DOI: 10.61782/fa.2023.0392

forum acusticum 2023

ALTERNATIVE MEASUREMENT METHODS FOR SPEECH LEVEL REDUCTION OF BOOTHS IN FIELD CONDITIONS

Jukka Keränen[1*] **Jarkko Hakala**[1] **Johann Laukka**[1] **Valtteri Hongisto**[1]

[1] Turku University of Applied Sciences, Acoustics Laboratory, Finland

ABSTRACT

The sound level reduction of enclosures and partial enclosures (booths, pods, partially closed furniture ensembles) should be primarily tested in laboratory (reverberation room) according to ISO 23351-1. The single-number outcome is speech level reduction, $D_{S,A}$. However, very large products cannot be tested in laboratory. In addition, field testing is needed when the declared product performances are verified, or prototype products are developed. Standardized field method does not exist. The purpose of this study is to compare methods reaching engineering grade of accuracy in field conditions.
The apparent speech level reduction, $D'_{S,A}$, is determined by measuring the sound power levels radiated by a constant sound source with (the sound source in the booth), and without the booth. The difference between these sound power levels determines the speech level reduction. The sound power levels can be measured according to ISO 3744, ISO 3747, or ISO 9614-2 with engineering grade of accuracy.
We tested one booth in laboratory and in six different field conditions. The results are compared and discussed. Field results show acceptable agreement to laboratory results. This work is expected to help the development of ISO DIS 23351-2.

Keywords: *speech, sound insulation, offices, enclosures, furniture.*

[*]***Corresponding author***: *jukka.keranen@turkuamk.fi.*

1. INTRODUCTION

Activity-based offices, schools, and public places are increasingly furnished by sound isolated, mobile enclosures or partial enclosures (booths, pods, partially closed furniture ensembles; later products) to locally provide ad hoc spaces with improved speech privacy. In addition, these products can be used for work tasks demanding concentration. Such products are increasingly available in the market. Their acoustic performance should be tested in laboratory conditions (reverberation room fulfilling ISO 3741 requirements) according to ISO 23351-1 [1,2,3]. However, large products, e.g., booths for 6 persons, are difficult to test in laboratory due to their large volume (>10 m^3). In addition, there is an obvious need to test the products also in situ, when the declared product performances need to be verified in normal rooms. Field test needs are also common in product development stage. However, consistent field test method does not exist.
The purpose of this study is to compare methods reaching engineering grade of accuracy in field conditions.
The work was promoted by the New Work Item Proposal 23351-2 which was recently approved in an international ballot.

2. DETERMINATION OF SINGLE-NUMBER VALUES

2.1 Speech level reduction (laboratory measurement)

The test result of ISO 23351-1 is a single-number value called speech level reduction, $D_{S,A}$ [dB] [1]. The sound power level, SWL, of the omnidirectional sound source, OSS (Fig. 1), without the booth, $L_{W,1}$ [dB], is determined in the empty reverberation room (Fig. 1). The SWL of the OSS with the booth, $L_{W,2}$ [dB], is determined so that the OSS is at the speaker's position inside the booth which is in the reverberation room. The speech level reduction, $D_{S,A}$, is determined based on SWL of standard effort speech, $L_{W,S,1}$, and the level reduction, D [dB], which is determined in octave bands by:

$$D = L_{W,1} - L_{W,2} \tag{1}$$

The SWL of speech with the booth is determined by:

$$L_{W,S,2} = L_{W,S,1} - D \tag{2}$$

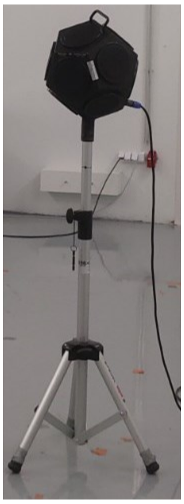
where $L_{W,S,1}$ is the SWL of standard effort speech. It is defined in octave bands in Ref. [1]. The A-weighted SWL of speech with the booth is determined by:

$$L_{W,S,A,2} = 10\log_{10}\left[\sum_{i=1}^{7} 10^{0.1\cdot(L_{W,S,2,i}+A_i)}\right] \tag{3}$$

The speech level reduction is defined by:

$$D_{S,A} = L_{W,S,A,1} - L_{W,S,A,2} \tag{4}$$

where $L_{W,S,A,1}$=68.4 dB is the A-weighted SWL of standard effort speech as defined in Ref. [1].



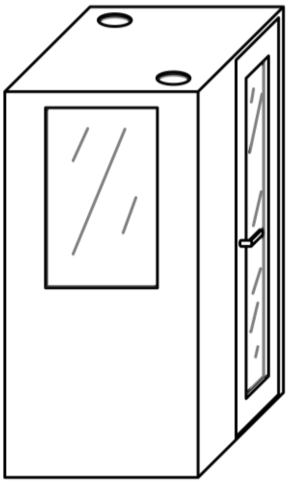


Figure 1. The OSS is used in all the measurements (left). Sketch of the studied booth (right).

2.2 Apparent speech level reduction (field measurements)

The apparent speech level reduction, $D'_{S,A}$, is determined in a similar way as $D_{S,A}$ using Eq. (3) and (4). However, the SWLs of the OSS with and without the booth are determined using field measurement standards of Sec. 3. The apparent level reduction, D', in octave bands is defined by Eq. (1) and the SWL of speech with the booth by Eq. (2).

3. STANDARDIZED MEASUREMENT METHODS FOR SOUND POWER LEVEL

3.1 ISO 9614-2

Very accurate method for SWL measurements in any field conditions is the sound intensity method ISO 9614-2 [4]. The only limitation of the method is that the surface of the object may not have strong sound absorption. The SWL is measured using a sound intensity probe by scanning the hypothetical surface that encloses the sound source. The total measurement area affects the SWL. The SWL is determined by:

$$L_W = L_I + 10\log_{10} S \tag{5}$$

The SWL was measured on the outer surfaces of the booth at the distance of 10 cm from the surface to the center of microphones. The entire scanned surface area that enclosed the booth was the total measurement area (Fig. 2a). The SWL of the OSS without booth, $L_{W,1}$, was also determined by Eq. (5).

3.2 ISO 3747

ISO 3747 is a measurement standard for SWL measurements in semi-reverberant rooms [5]. Semi-reverberant room means that the reverberation time and volume requirements of ISO 3741 need not to be met but the room is essentially reverberant (low sound absorption). $L_{W,OSS}$ is determined in a reverberation room before field measurements [3]. In the field test, the sound pressure level, SPL, is measured in several positions on a hypothetic surface at specific distance from the envelope of the product. The distances between the OSS and the measurement positions depend on the size of the envelope and the reverberation time of the room according to ISO 3747.
First, the OSS was placed in the position of the speaker inside the envelope but without the booth. The SPLs

produced by the OSS (without booth), $L_{p,OSS}$ [dB], were measured in the positions on the hypothetic surface. Second, the SPLs, L_p [dB], radiated by the booth (including the OSS) were measured using the same positions. The SWL of the OSS placed inside the booth, L_W, was determined by:

$$L_W = L_{W,OSS} - \bar{L}_{p,OSS} + \bar{L}_p \tag{6}$$

The SPLs were measured in nine positions at the distance of 1.0 m from the envelope (Fig. 2b).

3.3 ISO 3744

ISO 3744 standard describes measurement of SWL in essentially free field over a reflecting plane [6]. Essentially free field means that the room absorption must be significantly higher than in semi-reverberant room. A hypothetical measurement surface is defined around the envelope. The SPLs, $L_{p,i}$ [dB], are measured in several positions on the measurement surface. The energy average SPL is determined using the partial surface areas of the measurement surface, S_i [m^2], and SPLs, $L_{p,i}$, by:

$$\bar{L}_p = 10\log_{10}\left[\frac{1}{S}\cdot\sum_{i}\left(S_i\cdot 10^{0.1\cdot L_{p,i}}\right)\right] \tag{7}$$

The SWL is determined by:

$$\bar{L}_W = \bar{L}_p - K_2 + 10\log_{10}\left(\frac{S}{S_0}\right) \tag{8}$$

where S [m^2] is the total measurement area which is the sum of the partial measurement surface areas, and S_0 = 1.0 m^2. The correction to the SWL is determined by:

$$K_2 = 10\log_{10}\left(1 + \frac{4S}{A}\right) \tag{9}$$

The value of A is determined from the measured reverberation time [7].
The SPLs were measured around the booth in nine positions at the distance of 0.25 m from the envelope (Fig. 2c). The SPLs were measured without the booth to obtain $L_{W,1}$, and with the booth to obtain $L_{W,2}$. The reverberation time in the room was measured using two sound source positions and three measurement positions around the booth [7].

4. THE BOOTH AND TEST ROOMS

One booth was investigated. The outer surface of the booth was not sound absorbing (veneer) and it had reasonably smooth radiation pattern (no sound leaks).

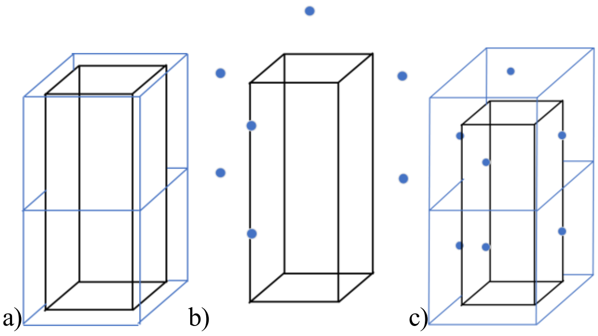


Figure 2. The measurement positions using different methods: a) ISO 9614-2 (surface scanning), b) ISO 3747 (points), c) ISO 3744 (points). Black line describes the outlines of the booth. Blue line describes the measurement surface. Blue dots describe the fixed measurement positions. Measurement positions in the back are not shown.

The booth was first tested in a reverberation room according to ISO 23351-1 [1]. Thereafter, the booth was tested using the alternative methods of Sec. 3 in a 71.5 m^3 room (with mainly concrete surfaces) where the sound absorption was modified to achieve acoustically different rooms 1–3. Additional measurements were made in larger office rooms 4–6. The descriptions of the rooms were the following:

- Room 1: No absorption treatment (reverb. time 2.4 s)
- Room 2: As room 1 but the walls were 50% covered with wool absorbers (50 mm wool, space 100 mm behind) (0.5 s).
- Room 3: As room 2, but the ceiling was 50% covered with abovementioned wool absorbers (0.3 s).
- Room 4: Large and 15 m high atrium (>3000 m^3) in an office building. The room was furnished and had a few sound absorption elements on walls (1.2 s).
- Room 5: Open-plan office with reflective glass and concrete walls. The ceiling was 80% covered with absorbers, but there were cooling panels below that covered 50% of the ceiling absorbers (0.7 s).

- Room 6: As room 5 but 90% of the walls were covered with cotton curtains (0.3 s).

5. RESULTS

The results of $D_{S,A}$ or $D'_{S,A}$ with different methods are presented in Table 1.

Table 1. The measured $D_{S,A}$ or $D'_{S,A}$ obtained with the methods of Secs. 3.1–3.3 for the booth.

Method	[dB]	Test room
ISO 23351-1, $D_{S,A}$	21.8	Reverberation room
ISO 9614-2, $D'_{S,A}$	23.0	Room 1
	25.3	Room 2
	23.2	Room 3
	23.1	Room 4
	22.4	Room 5
	22.5	Room 6
ISO 3747, $D'_{S,A}$	22.4	Room 1
	21.2	Room 2
	21.2	Room 3
	21.2	Room 4
	21.5	Room 5
	21.2	Room 6
ISO 3744, $D'_{S,A}$	23.0	Room 1
	22.3	Room 2
	21.9	Room 3
	22.6	Room 4
	22.4	Room 5
	22.4	Room 6

6. DISCUSSION

The reproducibility standard deviation of laboratory method is 1.1 dB [2]. The field test results deviate from the laboratory results less than 1.0 dB which is a good indication. The mean deviations are 1.5 dB, -0.4 dB, and 0.6 dB for methods ISO 9614-2, ISO 3747, and ISO 3744, respectively. However, there are some exceptions. First, ISO 9614-2 gave 3.5 dB higher results in Room 2 than in laboratory. We cannot explain this. Second, both ISO 3747 and ISO 3744 gave slightly larger values in Room 1 than in Rooms 2–6. This work is expected to facilitate the development of ISO CD 23351-2.

7. ACKNOWLEDGMENTS

Huonekalusäätiö ry. (Finnish Furniture Association).

8. REFERENCES

[1] ISO 23351-1:2020 Acoustics – Measurement of speech level reduction of furniture ensembles and enclosures – Part 1: Laboratory method.

[2] V. Hongisto, J. Keränen, and J. Hakala: "Accuracy experiment of ISO DIS 23351-1 – speech level reduction of furniture ensembles and enclosures," Applied Acoustics, 164, 107249, 2020.

[3] ISO 3741:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Precision methods for reverberation test rooms.

[4] ISO 9614-2:1996 Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 2: Measurement by scanning.

[5] ISO 3747:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Engineering/survey methods for use in situ in a reverberant environment.

[6] ISO 3744:2010 Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure. Engineering methods for an essentially free field over a reflecting plane.

[7] ISO 3382-2:2008 Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms.