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Short communocation

METHODOLOGY DEVELOPMENT AND PERFORMANCE TESTING OF AN ACOUSTICALLY ISOLATED BOOTH USING THE ISO 23351-1:2020 STANDARD

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Abstract: An acoustically isolated meeting booth is a specially designed structure used to isolate and reduce the level of speech. This pod is made in order to create a sound-isolated space, where you can work, record or perform sound in conditions of minimal noise and interference. Acoustically isolated pods are used for various applications such as music recording studios, movie theaters, conference rooms, and wherever it is important to limit sound transmission and ensure a quality acoustic environment. In this type of acoustically isolated rooms, acoustic characterization of all types of sound sources, as well as sound receivers, usually sound sensors, is carried out. The main objective of this research is to develop a methodology using the ISO 23351-1:2020 standard and test the performance of an acoustically isolated cabin. In addition to the primary goal of research, an additional goal is the analysis of the accuracy of the results obtained from a low-cost noise sensor through its comparison with a class 1 sound meter. The obtained results provide an opportunity for research and application of standardization that enables the development of a methodology for measurement and assessment of the characteristics of an acoustically isolated booth. In particular, the focus is on applying the methodology, measuring and comparing the results of noise measurements between a class 1 sound meter and a low-cost sensor unit.

Key words: acoustically isolated environment; sound sensors; measurement methodology; ISO 23351-1:2020 standard; acoustic measurements

РАЗВОЈ НА МЕТОДОЛОГИЈА И ТЕСТИРАЊЕ НА ПЕРФОРМАНСИ НА АКУСТИЧНО ИЗОЛИРАНА КАБИНА КОРИСТЕЈЌИ ГО СТАНДАРДОТ ISO 23351-1:2020

Апстракт: Акустично изолираната кабина е специјално дизајнирана структура или простор што се користи за изолација и редуцирање на нивото на говор. Оваа кабина се изработува со цел да се креира звучно-изолиран простор, каде може да се работи, снима или изведува звук во услови на минимален шум, бучава и интерференции. Акустично изолираните кабини се користат за разни примени како што се студијата за снимање музика, кино-салите, просториите за конференции, и секаде каде што е важно да се ограничи преносот на звук и да се овозможи квалитетна акустична околина. Основна цел на ова истражување е развој на методологија користејќи го стандардот ISO 23351-1:2020 и тестирање на перформансите на развиена акустично изолирана кабина. Покрај примарната цел на истражување, како дополнителна цел е анализа на точноста на резултатите добиени од нискобуџетен сензор за бучава преку негова споредба со звукомер од класа 1. Добиените резултати даваат можност за истражување и примена на стандард кој овозможува развој на методологијата за мерење и процена на карактеристиките на акустично изолирана кабина. Фокусот е насочен кон примена на методологијата, мерење и споредба на резултатите од мерењата на бучава помеѓу звукомерот од класа 1 и нискобуџетната сензорска единица.

Клучни зборови: акустично изолирана средина; сензори за звук; методологија за мерење; стандард ISO 23351-1:2020; акустични мерења

1. INTRODUCTION

An increasing number of individuals now work in open-plan and activity-based offices [1], while schools, hospital wards, and public spaces like libraries and lounges are increasingly adopting open architecture [2]. In such open environments, studies have shown that those trying to focus on individual tasks fail due to the disturbing noise caused by nearby intelligible conversations and frequent phone ringing [3, 4, 5]. Additionally, effective communication often requires a certain level of speech privacy, which can be challenging to maintain in a bustling open space [6]. This has led to the need for a silent space, where individuals can finish important tasks when needed, as well as make phone calls, without disturbing the rest of the group.

Fully isolated rooms with enhanced sound isolation can be a big investment for large institutions [7], so this study has a primary focus on developing a methodology for testing compliance of a modular furniture setup with a chosen standardization. The setup is consisted of a portable enclosure that users can easily assemble and position within open spaces, offering both accessibility and a means to monitor occupancy. A secondary focus is using the booth to later compare low-cost and high-grade standardized Class 1 sound sensors, as well as hypothesize that a low-cost sensor can be used in standardized experiments to define a space's acoustic classification. For this, the ISO 23351-1:2020 standardization guidelines [8] were defined as the most suitable standard for developing the measurement methodlogy.

In the field of acoustics, research in cutting-edge materials [9] and understanding the importance of investing in sound-isolating environments has been growing [10]. Using the right materials and dimensions for the cabin results in better isolation quality and a better sound environment in the cabin [11]. To define the effectiveness of these environments, proper standardization is necessary [12], as well as developing cost-effective methodologies for its testing [13, 14]. Similar studies on such environments have been created in the past for industry-based working areas [15], as well as offices, where the focus was the speech privacy when making phone calls [16]. These enclosures are entirely enclosed and typically come equipped with essentials such as doors, electrical outlets, lighting, windows, and ventilation fans [17, 18].

The primary performance indicator for this type of acoustically isolated booths in terms of sound reduction, according to existing standardization, is the class division indicator. The class division of acoustically isolated cabins depends on the level of noise prediction and sound pressure and is usually expressed by classes A+, A, B, C, and D [19], as shown in Table 1.

The Class 1 sound level meter has high accuracy and allows several analyses in time and frequency domain, while the low-budget sensor unit can only show the sound level and will be used in this paper to explore its performance, but testing this sensor is crucial in making acoustic testing available for lower budgets. The results of this paper are part of a student project financed by the University of Ss. Cyril and Methodius in Skopje, North Macedonia.

Table 1

Class division of acoustically isolated cabins according to speech level reduction, thus speech privacy guarantee, following the ISO 23351-1:2020 standard guidelines

Class	**Speech level reduction (dB)**	**Speech privacy guaranteed?**
A$^+$	> 33	Yes
A	30 – 33	Yes
B	25 – 30	Yes
C	20 – 25	Depends on background noise level
D	15 – 20	Depends on background noise level
Unclassified	< 15	No

2. METHODOLOGY

Proper definition of standardized measurements is of vital importance for this study. Initially, using the ISO 23351-1:2020 standard allows us to develop a methodology and select an appropriate experimental measurement protocol, including the choice of suitable sound sensors. With its assistance, it is defined and precisely determined which sound characteristics will be measured, which aids in a comprehensive segmentation and analysis of the sounds received in the isolated environment.

First, defining an environment where the isolation cabin will be placed is essential. The established standard acoustic conditions that largely prevent the penetration of external sources of noise must also be defined. If the room in which this cabin is located has windows, it needs to be positioned at least one meter away from the wall with the window and minimizing the number of objects in the room is necessary to reduce sound reflection [20].

The room in which the measurement is conducted should be a reverberation room that complies with the ISO 3741:2010 standard. One of the main criteria for accommodating an acoustically isolated environment is the size of the chosen room, which should have a minimum volume of 150 m^3 to be able to register a frequency of 125 Hz, while the volume of the cabin should be up to 5% of the volume of the room where the measurement will be performed [21].

According to the standard ISO 23351-1:2020 for analyzing the performance of acoustically isolated spaces, the measurement methodology is divided into four phases shown on Figure 1:

- **Phase 1:** Selection of hardware equipment.
- **Phase 2:** Defining 3 case studies.
- **Phase 3:** Defining measurement points and duration.
- **Phase 4:** Analysis, comparison, and validation of results.

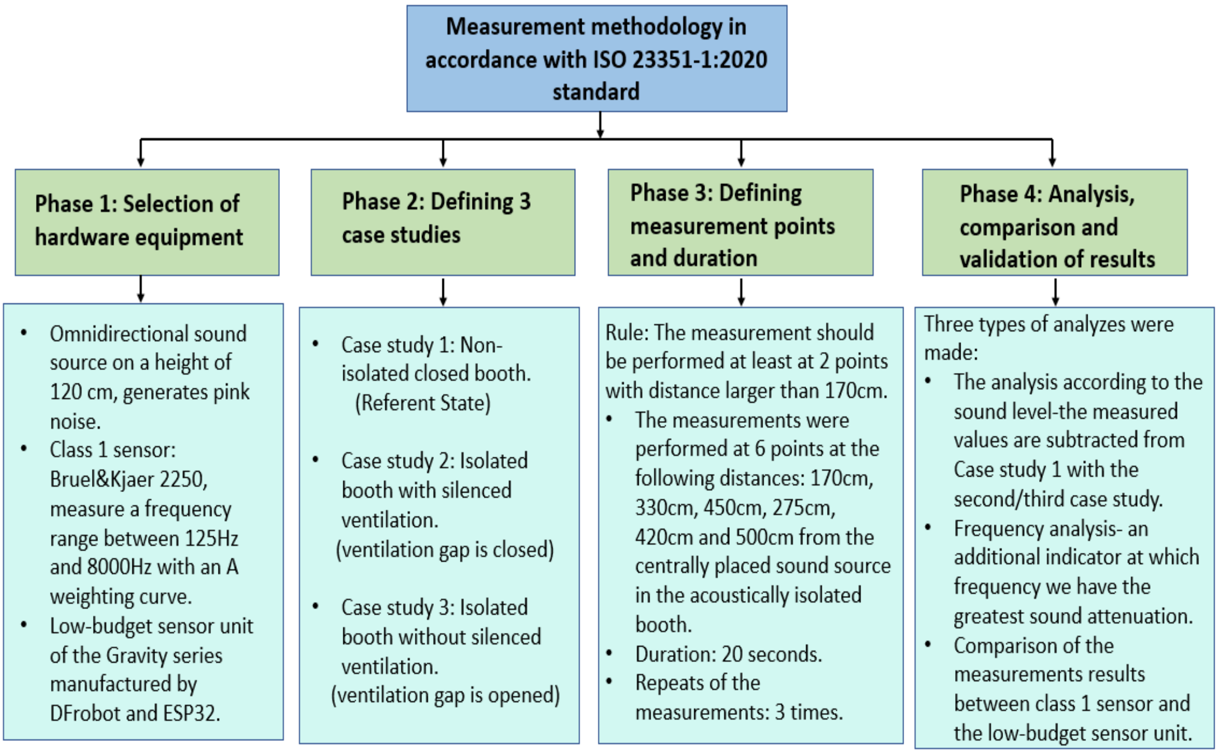


Fig. 1. Different phases of the measurement methodology following the ISO 23351-1:2020 standard

According to Figure 1, phase 1 is related to the hardware equipment, where Class 1 hand-held analyser is used for measuring the sound level, while the omnidirectional sound source is used for generating pink noise. To be able to do additional analysis, a low-cost budget sensor is used for seeing its performance.

The 2nd phase defines three case studies while performing the measurements, in order to be able to classify the booth. The initial referent measurement is performed in an open space, and in order to calculate the classes according to the speech level reduction, additional measurements in three case studies are performed. In the 1st case study, the measurement is performed while the sound source is in the booth without acoustically isolated materials, while in the 2nd and 3rd study cases, the booth is isolated. The difference between the 2nd and 3rd case study is the open and closed ventilation gap that is located on the top of the cabin.

The 3rd phase defines 6 measurement points, while at each measurement point the measurement is performed with time duration of 20 seconds and it is repeated 3 times. The 4th phase is related to analysis, comparison and validation of the gained results. According to the above defined phases, the experimental testing is done in the following section.

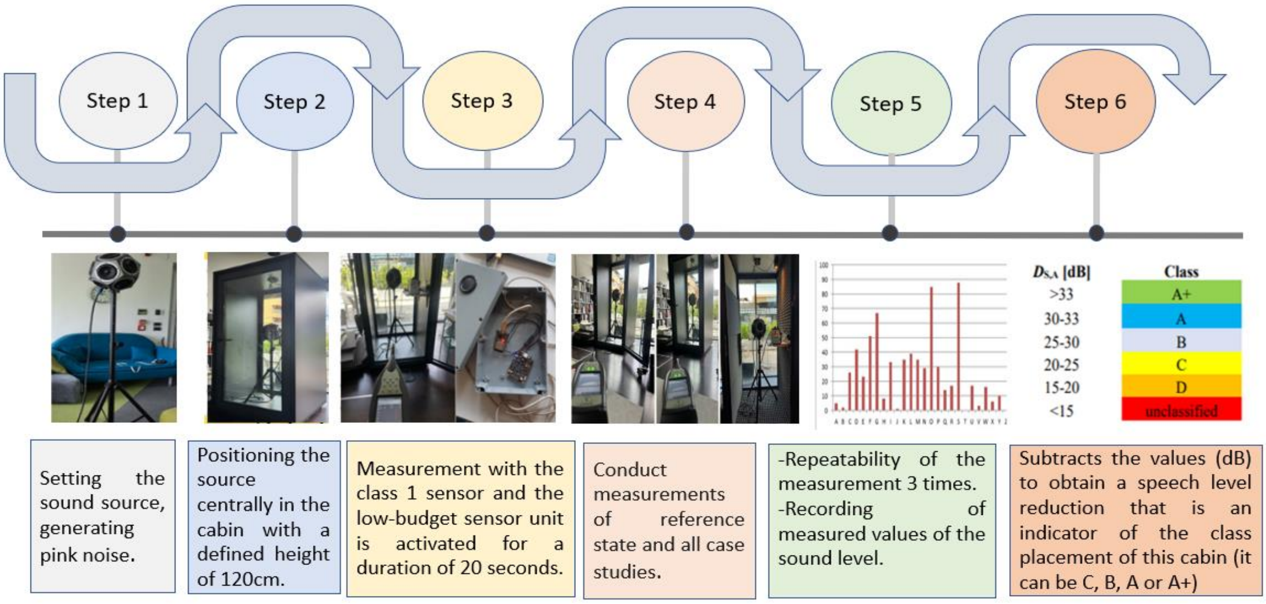
3. EXPERIMENTAL WORK

For better performance testing of the acoustically isolated booth, the sound level in the working environment was first measured without any isolating material and then various acoustic absorbers to improve sound absorption were added. This allowes obtaining multiple case studies with more results for analytical comparisons. The designed acoustically isolated environment shown in Figure 2 is designed to be used as a booth for a single occupant, while remaining more cost-effective than the currently available commercial cabins.

Fig. 2. Proposed prototype design of acoustically isolated booth for testing with dimensions of 2.2 × 1.5 × 1.5 m

Effective acoustic isolation is required to achieve good performance of the acoustically isolated booth. To implement this, several factors are taken into account, such as materials, construction, and sound transmission reduction [22]. When designing an effective acoustically isolated cabin, the following characteristics need to be considered: the chosen suitable acoustic materials should have good sound absorption and sound blocking properties, the room or object design with double or triple walls, floors, or roofs with air gaps between them should increase the space for sound isolation, and the use of acoustic materials that absorb sound would help reduce sound reflection in the space [23]. To achieve improved sound absorption, acoustic absorbers are of great importance. An absorptive material called "z-line" was used, made of high-quality polyester with a high coefficient of sound absorption for middle and high frequencies. Due to its open-cell structure and specific geometry, this corrugated absorber possesses exceptional sound isolation properties [24].

The designed booth was tested according to the developed methodology based on the standard ISO 23351-1:2020, while the measurement was carried out with 6 steps as shown on Figure 3.



Setting the sound source, generating pink noise.

Positioning the source centrally in the cabin with a defined height of 120cm.

Measurement with the class 1 sensor and the low-budget sensor unit is activated for a duration of 20 seconds.

Conduct measurements of reference state and all case studies.

-Repeatability of the measurement 3 times.
-Recording of measured values of the sound level.

Subtracts the values (dB) to obtain a speech level reduction that is an indicator of the class placement of this cabin (it can be C, B, A or A+)

Fig. 3. Six steps of conducting the sound isolation measurements

Omnidirectional sound source with an amplifier according to ISO 3382-1, is a sound source that generates pink noise with a defined height of 1.2 m (from the floor) adapted for acoustic measurement tests made in cabins for a sitting position [25]. Sound level meters from Class 1 are the main indicator when doing measurements and obtaining valid results for the goals of this paper. On the other hand, the low-budget sensor can obtain results, but they cannot be verified according to the standard. The data collected from the low-cost sensor unit is compared with the results of a B&K Class 1 sound meter which is taken as a reference device with greater accuracy and precision in obtained values. Their working principle for the sound level meter Class 1 and the low-budget sensor is shown on Figures 4 and 5, respectively.

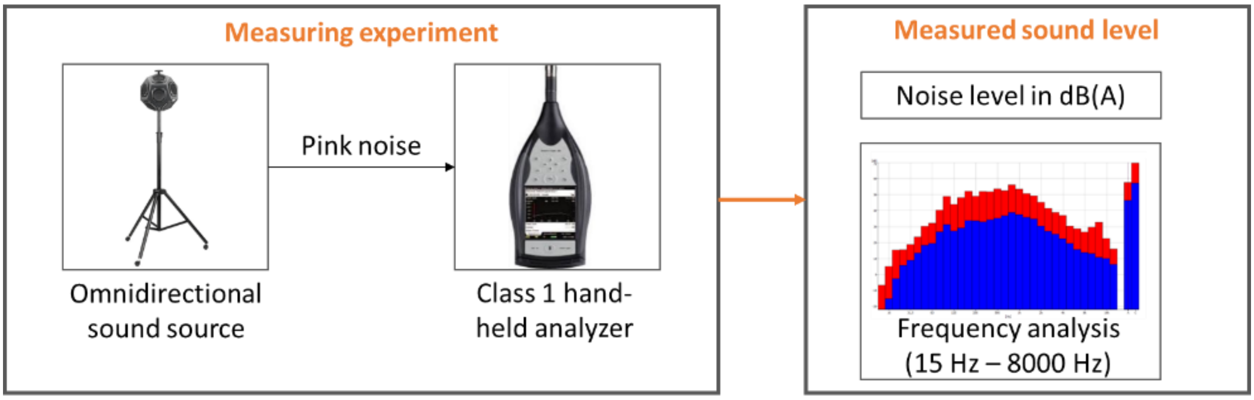


Fig. 4. Measuring experiments using the 1st class hand-held analyzer

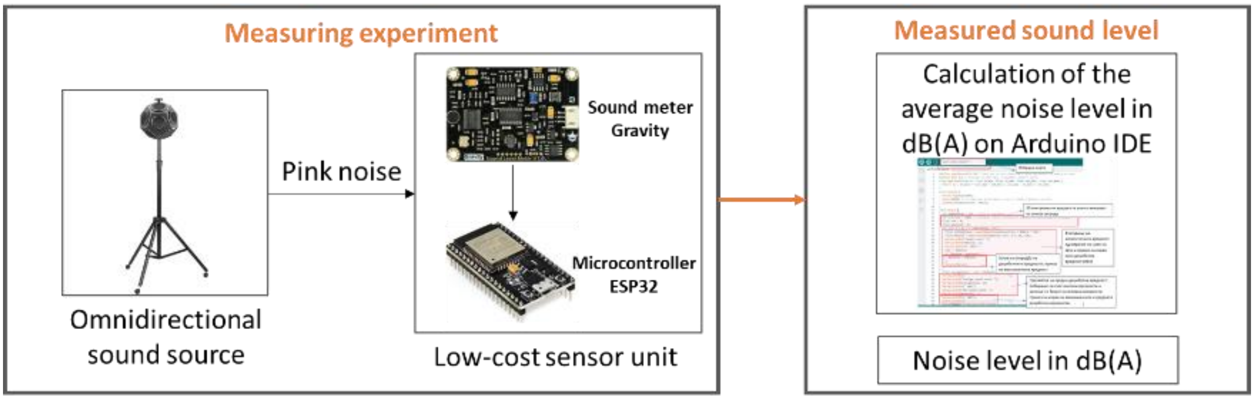


Fig. 5. Measuring experiments using the low-cost sensor unit

The B&K 2250 audiometer detects pink noise generated by the omnidirectional sound source and performs octave spectrum measurements, which means that it divides the entire audio spectrum into octave frequency bands. Specifically for this case, the frequency ranges are determined in accordance with the standard and are between 125 Hz and 8000 Hz with an A weighting curve. This analysis aims to determine how the intensities of different frequencies in the sound signal are distributed. The results are mean values from the 3 measurements. The low-cost sensor unit is consisted of Gravity Sound Sensor and sends the values to the ESP32 microcontroller, while the results that are sent to the Arduino IDE are average values of the sound level in dB(A) for 20 second interval, which means that 20 measured values (samples) enter this interval. The average equivalent sound value is calculated according to the formula:

$$L_{ekv} = 10 \times \log \frac{\sum_{i=0}^{n} 10^{\frac{ki}{10}}}{n}, \qquad (1)$$

where *ki* is the *i*th measured value in dBA, while *n* is the number of measurements.

4. RESULTS AND DISCUSSION

4.1. *Analysis of the performance of the acoustically isolated booth*

In order to perform an analysis of the performance of the acoustically isolated booth in the three case studies, it is necessary to calculate the difference between these sound levels or subtract their values to determine the reduction in speech levels. The measurement was done using the Class 1 hand-held analyzer for the three case studies as shown in the methodology, while the results are shown on Table 2.

The sound power level (SWL) emitted by a loudspeaker is measured according to ISO 3741 in two phases: (1) without the product for a bare omnidirectional sound source, and (2) with the product including the omnidirectional sound source at the centrally defined position.

The mathematical principle of determining speech level reduction is presented below. First, the level reduction is determined in octave bands 125–8000 Hz. Level reduction, D_i (dB), is the difference between the sound power level measured in the two phases mentioned before.

$$D_i = L_{w,P,1,i} - L_{w,P,2,i}, \tag{2}$$

where $L_{w,P,1,i}$ (dB) is the sound power level radiated by the sound source without furniture ensemble, and $L_{w,P,2,i}$ (dB) is the sound power level radiated by the specimen when the sound source is inside the booth. The octave band is denoted with i and P indicates pink noise.

Second, the speech level reduction, $D_{s,A}$ [dB], is calculated. $D_{s,A}$ is a single-number quantity that expresses the corresponding reduction in Aweighted sound power level of standard effort speech within 125–8000 Hz. The value of $D_{s,A}$ is calculated by

$$D_{s,A} = L_{w,s,A,1} - L_{w,s,A,2} \tag{3}$$

$$D_{s,A} = L_{w,s,A,1} - L_{w,s,A,3} \tag{4}$$

where $L_{w,s,A,1}$ is the sound power level from case study 1 which is the referent state (Non-isolated closed booth) from who we are subtracting $L_{w,s,A,2}$ (sound power level of study case 2- Isolated booth with silenced ventilation) and $L_{w,s,A,3}$ (sound power level of study case 3 – Isolated booth without silenced ventilation.

From the results it can be seen that the difference between the first case study with an open cabin and the second case study is approximately 9 dB. Furthermore, when comparing the difference between the first and third case study, there is a 3 dB difference measured.

The most significant comparison observed is between case study 2 and case study 3, which shows a 7dB difference. This difference effectively highlights the effects of ensuring a quality soundproof ceiling and silenced ventilation, resulting in the maximum difference that grants the cabin a higher classification (in this case Class A with a potential for A+). Cabins in this class have the highest efficiency in noise isolation. They are able to isolate even the most audible noises and sound pressures, which makes them ideal for applications where the highest quality of isolation is most important.

Although the second case study provides the best results, it is not a realistic solution due to the need for proper air exchange in the cabin. Therefore, the most optimal solution is to upgrade the cabin with a ventilation system that facilitates air circulation and exchange between the cabin and the external environment while providing maximum sound attenuation.

Table 2

Results from the measurements for defining the speech level reduction of the booth in the three case studies

Measurement point	Case study 1 Speech level reduction of the non-isolated booth dB(A)	Case study 2 Speech level reduction of the isolated booth with silenced ventilation dB(A)	Case study 3 Speech level reduction of the isolated booth without silenced ventilation dB(A)
1	25.1	31.7	26.7
2	24.0	30.9	26.9
3	24.1	33.8	26.4
4	23.8	33.7	26.9
5	22.6	31.6	25.5
6	22.9	32.2	26.4

4.2. *Frequency analysis*

The frequency analysis serves for further analysing and observing at which frequency range there is the most significant noise mitigation. From the analysis of the results in Figure 6, at the representative point with distance of 4.5 m, the highest sound levels measured in the open state without soundproofing material are observed at frequencies of 1000, 2000 and 4000 Hz. The most significant reduction (difference) of 46.3 dB is observed at a frequency of 8000 Hz. The highest sound level occurs at a frequency of 2000 Hz, with a value of 70.76 dB.

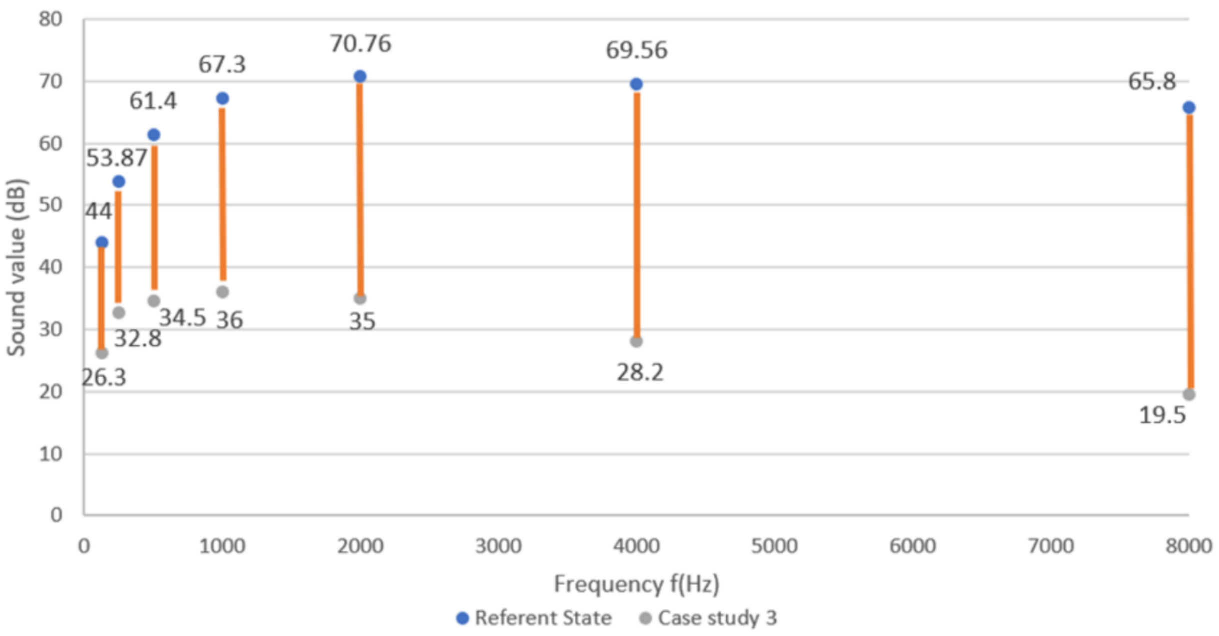


Fig. 6. Frequency data collected from representative measurement point 3

It can be noted that after isolating the cabin, the highest sound levels are found in the frequency range of 500 to 2000 Hz. Based on this, if further sound reduction is desired when selecting soundproofing materials, it is necessary to choose a material that provides attenuation in these frequencies between 500 Hz and 2000 Hz.

4.3. *Comparison between the results of the low-cost sensor unit and Class 1 hand-held analyzer*

The results of the low-cost sensor unit compared with the sound level meter are analyzed. Table 3 shows the results where the smallest difference in measurements is between the Class 1 sound level meter and the low-budget sensor unit. This value is between 0,4 and 1 dB, meanwhile the highest difference is 3.3 dB. The results from the low-budget sensor unit can serve as a good indicator for representing the noise level but cannot be used when measuring according to a standard.

It can be noticed that the low-cost sensor unit gives higher values of the measured sound level than the 1st class hand-held analyzer. The results from the low-budget sensor unit can serve as a good indicator for representing the noise level but cannot be used when measuring according to a standard.

Table 3

Results from differences between noise level of the low-cost sensor and the Class 1 hand-held analyser

	Measurement point 1	Measurement point 2	Measurement point 3
	Difference in dB(A)	Difference in dB(A)	Difference in dB(A)
Case study 1	1	2.2	0.4
Case study 2	4.4	2.7	0.9
Case study 3	1.2	2.8	0.4
	Measurement point 4	**Measurement point 5**	**Measurement point 6**
	Difference in dB(A)	Difference in dB(A)	Difference in dB(A)
Case study 1	1	0.3	2.1
Case study 2	1.4	2.8	1.3
Case study 3	1	1.2	0.4

5. CONCLUSIONS

The developed methodology enabled an acoustic study of the acoustically isolated booth. From the obtained results and their analysis, it can be estimated that the booth exhibits adequate performance in terms of acoustic isolation, potentially allowing it to be Class B or Class A. Additional measurements and research are needed to accurately determine the class to which the acoustically isolated booth belongs. Using the equipment, a measurement of sound levels was performed, as well as a frequency analysis that could provide guidance for selection of materials for additional sound isolation for the cabin.

As part of the conducted measurements, an additional analysis included the evaluation of the accuracy of the low-budget sensor unit, which was enhanced with software that directly records results according to the requirements for this testing. The results from the low-budget sensor unit were compared with results obtained from a Class 1 instrument, indicating that the low-budget sensor unit can be a good indicator for assessing sound levels. However, for these types of analyses, a Class 1 sound level meter is still required for precise measurements.

Through this paper, a methodology has been developed in accordance with the ISO 23351-1:2020 standard, which can serve as a basis for testing various acoustically isolated cabins in the future. In addition, there is an opportunity to improve the standard's acoustic conditions in order to improve the class placement itself, as well as the opportunity to enrich the hardware equipment, application of new sensor technology, automation of measurements and generation of results, testing of other measuring instruments and thus to obtain better results.

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