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Acoustic performance analysis of anechoic chambers based on ISO 3745 and ISO 26101: standards comparison and performance analysis of the anechoic chamber at the University of Split

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Summary

Anechoic chambers are designed to provide free sound field environments for various measurement applications. Recommended procedures for anechoic and hemi-anechoic chamber performance qualifications have been defined in ISO 3745 (first version published in 1977) and the new ISO 26101 published in 2012. In this paper, we compare the two standards and their current versions and present the actual performance measurements of the newly constructed small anechoic chamber at the University of Split, Croatia. We also present and analyze the reverberation time measurements (ISO 3382) of the chamber.

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1. Introduction

Free field conditions play a significant role in the acoustic measurements and sound perception experiments. This free-field acoustic conditions naturally exist in open outdoor spaces, high enough above a reflective surface of the earth. To realize the same behavior in a laboratory environment, it is required to have a special room whose boundaries efficiently absorb all disturbance sound in the desired frequency range, thereby creating essentially free field conditions.
Nowadays anechoic chambers are used in many laboratories of industry, academia and government [1]-[3] to make free-field measurements in applications free of objects that could reflect sound, i.e. precision measurements of noise source sound power levels, calibration of electro-acoustic measuring instruments and other various electro-acoustic products measurement for acoustic performance [4][5].
Since many important experiments or measurements and calibration work are done in the anechoic chambers; it is of critical importance that the acoustic characteristics of the anechoic chamber such as free-field characteristics strictly satisfy the international standards. The initial performance qualification of anechoic chamber ensures more accurate and reliable measurement results [6]. Anechoic chamber performance qualifications have been defined in ISO 3745 [7] and ISO 26101 [8] which provide methods, procedure, tolerance and measurement uncertainty.
This paper presents a discussion of two standards, highlighting contrasts between ISO 3745 and ISO 26101. Also, actual performance measurements of the small anechoic chamber at the University of Split, Croatia will be analyzed following the instructions defined by the two standards. Also, reverberation time measurements - ISO 3382 [9] of the chamber will be presented and analyzed.

2. ISO 3745 and ISO 26101 standard comparison

Anechoic chamber qualification procedures are specified in ISO 3745 Anex A and ISO 26101 standards. Both standards require that the instrumentation system, including the microphones and cables, shall meet the requirements of IEC 61672-1:2002, class 1.

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2.1. Sound source requirements

A sound source approximating a point source over the frequency range of interest shall be used for the qualification. One or more sources may be used to cover the overall frequency range of interest but all requirements should be met for each source over its applicable frequency range.
The source shell be compact, relatively omnidirectional (directionality criteria provided in both standards), able to generate sufficient sound output over the frequency range of interest (ISO 26101 - at least 6 dB above the background noise levels (preferably 15 dB); ISO 3745 - 10 dB above the background noise levels for all points on each microphone traverse), of high stability so that the radiated sound power does not change during measurements along the microphone traverse. Regarding stability, ISO 3745 states that sound power level of the test source (with the associated signal generation and amplification electronics) should not vary by more than ±0,5 dB in any one-third-octave band in the frequency range of interest during the measurements for each microphone traverse. It only advises to employ a “monitoring microphone” located at an arbitrary but fixed position in the room in order to verify that the source output during the test complies with the foregoing. On the other hand, ISO 26101 requires ±0.2 stability range and provides exact equation for calibration calculation:

$$L_{pi} = L'_{pi} - L_{p,ref,i} - L_{p,ref,0}\ [dB], \qquad (1)$$

where L_{pi} is the corrected sound pressure at measurement point i [dB], L'_{pi} is the measured sound pressure level at measurement point i [dB], $L_{p,ref,i}$ is the sound pressure measured by secondary monitor microphone at the reference location for measurement point i [dB], $L_{p,ref,0}$ is the sound pressure measured by secondary monitor microphone at the reference location for the initial measurement point 0 [dB].
According to ISO 3475, the test sound source shall be located so that the assumed position of the acoustic center coincides as closely as possible with a point identified as the geometric center of the measurement sphere, preferably in the center of the room. ISO 26101 specifies that the test sound source shall be located to coincide with the usual source position, preferably in the center of the test environment.
The test sound source should be placed in a chosen orientation and held in that orientation for all microphone traverses.

2.2. Microphone traverses

In ISO 3475, microphone traverses shall be made along at least five straight paths away from the geometric center of the measurement sphere in different directions. Key microphone paths are the lines from the geometric center of the measurement sphere to the room corners (where corner refers to the intersection of two walls and the ceiling or two walls and the floor), and lines normal to the wall (or ceiling) surfaces. ISO 26101 also requires at least five straight paths, but they are specified a bit differently and more precisely:
a) at least one traverse path shall be towards a dihedral corner of the environment that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;
b) at least one traverse path shall be towards a trihedral corner of the environment that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;
c) at least one traverse path shall be towards the center of the environment boundary surface that has the most uniform acoustic treatment properties and is most likely to be representative of the overall free sound field performance;
d) if the environment is not square in the plan area, then one traverse path shall be towards the closest boundary surface and one traverse path shall be towards the farthest boundary surface;
e) additional traverse paths shall be selected towards other boundary surfaces that contain unique features or non-uniformities in acoustic treatment (e.g. doors, viewing ports, ventilation openings and sound transmission openings).

2.3. Test procedures

2.3.1. Generation of sound

For both ISO 3475 and ISO 26101, the test source can be operated at discrete frequencies that cover, in sequential steps over one-third octave bands, the entire frequency range over which the test room is being qualified. Procedure may also be carried out using random noise instead of discrete frequencies.

2.3.2. Spatial resolution of measurement points

Sound pressure levels shall be measured along each microphone traverse using equally spaced measurements. For both standards, at least 10 measurement points should be taken per traverse.
Considering the minimum spacing between measurement points, for ISO 26101 the spacing

shall not exceed one-tenth wavelength (λ/10) at each frequency below 1 kHz and 25 mm at frequencies above 1 kHz. For ISO 3745, minimum spacing should not exceed 0,1m.
In ISO 3475, the measurement of sound pressure level shall be carried out starting 0.5 m from the acoustic center of the loudspeaker and ending at or beyond the measurement surface the user wishes to qualify. In ISO 26101, the measurement of sound pressure level shall be carried out starting, at most, a quarter of a wavelength (at the lowest frequency to be qualified) from the origin of the traverse, traversing at least half a wavelength (at the lowest frequency to be qualified) and to the hypothetical boundary of the anechoic space to be qualified. The one-half of the wavelength for traverse to be applied on low frequencies in ISO 26101:2012 posed a significant factor to the design and qualification of the chambers since, in some cases, depending on the chamber dimensions, ability for meeting the requirements was compromised. Therefore, the minimum traverse path length was reduced from half wavelength (λ/2) to quarter of the wavelength (λ/4) in ISO 26101:2017 revision [10].

2.3.3. Estimation of sound pressure levels based on the inverse square law

ISO 3745 estimates the sound pressure level of each traverse based on the inverse square law with the following equation:

$$L_p(r_i) = 20log\left(\frac{a}{r_i - r_0}\right)\ [dB] \qquad (2)$$

where a is a constant related to the sound power emitted from the test sound source:

$$a = \frac{Mr_0^2 + \sum_{i=1}^{M} r_i^2 - 2r_0 \sum_{i=1}^{M} r_i}{\sum_{i=1}^{M} r_i q_i - r_0 \sum_{i=1}^{M} q_i} \qquad (3)$$

r_i is the distance of the i-th measurement point from the center of the measurement sphere or hemisphere, r_0 is the collinear offset of the acoustic center along the axis of the microphone traverse - measurement of the separation between acoustic center of the test sound source and the origin of the microphone traverse

$$r_0 = -\frac{\sum_{i=1}^{M} r_i \sum_{i=1}^{M} r_i q_i - \sum_{i=1}^{M} r_i^2 \sum_{i=1}^{M} q_i}{\sum_{i=1}^{M} r_i \sum_{i=1}^{M} q_i - \sum_{i=1}^{M} r_i q_i} \qquad (4)$$

and

$$q_i = 10^{-0,05 L_{pi}} \qquad (5)$$

where L_{pi} is the sound pressure level at measurement point i [dB], M is the number of measurement points along the microphone traverse within the region where the inverse square law is followed.

ISO 26101 estimates the sound pressure level of each traverse based on the inverse square law with the following equation:

$$L_p(r_i) = b - 20\,log\left(\frac{r_i}{r_0}\right)[dB], \qquad (6)$$

where r_i is the distance of measurement point i from the acoustic center of the sound source [m],
r_0 is the reference value, r_0=1m,
b is a parameter that is adjusted to optimize the fit of the measured sound pressure levels into the tolerance range.
To determine b, iterative process can be used and calculated with following equation:

$$b = \frac{\sum_{i=1}^{N} 20log\left(\frac{r_i}{r_0}\right)\ dB + \sum_{i=1}^{N} L_{pi}}{N}, \qquad (7)$$

where L_{pi} is the measured sound pressure level (corrected for the source stability) at measurement point i [dB], N is the number of measurement points along the measurement traverse.

2.3.4. Deviations from the inverse square law and anechoic chamber qualification

Finally, deviations from the inverse square law (same for both standards) are determined by equation:

$$\Delta L_{pi} = L_{pi} - L_p(r_i)\ [dB], \qquad (6)$$

where ΔL_{pi} is the deviation from the inverse square law [dB], L_{pi} is the sound pressure level at the ith measurement position [dB], $L_p(r_i)$ is the estimation of sound pressure level at the ith measurement position based on the inverse square law [dB].
For test room to be qualified as anechoic, the deviations of measured pressure levels from those estimated using the inverse square law, defined according to both standards, should not exceed values stated in Table I.

Table I. Maximum allowable deviation of measured sound pressure levels from theoretical levels using the inverse square law.

One-third-octave band frequency [Hz]	Allowable deviation [dB]
≤ 630	±1,5
800 to 5000	±1,0
≥ 6300	±1,5

According to ISO 3745, if the deviations are within allowable limits for the range of at least 100 Hz to 10 kHz, this test room can be qualified as in full conformity with the standard. Otherwise, if the test room is qualified over a reduced frequency range (comprised of contiguous one-third-octave bands), the room can be qualified “in conformity” with the standard for this reduced range. ISO 26101 does not specify any required frequency range and allows a free-field environment qualification provided that the one-third-octave bands comprising the frequency range are contiguous.

3. Anechoic chamber measurements

We have recently constructed a small anechoic chamber (with internal dimensions LxWxH – 2.8 x 1.7 x 2.05m) at University od Split, Croatia. It was built inside our lab as a separate structure on vibration isolators. All our measurements were made following the recommendations in ISO 3745 and ISO 26101 standards. We used ARTA software for broadband noise generation (pink noise, Fs:48kHz, FFT:32k) and SPL measurements [11]. As discussed in the previous chapter, in ISO 3475, the measurement of sound pressure level shall be carried out starting 0.5 m from the acoustic center of the loudspeaker and the test sound source shall be located preferably in the center of the room. ISO 26101 specifies that the test sound source shall be located to coincide with the usual source position, preferably in the center of the test environment. Considering the small dimensions of our chamber and ISO 3745 recommendations, we were only able to measure sound pressure levels along the short traverses, starting from 0.5m from the sound source located in the center of the room. Considering ISO 26101:2017 specification that minimum traverse length should be a quarter of the wavelength (λ/4), in this scenario the lowest one-third-octave band we could measure was 250 Hz band in order to end the traverse 50 cm from the tips of acoustic wedges.
Figure 1. shows deviations from the free-field decay (ISO 3745 estimate) versus distance from the source, when the source was placed in the center of the room, for three typical microphone traverse paths (discussed in previous chapter). Red lines represent tolerance limits, according to Table I.
Figure 2. shows deviations from the free-field decay (ISO 26101 estimate) versus distance from the source, for the same scenario. Unlike ISO 3745 scenario, we used calibrated SPL values since ISO 26101 requires monitoring of ±0.2 stability range and provides exact equation for calibration calculation (as discussed in previous chapter).

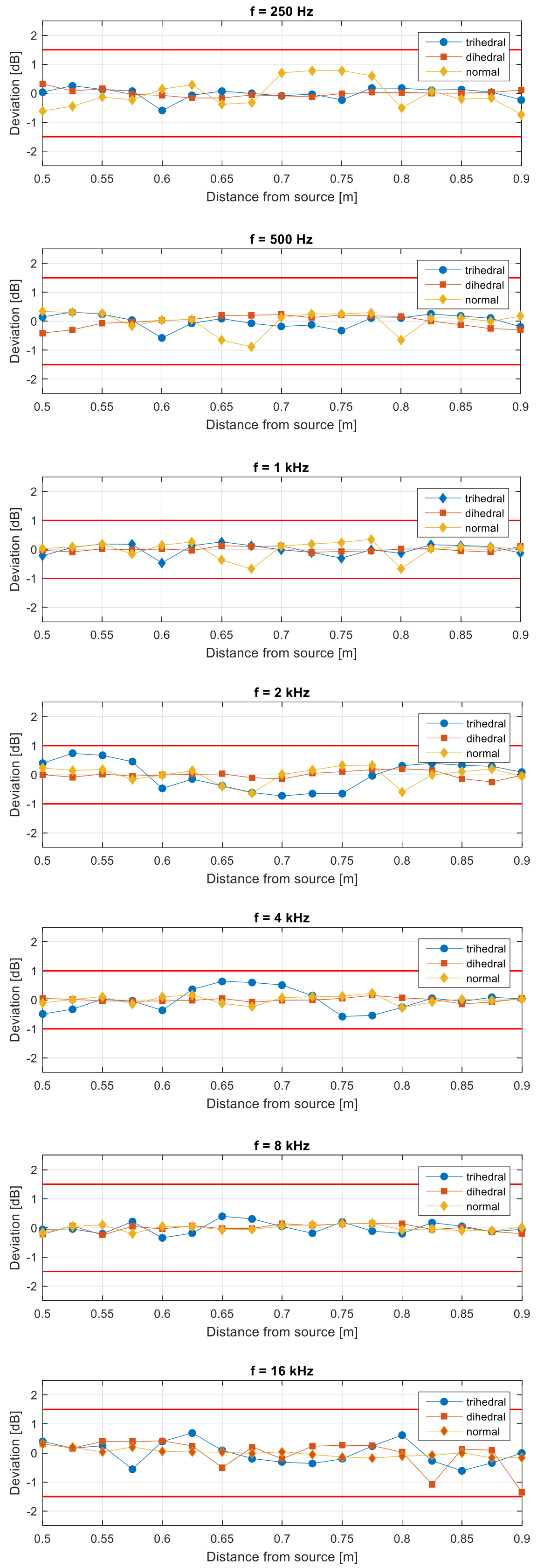

Figure 1. Deviations from the free-field decay (ISO 3745 estimate) versus distance from the source.

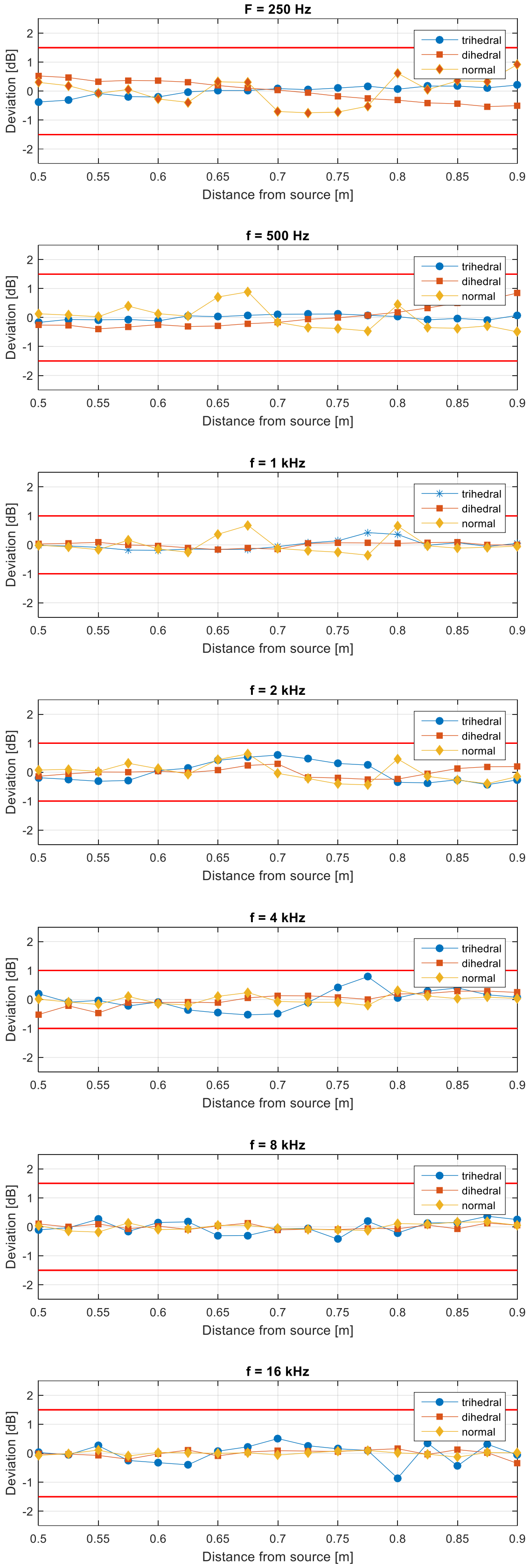

Figure 2. Deviations from the free-field decay (ISO 26101 estimate) versus distance from the source.

For both standards, all figures demonstrate that deviations from the free-field decay are within tolerance limits. However, because of the chamber dimensions, in this scenario, the measured range is small and not suitable for practical applications. Because of the space limitations, our chamber was designed with intention that practical measurements will be conducted with sound source at one side and that the free field conditions will be achieved towards the opposite side, in order to have larger measurement range. As discussed in the previous chapter, sound source placement in the center of the room is preferable, not mandatory - ISO 26101 even specifies that the test sound source shall be located to coincide with the usual source position.

In order to demonstrate the chamber performance in such scenario, with up to 2m distance from the source, Figures 3. and 4. show the results for two boundary experiments - low frequency performance test (200 Hz response) and high frequency performance test (16 kHz response), for both ISO 3745 and ISO 26101 standards.

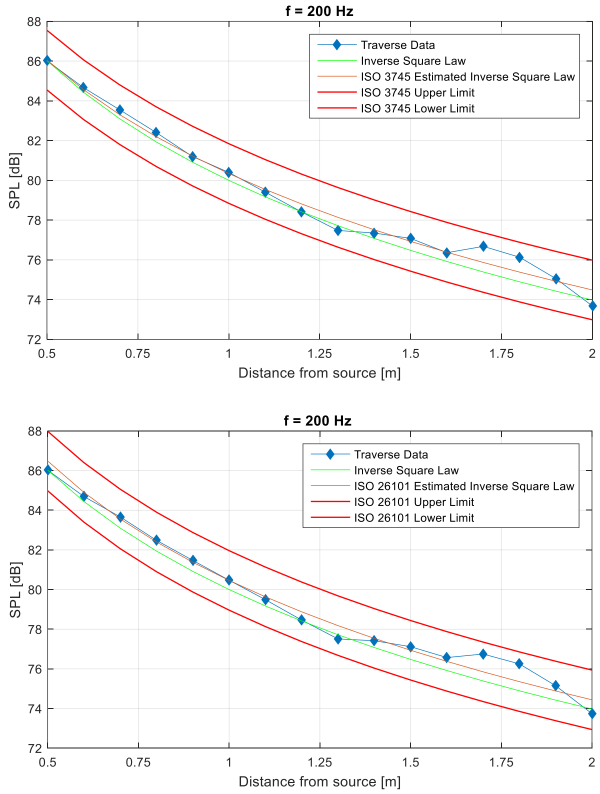

Figure 3. Inverse square law performance at 200 Hz for ISO 3745 and ISO 26101

Results show that this chamber performs within the limits of anechoic chamber qualifications for both standards, and actually very well follows the inverse square law performance.

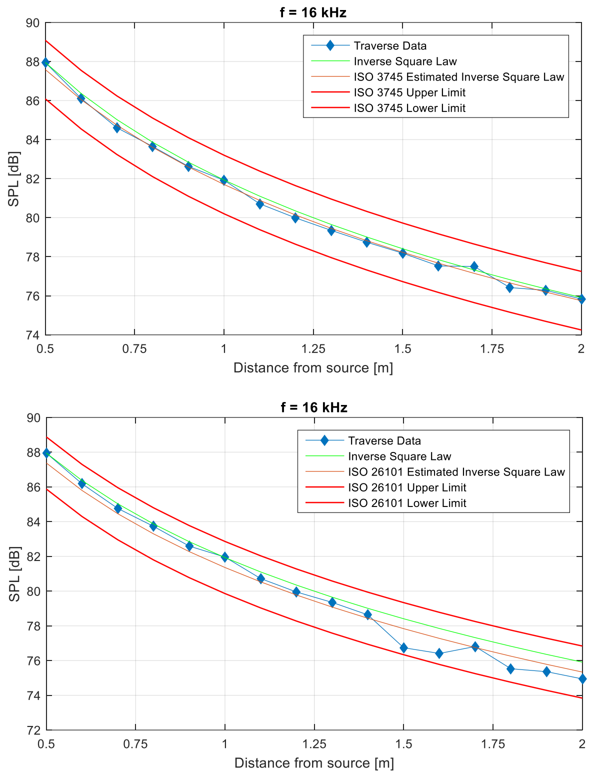

Figure 4. Inverse square law performance at 16 kHz for ISO 3745 and ISO 26101

We also wanted to investigate our anechoic chamber performance regarding reverberation time. We tested it for several source and microphone positions using Arta software and ISO 3382 reverberation time calculation from the impulse response. Figure 5. shows reverberation times RT60, in octave bands (calculated from RT30).

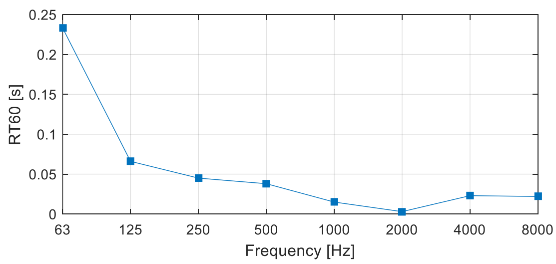

Figure 5. RT60 reverberation time in octave bands

Reverberation times may range from 0.1s (or less) in anechoic chambers, to 10 or more seconds in large public places [12]. Our results clearly show that our chamber achieves very low reverberation times.

4. Conclusion

Anechoic chambers are designed to provide free sound field environments for various measurement applications and it is very important that the free-field characteristics satisfy requirements defined in international standards ISO 3745 and ISO 26101.

In this paper, we compared and discussed the differences between the two standards and presented the actual performance measurements of a small anechoic chamber following the standard procedures. We also presented the reverberation time measurements RT60 of the chamber. Results showed that this chamber performs well, follows the inverse square law performance and achieves low reverberation times.

Acknowledgement

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References

[1] Y. Lu, X. Liu and X. Wu, "Localization error analysis of three-dimensional sound intensity measurement," 2017 9th International Conference on Modelling, Identification and Control (ICMIC), China, 2017, pp. 424-428

[2] Butler, R.A., Levy, E.T. and Neff, W.D., 1980. Apparent distance of sounds recorded in echoic and anechoic chambers. Journal of Experimental Psychology: Human Perception and Performance, 6(4), p.745.

[3] Tinney, C., Glauser, M., Coughlin, T., Ukeiley, L. and Hall, A., 2004. Designing an anechoic chamber for the experimental study of high speed heated jets. In 42nd AIAA Aerospace Sciences Meeting and Exhibit (p. 10).

[4] Fusaro, G., D'Alessandro, F., Baldinelli, G. and Kang, J., 2018. Design of urban furniture to enhance the soundscape: A case study. Building Acoustics, 25(1).

[5] Richard Tyler. How up-to-date is your sound level meter's calibration. Acoustics Bulletin, 2005, 30(3): 41

[6] Kopiev VF, Palchikovskiy VV, Bersenev YV, Makashov SY, Belyaev IV, Korin IA, Sorokin EV, Khramtsov IV, Kustov OY. Design and qualification of an anechoic facility in PNRPU. Procedia Engineering. 2017.; 176:264-72

[7] ISO 3745:2012, Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Precision methods for anechoic rooms and hemi-anechoic rooms, International Organization for Standardization, 2012.

[8] ISO 26101:2012, Acoustics – Test methods for qualification of free-field environments, International Organization for Standardization, 2012.

[9] ISO 3382:2009 Acoustics – Measurement of room acoustic parameters, International Organization for Standardization, 2009.

[10] ISO 26101:2017, Acoustics – Test methods for qualification of free-field environments, International Organization for Standardization, 2017.

[11] ARTA computer software - http://www.artalabs.hr/

[12] Brüel & Kjaer, RT analyzer 2250-F specifications, https://www.bksv.com/media/doc/bp2152.pdf