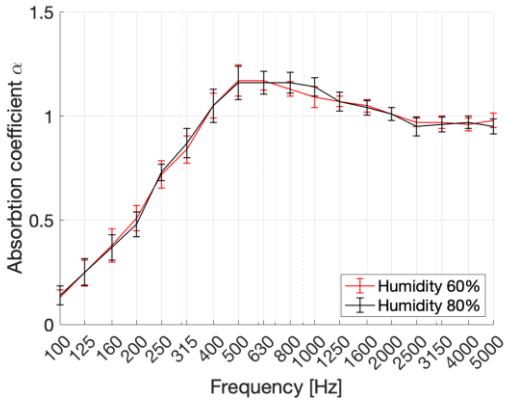

Figure 13. Humidity 80 % vs. 60 %. MLS method. Evaluation range T30. Sample - Isover 50 mm.

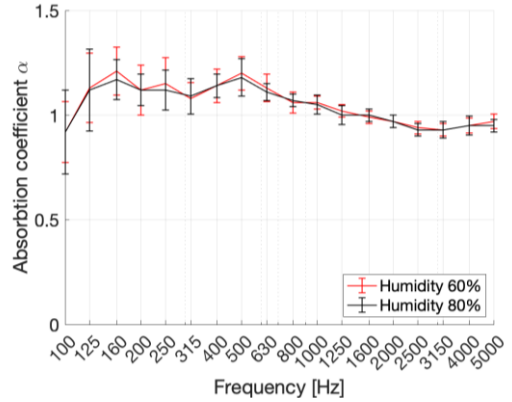

Figure 14. Humidity 80 % vs. 60 %. MLS method. Evaluation range T30. Sample - Isover 150 mm.

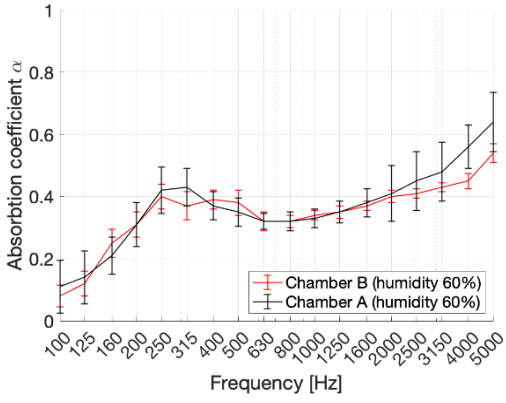

Figure 15. Chamber A vs. chamber B. MLS method. Evaluation range T30. Sample - Fiberboard 20 mm.

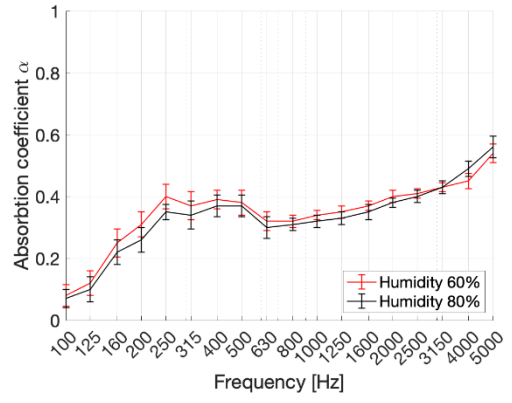

Figure 16. Humidity 80 % vs. 60 %.MLS method. Evaluation range T30. Sample - Fiberboard 20 mm.

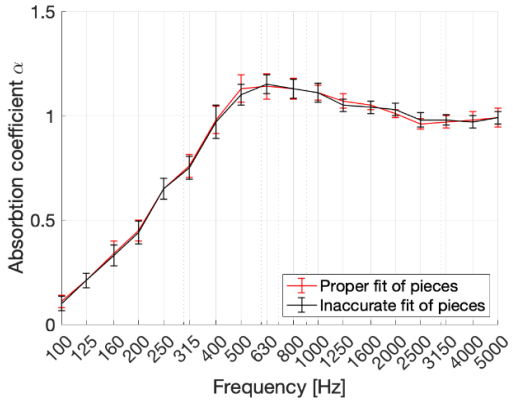

Figure 17. Proper fit of pieces vs. slapdash fit of pieces. MLS method, T30 evaluation range T30. Sample - Rockslab Acoustic 50 mm.

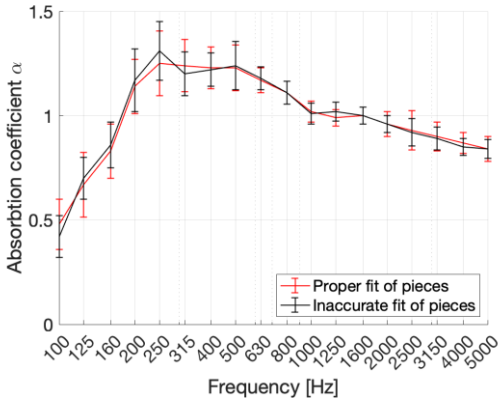

Figure 18. Proper fit of pieces vs. slapdash fit of pieces. MLS method, T30 evaluation range T30. Sample -Isover 100 mm.

3. Analysis

The RESS (Root Error Sum of Squares) index and the Pearson correlation coefficient were adopted as an objective evaluation of the variability of the tested parameters in the result of the measurement of the sound absorption coefficient. The RESS index informs about the distance of the curves (graph of the sound absorption coefficient), the greater the value, the greater the distance, while the Pearson coefficient is highly sensitive to outliers. The comparison of the RESS and Pearson coefficients for the tested samples made of fiberboard, Isover 50 mm and 150 mm wool and the average values (average) of all samples tested in the study [11] are presented in the Tab. 1-5.

Table 1. Comparison of the measurement method.
Impulse response measurement using MLS and interrupted noise method.

Quantity	Evaluation range	Fabric sample			
		Average	Fiberboard 20 mm	Isover 50 mm	Isover 150 mm
RESS	T20	0.12	0.09	0.15	0.13
Pearson correlation coefficient	T20	0.99	0.99	0.99	0.96
RESS	T30	0.09	0.07	0.12	0.11
Pearson correlation coefficient	T30	0.99	1.00	1.00	0.96

As can be seen, the test room had the greatest impact on the measurement result. When the measurement was carried out in a different test room, the RESS distance was 0.27 (Tab.2) compared to the distance of 0.08 to 0.1 when other factors were changed. Moreover, the mean Pearson correlation coefficient was 0.93, and in the case of the Isover 150 mm sample, even 0.7, with the RESS coefficient of 0.4. The deviation of the α coefficient measurement results in the case of the Isover 150 mm sample was noticeable in all tested cases, however, to a varying degree.

Table 2. Different test rooms (reverberation chamber A and B)
- Impulse response measurement using MLS.

Quantity	Evaluation range		Fabric sample		
		Average	Fiberboard 20 mm	Isover 50 mm	Isover 150 mm
RESS	T20	0.27	0.19	0.24	0.40
Pearson correlation coefficient	T20	0.93	0.96	0.99	0.71
RESS	T30	0.27	0.19	0.23	0.38
Pearson correlation coefficient	T30	0.93	0.96	0.99	0.70

The comparison of the T20 and T30 methods shows that in almost all cases smaller distances between the α coefficient plots were obtained in the T30 evaluation range, regardless of the way the chamber was stimulated, with noise interrupted by the MLS sequence.

However, the comparison of the intermittent noise method and the MLS method does not show a significant discrepancy in the mean values of the results (except for the 500 Hz frequency band). However, in the MLS method the results are characterized by a smaller dispersion (Fig. 9-10), therefore, in further comparisons, when changing other parameters, the results of the measurement of the reverberation time using the MLS method (evaluation range T30) have already been published.

Table 3. Changed humidity in the test room (60 % vs. 80 %)
- Impulse response measurement using MLS.

Quantity	Evaluation range		Fabric sample		
		Average	Fiberboard 20 mm	Isover 50 mm	Isover 150 mm
RESS	T20	0.14	0.12	0.14	0.15
Pearson correlation coefficient	T20	0.98	0.99	1.00	0.94
RESS	T30	0.12	0.11	0.11	0.14
Pearson correlation coefficient	T30	0.98	0.99	1.00	0.95

Table 4. Storage in test rom for 24 hours and outdoor storage
- Impulse response measurement using MLS.

Quantity	Evaluation range		Fabric sample	
		Average	Isover 50 mm	Isover 150 mm
RESS	T20	0.15	0.16	0.14
Pearson correlation coefficient	T20	0.97	1.00	0.94
RESS	T30	0.10	0.07	0.13
Pearson correlation coefficient	T30	0.97	1.00	0.93

On the one hand, tests with different moisture content of the sample and, on the other hand, with different humidity in the reverberation chamber during the tests did not show a significant effect of the change in humidity from 60% to 80% on the results of measuring the α coefficient of samples made of mineral wool - Isover 50 mm and 150 mm (Fig. 13-14). A clearly noticeable change in the results in the case of fibreboard (Fig. 16). Outdoor seasoning of the samples (warm and sunny weather) had a slightly more effect on the thicker sample (Isover 150 mm) compared to the Isover 50 mm sample (Tab.4), but without any trend.

Table 5. Way of fitting the material in the sample (neatly vs. slapdash) - Impulse response measurement using MLS

Quantity	Evaluation range	Fabric sample		
		Average	Isover 50 mm	Isover 150 mm
RESS	T20	0.10	0.06	0.14
Pearson correlation coefficient	T20	0.99	1.0	0.99
RESS	T30	0.08	0.05	0.11
Pearson correlation coefficient	T30	1.00	1.00	0.99

4. Conclusions

The influence of selected factors on the result of the measurement of the reverberation coefficient of absorption of samples made of mineral wool Isover 50 mm and Isover 150 mm, fibreboard 20 mm was investigated.

Examinations indicate a significant influence of the test room on measurement results, both in quantity (average distance, RESS = 0.27) and qualitative (Pearson correlation coefficient is 0.93), which can also be seen in the graphs (Fig. 7, 8, 15). This result confirms the poor reproducibility of the results obtained in different laboratories and indicates an insufficient representation of the conditions that prevail in each laboratory and affecting the result of the measurement of the sound absorption coefficient.

The results of the research on the impact of other factors indicate better reproducibility of the results when using impulse excitation to measure the reverberation time using the MLS sequence than when using the intermittent noise method. In addition, it proved to be a better method of measuring the reverberation time for the evaluation T30 with both noise and impulse excitation.

However, there was no significant effect of increasing humidity in the reverberation chamber and the humidity of the test sample on the measurement results. Although the extent of humidity at which the tests were conducted was not large (60% and 80%).

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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