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Design of room acoustics for open offices

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Objectives Noise control in open offices should aim at reducing disturbances caused by speech noise (ie, improve speech privacy). Room acoustics can be controlled with high room absorption, high screens and book cases, and sufficient masking sound. The interaction between these means is complicated, especially when speech privacy is studied at different distances from a speaking worker. The aim of this study was to develop a simple and fast model that predicts the room acoustics in an open office in a way that has a high correlation with the experienced acoustic environment.
Methods Room acoustics were measured in 15 open offices. The model was developed using a multivariable regression analysis of the experimental data.
Results The accuracy of the model was found to be sufficient for practical design work.
Conclusions The modeling tool is freely available on the Internet. It facilitates acoustical design significantly in all phases of building design.

Key terms office; noise; speech privacy; speech distraction; work performance.

Most office workers are located in open-plan and landscaped offices (referred to throughout this paper as open offices). Noise is often the most severe indoor environment problem in open offices. Usually, speech is considered to be the most distracting noise source. So far, there is no standardized test method with which to determine the acoustical conditions in open offices. Therefore, national building codes lack appropriate regulations for room acoustical design with respect to open offices.

In previous studies, measurement methods were developed mainly for research purposes either in open-office laboratories (1, 2, 3) or open offices (4). These methods were restricted to two neighboring workstations. Interoffice differences are small at short distances (ie, between two neighboring workstations). But at large distances, interoffice differences can be significant, depending on the acoustical quality of the room space. Because noise complaints are not restricted to short distances, the investigation of the whole office space is necessary.

Noise control in open offices should aim at reducing distractive speech noise. Applicable noise control methods include, for example, the design of room acoustics, architecture and layout, the team arrangement of workers, and behavioral rules in the office. This study focuses on room acoustics. It can be controlled with high room absorption, high screens and book cases, and sufficient masking of sounds. The interaction between these aspects is complicated, especially when speech privacy is investigated at different distances from a speaking worker. Evidently, the distraction caused by speech decreases as the sound level of speech and speech intelligibility decreases.

In this study, a simple measurement method for determining the acoustical conditions of open offices was developed. The measurement results are easily understandable, single number values. Recommendations for the acoustic classification of open offices are suggested. Finally, a model that predicts the acoustical conditions in open offices in a way that has a high correlation with experienced acoustical conditions is presented.

Material and methods

Measurements

A measurement method that highly correlates with the subjective experience of speech distraction was applied in 15 very different open offices (5). An omnidirectional sound source was used to simulate a speaking office worker. It was placed into one workstation, and the measurements were carried out along a straight line

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that passed over several workstations (figure 1). The length of the measurement line varied between 10 and 30 meters and included at least four workstations. Both the sound source and measurement microphone were at a height of a sitting worker's ear, 1.2 meters from the floor. The sound level produced by the omnidirectional sound source, background noise level, and impulse response was measured at each workstation along the measurement line. We applied the concept of the modulation transfer function and speech-to-noise ratio (6) to obtain a speech transmission index (STI).

We determined the spatial decay of both the A-weighted speech sound level and the STI using the measurement data. The spatial decay of the A-weighted speech level per distance doubling (DL_2) was determined using the linear least squares fitting technique according to ISO 14257 (7).

The DL_2 cannot be the descriptor of speech privacy alone since it is unaffected by the background noise level (ie, masking sound level) of the room. Thus another parameter was needed. The most appropriate descriptor was the STI since it is physically measurable and it explains the distracting power of speech in offices (8). The radius of distraction (r_D) was defined as the distance from the speaker at which the STI falls below 0.50. This value was presented as the limit below which the distracting effect of speech starts to reduce (8).

During the measurements, detailed information on the office was collected (eg, room geometry, absorption coefficients of surfaces, dimensions and properties of screens and furniture, and layout metrics). The room lengths were between 16 and 70 meters, the room widths were between 4 and 45 meters, and the room heights were between 2.5 and 5.9 meters. The screen heights varied between 1.2 and 2.2 meters. The estimations of the absorption coefficients were based on material absorption databases since the most prominent surface materials could be identified. The ranges of the ceiling absorption coefficients, the floor absorption coefficients, and the wall absorption coefficients were 0.1–0.8, 0.1–0.4, and 0.1–0.9, respectively.

Prediction model

The experimental data were analyzed using a single-variable and multivariable linear regression analysis. The selected input parameters were room length, room width, room height, screen height, screen width, and the average absorption coefficients of the floor, ceiling, walls, and screens. Some typical measurable room acoustical parameters (eg, reverberation time) were also tried as input parameters. However, it was found that no single input parameter had a high correlation with the DL_2. Finally, the multivariable linear regression analysis produced empirical equations that were used together to predict the A-weighted speech level at various distances from the speaker.

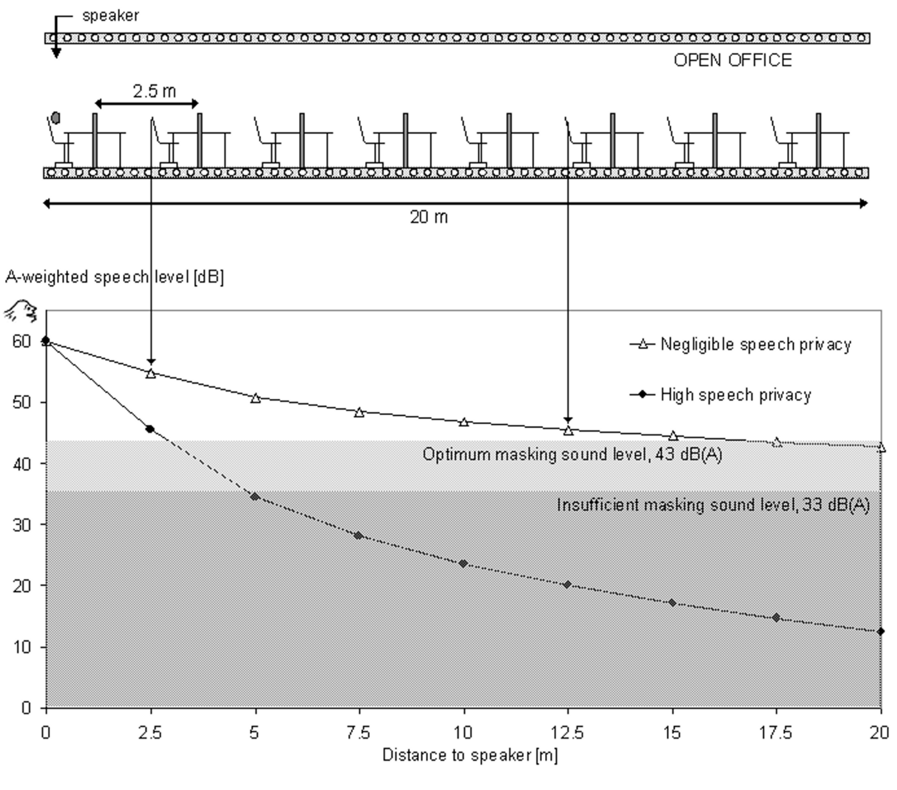

Figure 1. Illustration of spatial decay of A-weighted speech. Measurements are made at each workstation, and the results are plotted as a function of distance to the speaker. Speech privacy improves significantly when the speech level falls below the masking sound level of the office (grey).

Ideally, the predicted A-weighted speech level can also be used for predicting the spatial decay of the STI, which is used to determine the radius of distraction (r_D) Naturally, the background noise level and room reverberation must be taken into account.

The prediction model was programmed into a JAVA applet, which is freely available on the Internet (9). The applet has a simple interface for selecting the input parameters (figure 2). The room dimensions can be selected within reasonable ranges. A few typical surface materials for the walls, ceiling, floor, and screens are selectable from list boxes. Speech effort and the masking sound levels are also adjustable. The spatial decays are presented graphically. The single number values DL_2 and r_D are given, and they can be compared with the recommendations visible in the interface. The recommendations are based on national directions (10). The user can select a display of either the A-weighted speech level or the STI using a radio button.

The accuracy of the prediction model was determined for individual measurement points in the 15 open offices of this study. The prediction error of the A-weighted speech level and the STI was determined for every measurement point in the 15 open offices. The mean accuracy and standard deviation were determined individually for the 15 open offices.

Results

The mean accuracy of the prediction of the A-weighted speech level in the individual offices was -5.5–+3.8 dB, and the standard deviation was 0.6–3.5 dB. The mean accuracy of the STI prediction was -0.12–+0.13, and the standard deviation was 0.01–0.09. These accuracies are acceptable for practical design purposes.

Discussion

DL_2 and r_D are suggested as the main descriptors of the acoustical conditions of an open office. They are also very easy to explain to clients. Preliminary recommendations for DL_2 and r_D are presented in figure 2 (10). The classification requires that both parameters be simultaneously in the range. According to the experimental data of

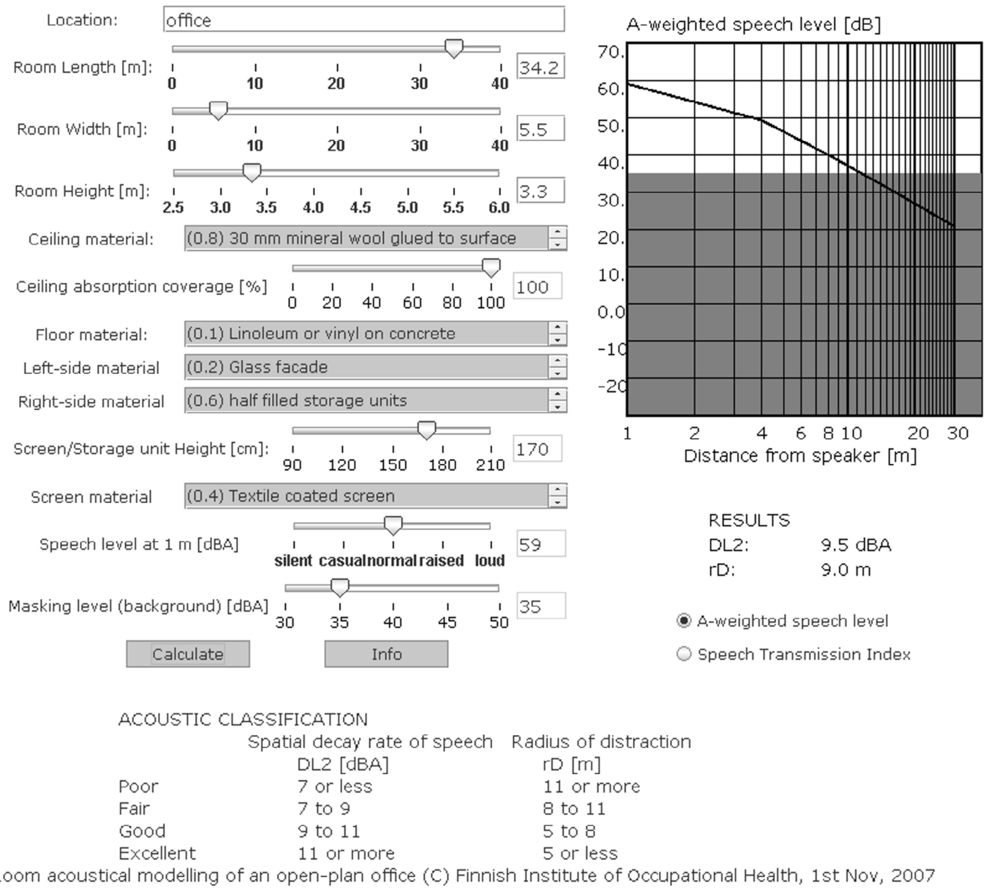

Figure 2. Screen capture of the prediction model. Spatial decay of A-weighted speech is shown on the right. The resulting single number values DL2 (distance doubling) and rD can be directly compared with the classification below the screen.

this study (5), it is possible to reach excellent acoustic quality when sound absorption, isolation, and masking are properly considered.

The new prediction model has been designed for all parties that are involved in the acoustic design of new or renovated open offices. The prediction model has received positive feedback from acoustical designers, material manufacturers, students, architects, and interior designers.

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