HAMBURG 2016

Acoustic testing of office workstations and booths

Valtteri HONGISTO[1]; Jukka KERÄNEN[2]; Petra VIRJONEN[3]; Jarkko HAKALA[4]

[1-4] Finnish Institute of Occupational Health; Turku University of Applied Sciences.

ABSTRACT

Office environments involve various kinds of furniture ensembles which are expected to reduce noise: open and enclosed workstations, pods, sofa groups, chairs, and booths. The diversity and market is strongly growing. However, there is no standardized method to declare their sound reduction properties. Our purpose was to introduce a laboratory method to determine the sound reduction of furniture ensembles. An easy-to-understand single-number quantity was desirable to facilitate communication with end users and designers who usually do not have education in acoustics. The test is conducted in a reverberation room. Speech source is placed to the position of the occupant's mouth inside the ensemble. Sound power level (ISO 3741) is determined with and without the ensemble. The level difference in 1/1-octaves describes the sound reduction. The single-number outcome of the test is the speech reduction index, D_S, which describes how much the ensemble reduces the A-weighted sound level of normal effort speech outside the ensemble. Six furniture ensembles were tested to demonstrate the method. The results show a consistent pattern. The measurement uncertainty is less than 1 dB. The paper is based on Hongisto et al. (2015, Acta Acust united Ac).

Keywords: 31.2.2 Barriers in open-plan offices; 35.4.2 Furnishings and chairs; 51.7 Landscaped (open plan) offices and lobbies; 32.1 Sound absorptive materials in enclosures; 14.1.5 Furniture and fixtures (SIC 25); 51.4 Sound-insulating structures, transmission coefficients and transmission loss

1. INTRODUCTION

Office noise and lack of acoustic privacy are among the most disturbing environmental factors in open-plan offices [1]. Colleagues' speech is the most disturbing source of noise [2,3]. It has been shown that highly intelligible speech reduces cognitive performance of office workers even by 7% compared to silence [4]. It was proven recently that colleagues' speech can reduce performance also in private office rooms if the sound insulation is less than 35 dB R'_w and background noise level is less than 33 dB L_{Aeq} [5]. Noise problems have not ceased in modern activity-based offices [6]. However, adequate noise control design can significantly alleviate noise detriments in open-plan offices [2, 7].

In modern office environments, diversity of spaces is preferred to provide different places for different work tasks, such as communication, private work and collaboration. Open-plan offices, activity-based offices, lounges, educational spaces and related open workspaces can involve various kinds of furniture ensembles, which are expected to reduce noise:

- open and enclosed workstations
- pods
- sofa groups
- chairs
- booths and
- mobile rooms.

The diversity and market of such ensembles is strongly growing. However, there is no standardized method to declare their sound reduction properties. Therefore, furniture manufacturers usually declare the sound absorption properties of the surface materials determined by e.g. ISO 354 standard. In some cases, the free-field insertion loss of the screens by e.g. ISO 10053 or ASTM E1111 are declared. However, these insertion loss methods overestimate the performance *in situ*. This was demonstrated by

[1] valtteri.hongisto@turkuamk.fi
[2] jukka.keranen@turkuamk.fi
[3] petra.virjonen@turkuamk.fi
[4] jarkko.hakala@turkuamk.fi

Virjonen et al. (8) who showed that the insertion loss produced by the same screen varied between 6 and 17 dB depending on room acoustic conditions.

Our purpose was to introduce a laboratory method to determine the sound reduction of furniture ensembles and to introduce a single-number quantity, speech reduction index, which can be used to declare the acoustic performance in a way which can be understood by the designers and end users. Full results are published in Ref. (9).

2. METHOD

2.1 General

This chapter describes a method to determine the sound reduction of furniture in 1/1 octave bands within 125 and 8000 Hz. The test result are expressed using a single-number quantity, speech reduction index, D_S.

The furniture ensemble shall have a predefined size and geometry and the position of the user shall be unambiguously defined. Changes in size, geometry or materials may lead to significant changes in speech reduction index. Therefore, the results are only valid for the tested furniture configuration.

If a chair is included to the ensemble under test, the results are only valid for the ensemble where this specified chair type is used. It is common that office workers are able to choose the chair by their own. Therefore, the default situation is that the chair is absent during the test.

2.2 Installation of the specimen and the test loudspeaker

The method determines how much a specimen (the furniture ensemble) reduces the speech emission radiated by a hypothetic surface comprising the test specimen compared to the situation when the specimen is absent and only the sound source is present (Figure 1). The measurements are performed in a reverberation room according to ISO 3741. The measurements are carried out in octave bands from 125 to 4000 Hz.

The hypothetic surface represents the surface area of the smallest possible polyhedron within which the specimen can be completely fitted.

The test loudspeaker is used to simulate the speech produced inside the specimen. It is placed to the most probable position of the user's mouth inside the specimen. Therefore, the position of the user's head shall be clearly defined before the test can be conducted. The height of a sitting person is 1.20 meters from the floor and the height of a standing person is 1.55 meters. Other heights can be used if feasible.

The loudspeaker is fed by pseudorandom noise, like pink noise. The level of the noise should preferably exceed the background noise level of the test room by 15 dB. The background noise correction is made according to ISO 3741.

The loudspeaker has a directivity resembling the directivity of mouth.

The distance of the hypothetic surface shall be at least 1.0 m from the walls and the ceiling of the reverberation room. The microphones are located at least 0.75 metres away from the hypothetic surface, room surfaces and diffusers, and at least 1.5 metres from the loudspeakers used in the test.

The volume of the specimen shall not exceed 5 m^3 to maintain acoustic diffusion properties of the reverberation room.

2.3 Measurement of sound reduction

The sound reduction of the ensemble, D [dB], is determined by

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

where $L_{W,P,1}$ and $L_{W,P,2}$ are the measured sound power levels radiated by the hypothetic surface with and without the furniture ensemble, respectively. Sub-index P indicates pseudo-random noise as a distinction to sub-index S indicating speech in the Equations (2-3). The sound power levels [dB re 1 pW] are determined according to ISO 3741 (direct method).

a) b) c)

Figure 1 – The loudspeaker is placed to the most probable position (b) of the occupant using the furniture ensemble (a). The sound power level radiated by the loudspeaker is determined without (c) and with (b) the furniture. (Specimen #6)

2.4 Determination of speech reduction index

Speech is the primary sound produced inside the furniture ensemble. Therefore, a single-number quantity describing the reduction of A-weighted speech level can be defined. The standardized sound power level of normal effort speech, $L_{W,S,1}$, conforms with ISO 3382-3 and it is given in Table 1. The sound power level of speech, $L_{W,S,2}$, radiated by the hypothetic surface, when the specimen is installed, is

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

where D is obtained from Equation (1) in octave bands 125-4000 Hz. Finally, the speech reduction index D_S is determined from

$$D_S = L_{W,S,A,1} - L_{W,S,A,2} \tag{3}$$

where $L_{W,S,A,1}$ and $L_{W,S,A,2}$ are the total A-weighted sound power levels determined from $L_{W,S,1}$ and $L_{W,S,2}$, respectively. A-weighting is based on Annex F of ISO 3741.

An example of the measurement and calculation procedure is presented in Table 1.

Table 1 – Calculation example for specimen #2.

	Linear			Linear			A-weighted	
	$L_{W,P,1}$ [dB]	$L_{W,P,2}$ [dB]	D [dB]	$L_{W,S,1}$ [dB]	$L_{W,S,2}$ [dB]	A-weight [dB]	$L_{W,S,1}$ [dB]	$L_{W,S,2}$ [dB]
125	88.4	85.4	3.0	60.9	57.9	-16.1	44.8	41.8
250	88.9	84.9	4.0	65.3	61.3	-8.6	56.7	52.7
500	88.2	84.2	4.0	69.0	65.0	-3.2	65.8	61.8
1000	88.8	84.7	4.1	63.0	58.9	0.0	63.0	58.9
2000	89.9	85.9	4.0	55.8	51.8	1.2	57.0	53.0
4000	88.0	84.0	4.0	49.8	45.8	1.0	50.8	46.8
							$L_{W,S,A,1}$	**68.4**
							$L_{W,S,A,2}$	**64.4**
							D_S	**4.0**

2.5 Test specimens

The six furniture ensembles, which were tested by the method, are shown in Figure 2.

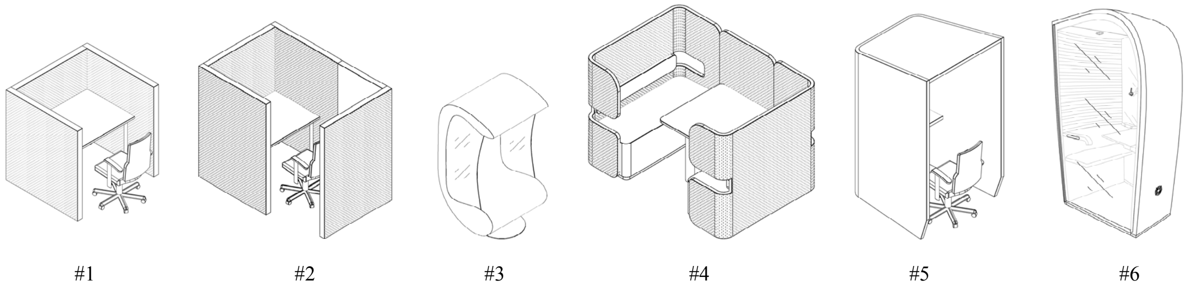

Figure 2 – The specimens. The heights are 1.27, 1.64, 1.50, 1.26, 1.80 and 1.80 meters, respectively. Grey surfaces indicate sound absorption class C or larger (ISO 11654).

2.6 Measurement uncertainty

Specimen #6 was tested five times repeatedly in three different reverberation rooms R1-R3 by the same operator to see the variation of D_S. The position of the specimen and microphones were changed between the five measurements.

3. RESULTS

The test results of the six specimens are shown in Figure 3 and Table 2.

Fifteen test results of the specimen #6 obtained in three reverberation rooms are shown in Figure 4 and in Table 3. The reproducibility value was 0.9 dB. This value is an estimation of the inter-laboratory difference of the method for ensembles resembling the specimen #6 (phone booth).

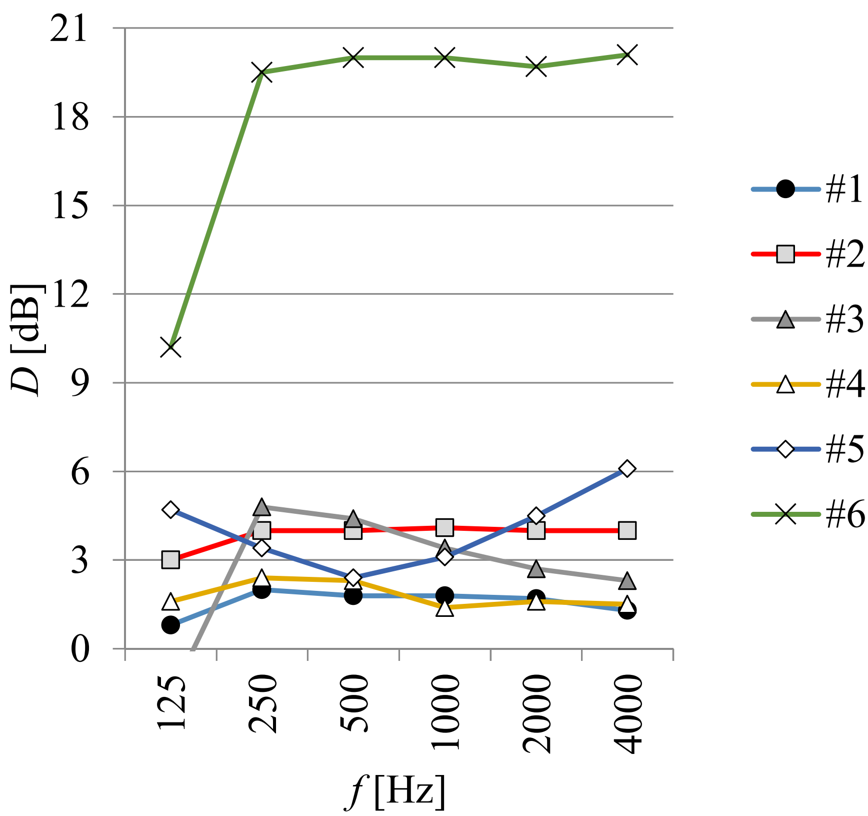

Figure 3 – The sound reduction *D* as a function of frequency *f* for the six specimens.

Table 2 – Speech reduction index, D_S, of specimens #1-#6.

Specimen	D_S [dB]
#1	1.8
#2	4.0
#3	3.9
#4	1.9
#5	2.8
#6	19.8

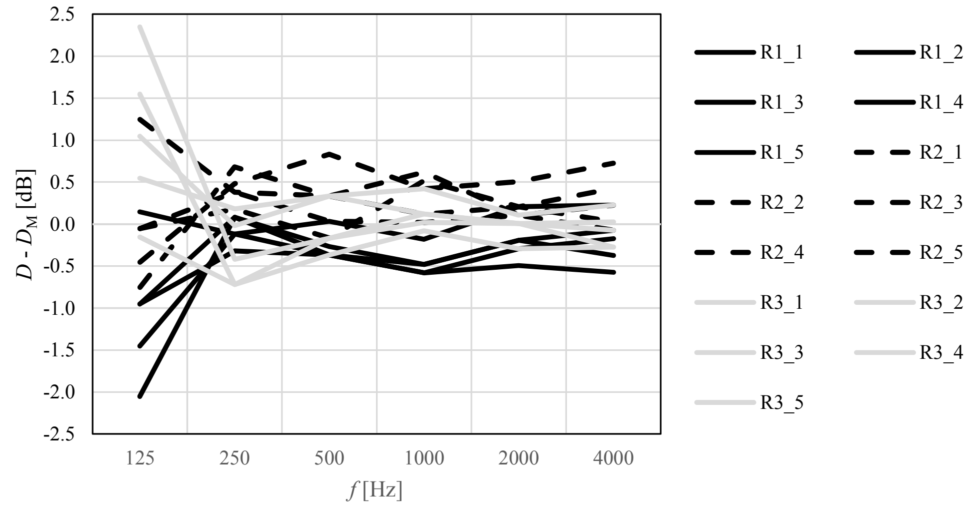

Figure 4 – The sound reduction D of specimen #6 as a function of frequency f for five successive measurements conducted in three reverberation rooms R1-R3.

Table 3 – Speech reduction index, D_S, of specimen #6 for five successive measurements conducted in three reverberation rooms.

	D_S [dB]				
Room	1	2	3	4	5
R1	18.9	18.5	18.5	18.5	18.5
R2	19.0	19.2	19.0	19.5	19.4
R3	19.3	19.2	18.9	18.7	18.8

4. DISCUSSION

The sound reduction values showed a consistent pattern. The sound reduction increased with increasing coverage (degree of enclosure). The reproducibility value of D_S was 0.9 dB which means that the method is capable of discriminating products from each other, provided that the difference between the products is larger than 0.9 dB.

Speech reduction indices of workstations were always less than 4 dB. We expect that larger values than 4 dB can be achieved for workstations by using larger sound insulation in screens, larger sound absorption of internal surfaces and higher screens.

The phone booth, specimen #6, achieved a value of about 20 dB. We expect that D_S values up to 35 dB are relatively easy to achieve for booths without significant increment of the size by more careful sealing of ventilation ducts and door seams, larger sound insulation and larger surface absorption of inner surfaces. It should be noted that larger speech reduction indices than 35 dB are hardly needed in open-plan office environments.

The single-number quantity D_S describes how much the ensemble reduces the A-weighted level of speech in a reverberant environment. That is, the test results are valid even in a very bad room acoustic conditions, where sound-absorbing materials are not used in room surfaces next to the ensemble. However, when the room absorption is large, the room reflections excessively found in the reverberation room are missing and the insertion loss produced by the ensemble is larger. Thus, the test result D_S represents the worst case. In practice, significantly larger insertion loss values than D_S can be achieved in highly sound-absorbing spaces.

The furniture manufacturers are encouraged to apply this method in product development. The method is easy to apply in standard reverberation rooms. The meaning of D_S is easy to understand by end users and designers.

The method might be considered when new test standards are developed. Some clarifications may be needed such as the type (directivity) of the loudspeaker, the necessity of using a human body (dummy), and the number of measurement positions. Based on our experience, the number of specimen positions should be at least two. If the values agree to a sufficient degree, no more positions are needed.

The method would benefit from a proper Round Robin test because the reproducibility value of this study, 0.9 dB, is only preliminary: two of the three reverberation rooms did not fulfill the requirements of the ISO 3741 standard and a proper Round Robin test presumes the involvement of at least five independent laboratories. It is probable that the reproducibility value is smaller for workstations than for booths, because the latter are sensitive to the closing of the door (sound leaks) between successive measurements.

5. CONCLUSIONS

A new test method for describing the sound reduction of furniture ensembles was developed. The outcome of the method, the speech reduction index, should be easy to understand by the end users and office designers because the value describes how many decibels the product reduces the A-weighted sound pressure level of normal effort speech in reverberant environments.

ACKNOWLEDGEMENTS

The study was funded by the Finnish Institute of Occupational Health. Thank you for the furniture manufacturers offering the test specimens for this research.

REFERENCES

1. Haapakangas, A., Helenius, R., Keskinen, E., & Hongisto, V. (2008). Perceived acoustic environment, work performance and well-being – survey results from Finnish offices. Proceeding of the 9th International Congress on Noise as a Public Health Problem (ICHBEN) 2008 (pp. 434-441). Mashantucket, Connecticut, USA.
2. Hongisto V, Haapakangas A, Varjo J, Helenius R, Koskela H, Refurbishment of an open-plan office –environmental and job satisfaction, Journal of Environmental Psychology 45 2016 176-191. DOI: 10.1016/j.jenvp.2015.12.004.
3. Kaarlela-Tuomaala A, Helenius R, Keskinen E, Hongisto V, Effects of acoustic environment on work in private office rooms and open-plan offices - longitudinal study during relocation, Ergonomics 52 (11) 2009 1423-1444.
4. Hongisto V, A model predicting the effect of speech of varying intelligibility on work performance, Indoor Air 15 2005 458-468.
5. Hongisto V, Varjo J, Leppämäki H, Oliva D, Hyönä J, Work performance in private office rooms: The effects of sound insulation and sound masking, Building and Environment, Accepted for publication, 20 April 2016.
6. Haapakangas A, Hongisto V; The role of distractions and office layout on environmental perception and employee well-being – Evidence from two office relocations, Submitted manuscript, 2016.
7. Hongisto V, Haapakangas A, Helenius R, Keränen J, Oliva D, Acoustic satisfaction in an open-plan office before and after the renovation, Euronoise 2012, June 10-13, 654-659, Prague.
8. Virjonen P, Keränen J, Helenius R, Hakala J, Hongisto V, Speech privacy between neighboring workstations in an open office - a laboratory study, Acta Acustica united with Acustica 93 2007 771-782.
9. Hongisto V, Keränen J, Virjonen P, Hakala J, New method for determining sound reduction of furniture ensembles in laboratory, Acta Acust united Ac 102 2016 67-79.