ACOUSTICS IN OPEN-PLAN OFFICES – A LABORATORY STUDY

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1. INTRODUCTION

According to questionnaire studies [1], speech heard from neighbouring desks is the most distracting noise source in open-plan offices. In the planning of open-plan offices, the aim is efficient attenuation of speech and reduction of speech intelligibility between workstations so that the concentration of the worker will not be disturbed. Speech can be attenuated, e.g. using absorbing ceiling material and screens between adjacent workstations. A properly planned masking noise system can also be used, if the background noise level of the room is not sufficient to mask the speech. However, the resulting acoustics in an open-plan office cannot be predicted only using product information such as the absorption coefficients of a suspended ceiling or the type of a screen but the outcome depends on many variables in a complex way.

The aim of this study was to investigate the acoustics of an open-plan office in laboratory conditions. The architects can exploit the results when designing offices. In addition, the results will be exploited in the validation of a room acoustics model, with which the acoustics of an open-plan office can be predicted [2-3].

2. METHODS

2.1. Test arrangement

The measurements were made in a special room where two workstations were opposite each other (Figure 1). The walls were totally absorbing in order to prevent the lateral reverberation so that the situation simulated a pair of workstations in a large open-plan office. The floor was made of concrete.

A screen extending from wall to wall was placed in the middle of the room. It divided the room into two equally large spaces called the *transmission side* and the *receiver side*. A table and two chairs were placed on each side. In addition, a computer screen was placed on the receiver side table to reduce unfavourable flutter echo.

A loudspeaker simulating the talker was placed on the transmission side at the *talker's position* at height of 1.2 m and at distance of 1.2 m from the screen. A microphone was correspondingly placed on the receiver side at the *listener's position* 1.2 m from both the floor and the screen.

A masking noise loudspeaker was attached to the suspended ceiling above the microphone, i.e. the assumed listener. The measurements were made with three levels of masking noise: the A-weighted levels were 35, 42 and 48 dB. Measurements were also made without any masking noise. Then the A-weighted level was approximately 27 dB resulting from the steady background noise of the laboratory. The masking noise spectrum was adjusted to correspond a speech-like, pleasant sounding masking noise spectrum suggested by Beranek [4]. That spectrum is presented in Figure 2 at A-weighted levels of 35, 42, 48 dB. In addition, the room background noise spectrum and the standardized speech spectrum (according to ANSI S3.5-1997) are presented. The speech spectrum is shown at A-weighted level of 48 dB.

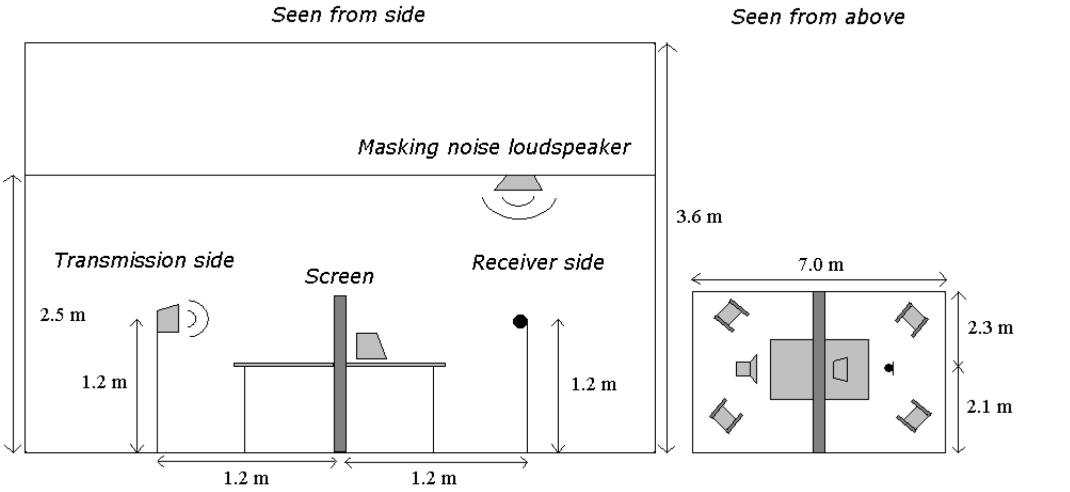


Figure 1. *Measurement arrangement.*

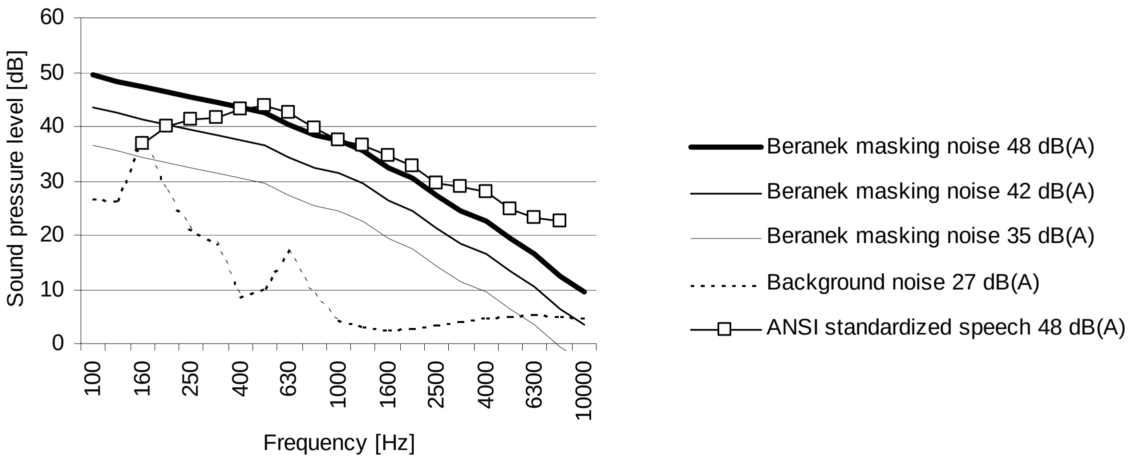


Figure 2. *The masking noise, background noise and standardized speech spectra.*

2.2. The measured quantities

The measured quantities were *RASTI* (*Rapid Speech Transmission Index*), insertion loss of the screen and received speech level at the listener's position. *RASTI* reflects the speech intelligibility and takes into account the effects of background noise and reverberation. Therefore, it is perhaps the most appropriate quantity of these three to characterize the speech privacy between two adjacent workstations.

Background noise and reverberation of the room make it more difficult to perceive speech. Their effect on the speech signal can be measured with the *RASTI* method according to standard IEC 60268-16. *RASTI* gets values from 0.00 – 1.00. 1.00 can be considered as perfect speech intelligibility and 0.00 as perfectly unintelligible. In open-plan offices, the aim is naturally as low *RASTI* as possible (high speech privacy). An adequate value between two workstations would be below 0.50, i.e. the neighbour's speech can still be heard but it does not cause distraction. *RASTI* values were measured with equipment according to IEC 60268-16 (Brüel&Kjær Speech Transmission Meter 3361).
Insertion loss of the screen, D_S, was measured according to the ISO 11821 -standard. Pink noise was played

with a loudspeaker (Genelec 1029A) placed at the talker position. The produced sound pressure levels were measured with and without the screen at the listener position with a real-time analyser (Norsonic RTA 840, Brüel&Kjær 4190 microphone with preamplifier 2669). The weighted screen insertion loss, $D_{S,W}$, was then determined from the octave band insertion losses according to ISO 10053.

The speech level at the listener position was measured in the following way. A 40 second speech sample of a male speaker was played with a loudspeaker (Genelec 1029A) placed at the talker position. The received speech level, $L_{Aeq,S}$, was measured at the listener's position with the real-time analyser. The long-term speech spectrum level of the speech sample was in conformance with ANSI S3.5-1997 standardized speech spectrum at normal speech effort at distance of 1 m in front of the speaker in free field.

3. MATERIALS

Measurements were made using six commercial suspended ceiling materials: two glass wool plates (*Master 40, Focus 20*), three perforated gypsum plates (*Point 11*, *Quattro 20*, *Plaza 600 M*) and one non-perforated gypsum plate (*Plaza 600 R*), which was almost totally sound reflecting. The plate elements (590 mm x 590 mm) were mounted either at a height of 2.5 m or 3.3 m so that there was left either a 1.1 m or 0.3 m wide air gap between the plates and the ceiling, respectively. In addition, measurements were made with 300 mm glass wool plates mounted directly on the ceiling without any air gap.

Both self-made and commercial screens (*Stacks*, *Kanvas*) were used. There were two different *Stacks* screens, a glass and a fabric coated. The fabric coating was only 5 mm thick and not very sound absorbing. Measurements were made with screen heights of 130 and 168 cm. The fabric coated *Kanvas* was 168 cm high. An acoustically hard non-commercial screen ("*hard*") was made of 12 mm thick chipboard. An absorbing version of it ("*soft*") was made attaching a 45 mm thick glass wool plate on the transmission side of the screen. The non-commercial screen heights were 210, 168 and 130 cm. Some of the tests were conducted by covering the floor with soft textile plates (*Tecsom*).

The absorption coefficients of the ceiling plates, floor material and Kanvas screen are presented in Figure 3 at frequencies 250 – 4000 Hz.

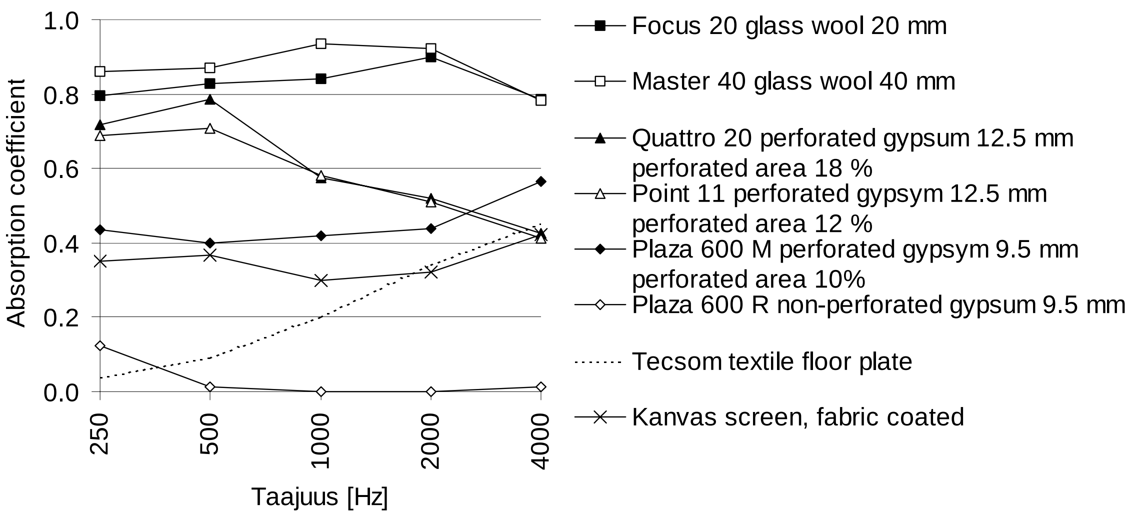


Figure 3. *The absorption coefficients of the ceiling plates, soft floor material and a fabric-coated screen*

4. RESULTS

RASTI as a function of the screen height in different background noise levels is presented in Figure 4. In the left one, the ceiling was acoustically hard (Plaza 600 R). In the right one, it was the well-absorbing glass wool ceiling (Master 40). The screen was 12 mm thick chipboard and the height of the suspended ceiling was 2.5 m. As the background noise grew the *RASTI* values naturally decreased. The raising of the screen height also decreased *RASTI* as long as the background noise level was not too low. The screen was ineffective without sufficient masking. The speech intelligibility was nearly perfect (*RASTI*>0.85) even though there was a 210 cm high screen. With the more absorbing ceiling, both the increase of the screen height and background noise level caused more substantial changes in *RASTI*. With the lowest background noise level, however, the *RASTI* values were smaller with the acoustically hard ceiling because of higher reverberation.

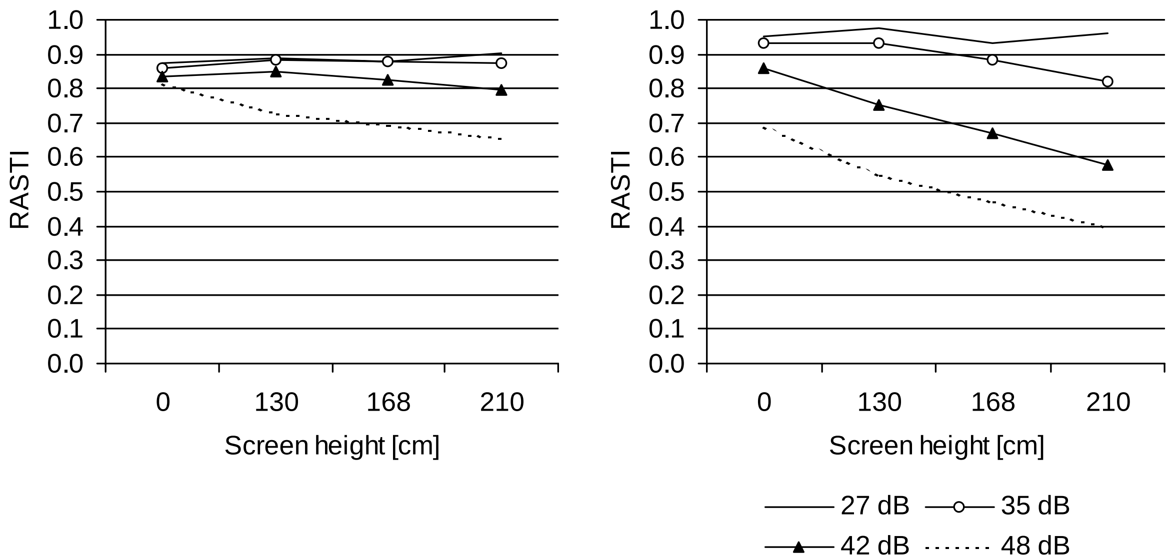


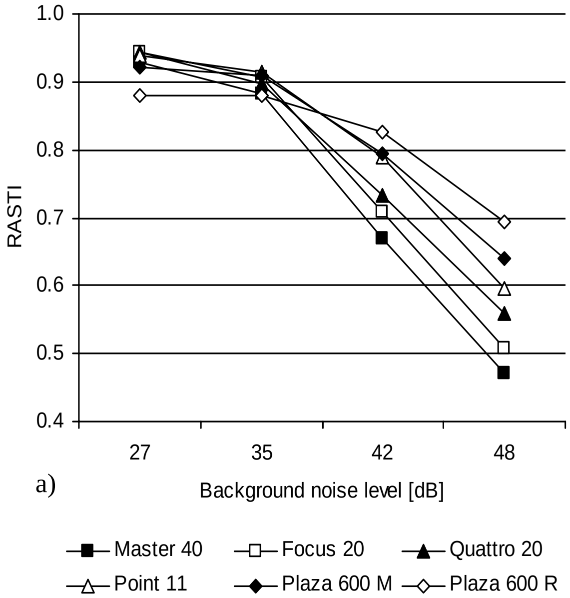
Figure 4. *Measured RASTI values with different screen heights and ambient noise levels when the ceiling material was acoustically hard (left) and well-absorbing (right).*

RASTI values with different ceiling materials are presented in Figure 5a. The screen was 168 cm high chipboard and ceiling height was 2.5 m. In Figure 5b, *RASTI* values can be seen with different screen surface materials when ceiling material was Plaza 600 R, screen height was 168 cm and ceiling height was 2.5 m. Ceiling material has a stronger effect on speech intelligibility than screen material or screen height. Evidently, lower *RASTI* values were obtained with more absorptive ceiling material. Instead, the differences in *RASTI* values obtained with different screen surface materials were very small. The effect of floor coating was also negligible.

Speech level as a function of screen height with three ceiling materials is presented in Figure 6. The screen was made of chipboard and the ceiling height was 2.5 m. Speech level cannot be attenuated more than 13 dB, compared with the situation without the screen when a high acoustically hard screen (210 cm) and a well-absorbing ceiling are used with the ceiling height of 2.5 m. The smallest attenuation with the ceiling height in question was obtained with hard, 130 cm high screen and hard gypsum ceiling. Then the speech attenuation was only 4 dB.

Screen insertion losses with two ceiling heights and two ceiling materials are presented in Figure 7. The screen was made of chipboard. Raising the ceiling height increased the insertion loss and decreased also speech level and intelligibility. The more absorbing the ceiling, the more rapidly insertion loss increased as the screen height increased.

The detailed results are published in reference [5], which is in Finnish. They will be published later in English.



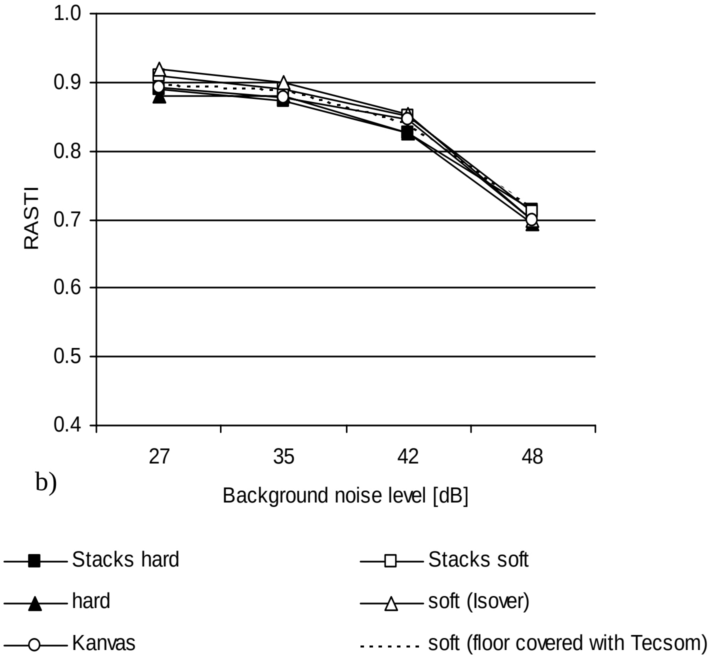
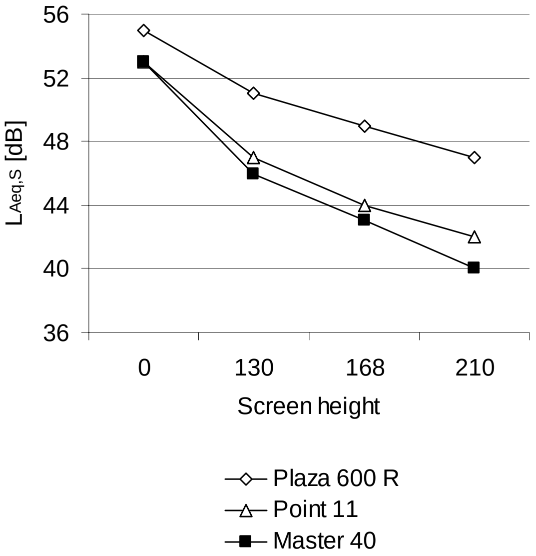


Figure 5a. *The dependence of RASTI of different ceiling materials.*

Figure 5b. *The dependence of RASTI of different screen materials.*



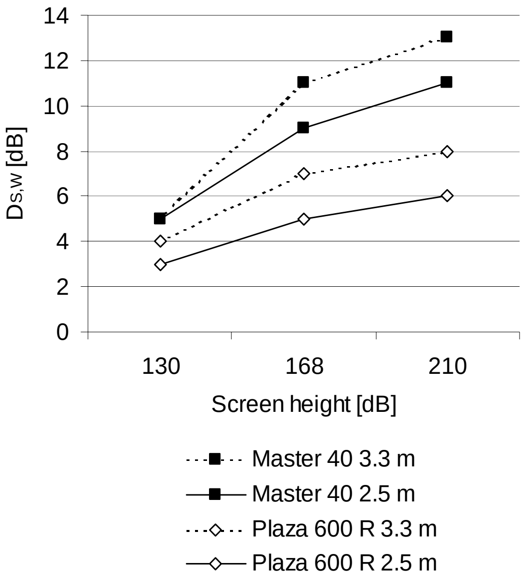


Figure 6. *Speech levels.*

Figure 7. *Weighted screen insertion losses.*

5. DISCUSSION

Only two workstations opposite each other were studied with this arrangement. If the workstations are more apart from each other, the relative effects of ceiling materials, floor covering and screens are more considerable. However, a good design of all adjacent workstations in an open-plan office will guarantee good acoustics also in the far field.

In real open-plan offices, the sound can bypass the screen also from below and from the sides. The room walls are reflective and the positions of the mutual workers differ. These factors typically deteriorate the attenuation and improve the speech intelligibility between workstations. A recent study [6] gives evidence that the speech levels in open-plan offices can be a few decibels lower than the standard speech level of ANSI S3.5, which was used in this study. This, on the other hand, means that lower *RASTI* values are a bit easier to reach than expected. As a whole, the laboratory values should not be used as such but yet they reflect the combinatory effects of different ceiling and screen combinations between workstations, and, therefore, they can be exploited in the acoustical planning of open-plan offices.

6. CONCLUSIONS

An efficient attenuation and low speech intelligibility are the main goals when planning an open-plan office. Speech intelligibility can be most efficiently reduced when all the affecting factors – background noise level, the suspended ceiling height, ceiling material and screen height – are taken into account simultaneously. In practice there is no use of screens and ceiling materials if the background noise level is not sufficient.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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