Prediction of spatial decay of speech in open-plan offices applying ISO 3382-3 principles

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Summary

The aim of this study is to present a model that can be used to predict the single-number quantities of ISO 3382-3. A regression model was created to predict the speech levels. The measurement data in 16 different open-plan offices was used as the empirical data. Speech Transmission Index *STI* was calculated according to IEC 60268-16. The prediction model yields the spatial decay rate of the A-weighted level of speech, $D_{2,S}$, the A-weighted level of speech at 4 m from the speaker, $L_{A,S,4m}$, and the distraction distance, r_D, i.e. the distance where *STI* gets below 0.50. The prediction accuracy of the model was determined in 10 additional offices which were not used in the development of the model. The prediction errors of $D_{2,S}$, $L_{A,S,4m}$ and r_D were less than 1.5 dB, 3.0 dB, and 2.5 m in most cases, respectively. This is sufficient for most practical purposes. The model is freely available on the internet.

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1. Introduction

The room acoustic measurements of open-plan offices can be done according to ISO 3382-3. The method ignores the noise of employees because it is basically a room acoustic standard. However, it considers the room acoustic performance of the whole office space. The spatial decay of speech level and Speech Transmission Index, *STI*, are measured at various distances from the speaker. Both the speaker and the measurement points are located in workstations so that the result corresponds well with the employees' experiences of speech arriving from various distances.
Three single-number quantities are determined from the spatial decay curves:

- The spatial decay rate of the A-weighted sound pressure level (SPL) of speech, $D_{2,S}$. It describes how many decibels the SPL of speech reduces when the distance to the speaker is doubled. Large value means strong attenuation.
- The A-weighted SPL of speech at 4 m from the speaker, $L_{A,S,4m}$. Small value means strong attenuation in the near-field.
- The distraction distance, r_D. The value means the distance where *STI* falls below 0.50. Small value means that good acoustic privacy is achieved near to the speaker. Hongisto (2005) has suggested that cognitive performance is expected to improve with decreasing value of *STI*.

The speech privacy can be objectively evaluated by distraction distance because it considers also the background noise level of the office.
Reverberation time shall does not belong to ISO standard because it has very weak association with the attenuation of speech (Virjonen et al. 2009).
Open-plan offices are designed by architects, who may be consult an acoustic specialist. The acoustic design process is usually fast and there is not much time for detailed acoustic discussions unlike in e.g. concert halls. Therefore, the design process would benefit from a room acoustic design tool which is fast, in conformance with ISO 3382-3, sufficiently accurate, and scientifically justified. The first version of such a model was presented by Keränen et al. (2007).
The aim of this study was to present a simple model which can be used to predict the room acoustic performance of open-plan offices. This paper is based on a more extensive article of Keränen and Hongisto (2013).

2. Materials and methods

The model was developed using the measurement data published by Virjonen et al. (2009). The data consists of measurements according to ISO 3382-3 in sixteen offices (offices 1-16). The offices were chosen so that very different room variables were included.
The following room variables were recorded in each office during the measurements:

- Room length L, in metres.
- Room width W, in metres,
- Room height H, in metres,
- Mean screen height h, in metres,
- Mean ceiling absorption coefficient α_c,
- Apparent furnishing absorption coefficient α_f,
- A-weighted background noise level $L_{A,B}$ [dB].

The range of the values is shown in Table 1. The absorption coefficients were determined as the mean value of the octave bands 250-4000 Hz. The absorption coefficients take into account the proportion of hard and sound-absorbing parts.

Table 1. The range of the values of the room variables among the two groups of offices.

Variable	Offices 1-16	Offices A-J
L [m]	16 … 70	16 … 69
W [m]	4 … 45	6 … 29
H [m]	2.5 … 5.9	2.6 … 5.1
h [m]	0 … 2.2	1.2 … 1.7
α_c	0.1 … 0.8	0.3 … 0.9
α_f	0.1 … 0.6	0.3 … 0.6

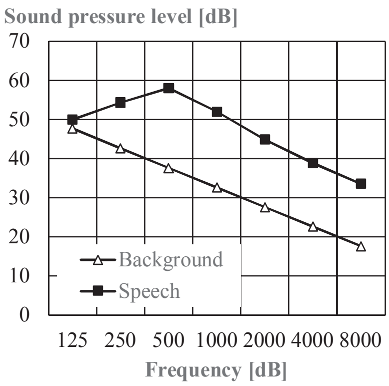

Figure 1. The shapes of the spectra for speech and background noise level during *STI* calculation. Background is shown at level $L_{A,B}$=40 dB and Speech is shown at level $L_{A,S,1m}$=57.4 dB. The octave band values are changed according to the current value of L_B and L_S.

The model was developed by applying single-variable and multi-variable linear regression analysis to the measurement data of offices 1-16.
The prediction accuracy was defined as the difference between the predicted and measured value. The prediction accuracy was determined first for offices 1-16. In addition, we performed additional measurements in ten offices (offices A-J) where the prediction accuracy was also determined.

3 Results

3.1 The prediction model

The spatial decay rate of the A-weighted SPL of speech is calculated by

$$D_{2,S} = 8.00\frac{h}{H} + 0.16\frac{L}{H} + 4.00\alpha_c + 1.70\alpha_f \quad (1)$$

The A-weighted SPL of speech at 4 m from the speaker is calculated by

$$L_{A,S,4m} = L_{A,S,1m} - 3.0h - 0.1W - 4.6\alpha_c - 0.8\alpha_f \quad (2)$$

where $L_{A,S,1m}$ [d B] is the A-weighted SPL of speech at one metre distance. Typically, normal effort speech is expected and the value is 57.4 dB.
The spatial decay curve of the A-weighted SPL of speech is calculated by

$$L_{A,S}(r) = L_{A,S,4m} - 3.3D_{2,S}\left[\lg(r) - \lg(4)\right] \quad (3)$$

where r [m] is the distance to the speaker. The equation is valid at distances exceeding 4 metres.
The calculation of r_D requires that *STI* at various distances is known. The prediction of *STI* is made according to IEC 60268-16. The calculation is made in 1/1 octaves within 125-8000 Hz. The following data is used:

- SPL of background noise, L_B. The typical source is either ventilation or sound masking system. The measured spectrum is used. If it is not available, it is safe to expect a slope of -5 dB per octave doubling (Figure 1).
- SPL of speech, L_S. The spectrum is expected to follow the spectrum of normal-effort speech (Figure 1).

- Reverberation time of the room. The value is calculated using Sabine's formula. *STI* should be determined using Early Decay Time. However, its' value is expected to be sufficiently close to reverberation time.

3.2 Prediction accuracy

The differences of the predicted and measured values of $D_{2,S}$, $L_{A,S,4m}$ and r_D were determined in offices 1-16 and offices A-J. The prediction errors are shown in Figures 2. The statistics are shown in Tables 2 and 3.

3.3 Internet application

A Java application was programmed to apply and deliver the model for free use:

- www.ttl.fi/openofficeacoustics
- www.ttl.fi/avotoimistoakustiikka

The interface is shown in Figure 3.

Table 2. Statistics describing the prediction accuracy of the model in offices 1-16. MD is the mean difference. SD is the standard deviation of the difference. ND is the largest individual negative difference. PD is the largest individual positive difference.

	$D_{2,S}$ [dB]	$L_{A,S,4m}$ [dB]	r_D [m]
MD	0.2	0.1	-1.1
SD	1.5	2.2	3.6
ND	-1.4	-2.9	-6.3
PD	3.3	4.7	6.2

Table 3. Statistics describing the prediction accuracy of the model in offices A-J.

	$D_{2,S}$ [dB]	$L_{A,S,4m}$ [dB]	r_D [m]
MD	-0.1	1.0	0.0
SD	1.0	2.8	2.2
ND	-1.3	-3.9	-3.3
PD	1.9	5.3	3.6

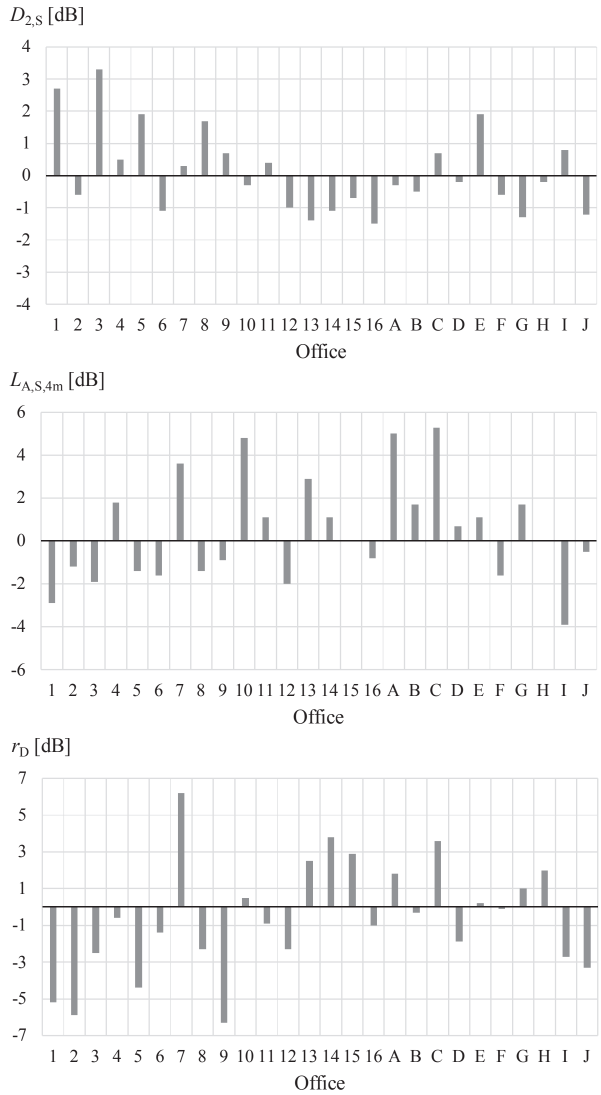

Figure 2. The difference between predicted and measured values for the 26 investigated offices.

4 Discussion

The prediction accuracy is not always good but it is, on average, sufficient concerning the practical purpose of the model. The model is very beneficial in situations when the mutual effects of various room variables need to be demonstrated to the clients. If the achievement of the highest possible prediction accuracy is of high importance, a commercial room acoustic software is recommended. However, the setup time of such models is significant because open-plan offices are strongly fitted. Therefore, the prediction error is not necessarily smaller.

The model should be developed in the future to take better into account the variations in room volume and vertical absorption. The room heights of offices 1-16 were mostly below 3.5 metres. We have observed that $L_{A,S,4m}$ decreases strongly with increasing room height. This has a significant effect on speech privacy at short distances from the speaker. In addition, the apparent furnishing absorption, i.e. vertical absorption, was negligible in offices 1-16. Nowadays, the amount of absorption can be relatively high in some offices. Hongisto et al. (2015) found that sound-absorbing screens can reduce the value of $L_{A,S,4m}$ significantly.

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References

[1] Hongisto V, Haapakangas A, Varjo J, Helenius R, Koskela H, Refurbishment of an open-plan office – effects on environmental and job satisfaction, Submitted to Journal of Environmental Psychology, February 2015.

[2] Hongisto V, A model predicting the effect of speech of varying intelligibility on work performance, Indoor Air 15 2005 458-468.

[3] ISO 3382-3:2012 Acoustics - Measurement of room acoustic parameters - Part 3: Open plan offices.

[4] Keränen J, Virjonen P, Hongisto V, A new model for acoustical design of open-plan offices, International Congress on Acoustics, paper RBA-10-006-IP, 2-7 September 2007, Madrid, Spain.

[5] Keränen J and Hongisto V, Prediction of the spatial decay of speech in open-plan offices, Applied Acoustics 74 2013 1315-1325.

[6] Virjonen P, Keränen J, Hongisto V, Determination of acoustical conditions in open-plan offices - Proposal for new measurement method and target values, Acta Acustica united with Acustica, 95 (2) 2009 279-290.

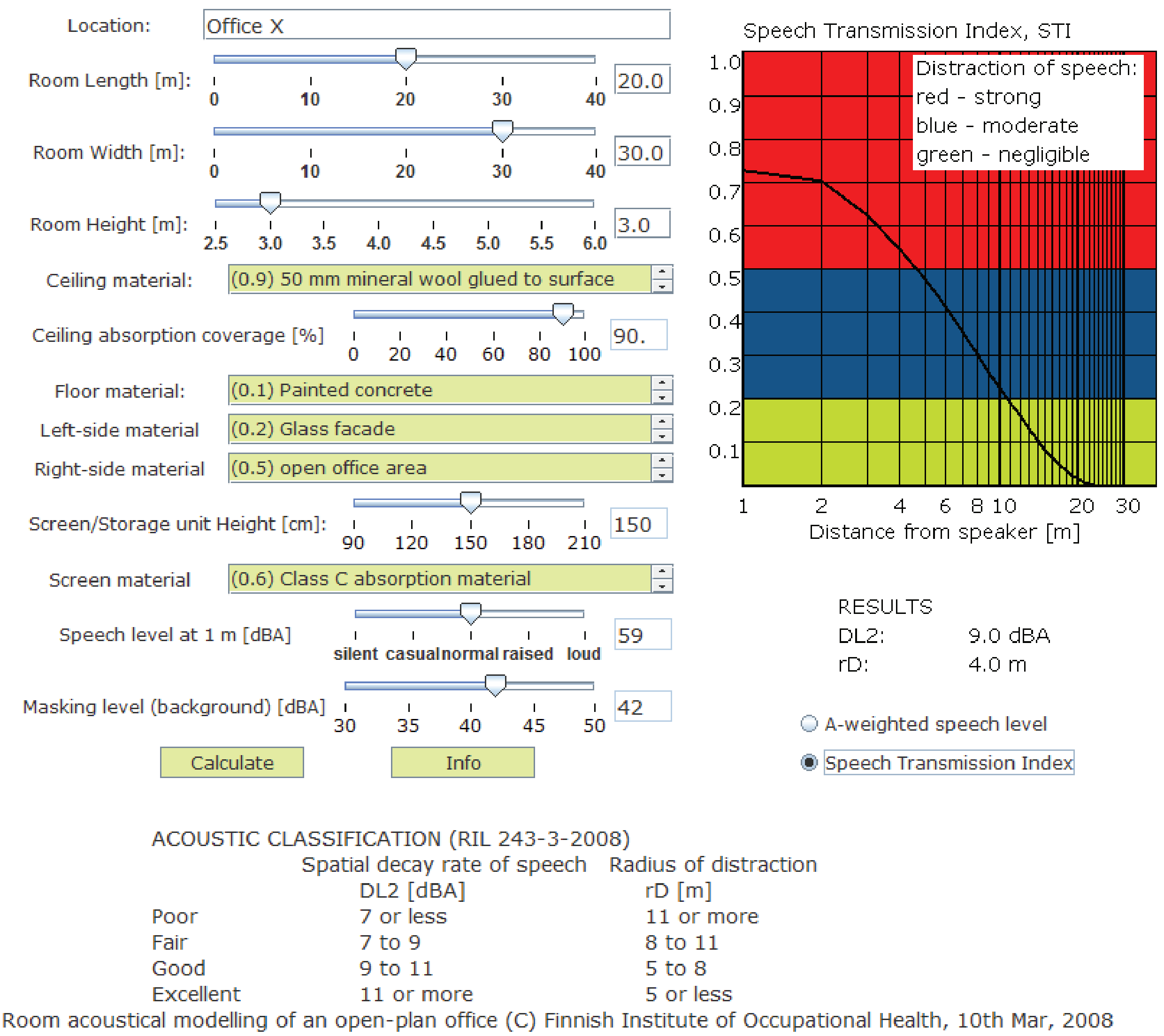

Figure 3. The interface of the internet application. The spatial decay of either *STI* or A-weighted SPL can be chosen in the graph.