Open plan office acoustics – a multidimensional optimization problem

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Introduction

The international standard ISO 3382-3:2012 [1] defines a number of measurable room acoustic parameters for the objective evaluation of the acoustics of open plan offices. Four quantities are mandatory:

- distraction distance r_D
- spatial decay rate of A-weighted sound pressure level (SPL) of speech, $D_{2,S}$
- A-weighted SPL of speech at 4 m, $L_{p,A,S,4\,m}$
- average A-weighted background noise level, $L_{p,A,B}$.

The distraction distance is defined as the distance from a source within which the speech transmission index (STI) ≥ 0.5. In addition, two quantities may be determined; STI in nearest work station, and the privacy distance, r_P (STI = 0.2).

The main acoustical problem is distraction by speech and conversation between other people. However, this is not a simple one-dimensional noise problem that can be solved by a sufficiently high damping of the room. If the reverberation time is very short, the remote voices are heard with high clarity and thus the amount of distraction is high. However, a long reverberation time leads to a very noisy environment, which is also disturbing. Experiments in the laboratory have shown that excessive sound absorption may have a negative impact on occupants' perception of noise, acceptability of noise and performance of office work [2].

Similarly with the background noise: It should be neither too low nor too high. People may be concerned by silence as much as with the noise [3].

The distraction distance is a particularly interesting parameter because it takes into account most of the important acoustic parameters, namely the amount of absorption, the effect of screens, the spatial attenuation and the masking from background noise. The background noise in the empty office must be applied for measurements in accordance with ISO 3382-3, but the standard opens for additional calculation of results using other kinds of background noise, e.g. that from human activity in the office.

Noise from human activities

The French standard NF S 31-199 [4] divides open-plan offices into four categories with different type of activity and thus with different levels of noise from human activity:

- mainly telephone, $L_{A,eq}$ = 48 dB to 52 dB,
- collaborative work, $L_{A,eq}$ = 45 dB to 50 dB,
- individual work, $L_{A,eq}$ = 40 dB to 45 dB,
- receiving the public, $L_{A,eq}$ < 55 dB.

Measured noise level and time distribution for various office activities were reported together with a prediction model for human activity noise in an office [5]. Talking was the source with highest sound pressure level, $L_{p,A}$ = 58 dB in 1 m distance. Another empirical model for human activity noise was derived from measurements in five offices [6].

Disturbance by speech noise

A recent investigation in 21 Finnish offices [7] showed that the percentage highly disturbed (% HD) by speech was correlated with the distraction distance and other pameters, see Table 1. The correlation with the background noise (measured without human activity) was negative, i.e. higher background noise causes less disturbance by speech. It is remarkable that there was no correlation with the spatial decay rate $D_{2,S}$. The highest correlation was found with $L_{p,A,S,4\,m}$. However, it was concluded in [7] that the distraction distance is the most relevant acoustic parameter for prediction of disturbance by noise in open-plan offices.

Table 1: Relation between % HD by speech and the ISO 3382-3 parameters. Data from Haapakangas et al. [7].

Acoustic parameter	R^2 for % HD by speech
r_D (m)	0.294
$D_{2,S}$ (dB)	0.007
$L_{p,A,S,4m}$ (dB)	0.327
$L_{p,A,B}$ (dB)	0.266

Simulations with background noise from speech

In order to through some light on the complicated relationship between the acoustical properties and parameters, a series of simulations was made using the ODEON room acoustic software. The basic room model was the same as used in a previous study [8]. The ceiling was either highly absorbing or highly reflecting, yielding reverberation time around 0.4 s and 1.2 s, respectively. The rooms were fully furnished and either without screens or with sound absorbing screens. Three different heights of the screens were used, namely 1.2 m, 1.5 m and 1.75 m. The reverberation times with screens was a little lower than without scteens, approximately 0.4 s and 1.0 s, respectively.

The simulations were made using four different source positions and four related lines of receiver positions. The results of each simulation was the room acoustic parameters averaged over the four lines of sound propagation in accordance with ISO 3382-3.

The background noise was varied from 30 dB (A-weighted) to 60 dB in steps of 5 dB. Since the purpose was to simulate noise from human activities, i.e. mainly speech, the spectrum applied for the background noise was a typical speech spectrum, see Figure 1.

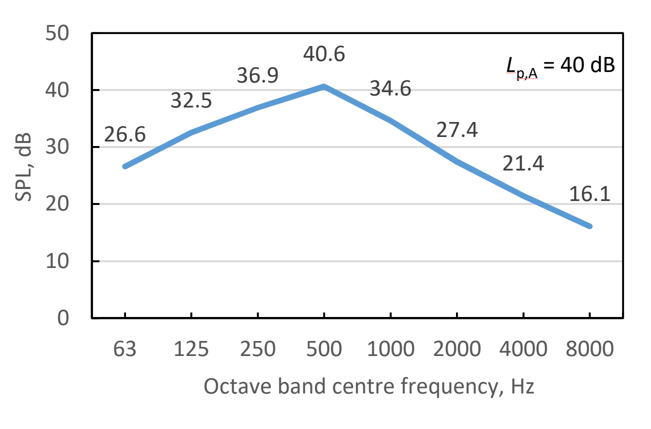

Figure 1: Speech spectrum applied for the simulations. The value at 63 Hz is from [9], the other values are from [1].

Results of simulations

First, we look at the results from offices without screens. The distraction distance r_D and the privacy distance r_P are shown as functions of the level of background noise in Figure 2. While the distraction distance is relevant at noise levels below 50 dB, the privacy distance is more relevant in case of higher levels of the background noise. The distraction distance cannot be determined in the higher noise levels because STI < 0.5 everywhere, even in the closest positions.

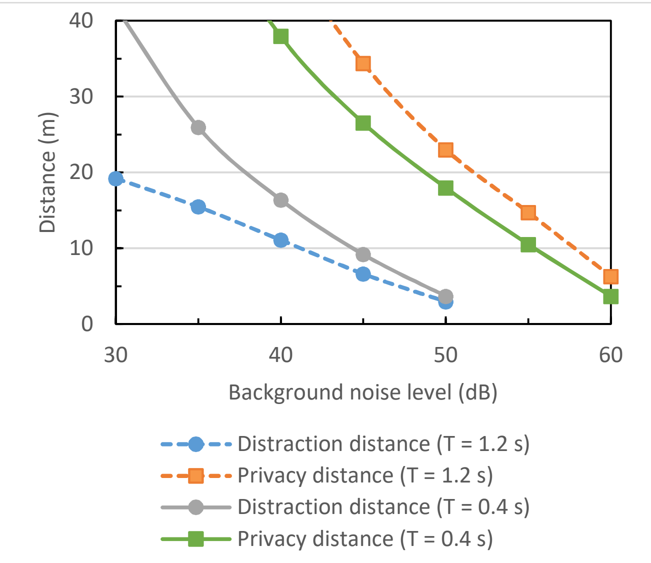

Figure 2: Distraction distance and privacy distance as functions of background noise level. Results from computer simulations.

Increasing the reverberation time has the effect that STI decreases, and thus it is expected that r_D and r_P decrease. While this is true for r_D, the result is the opposite for r_P. The explanation is that the longer reverberation time decreases STI in the close positions, but does not influence STI in the remote positions, where the signal-to-noise level is low. Thus, the slope of the STI/distance curve is more shallow with long reverberation time than with a short reverberation time, and the point where STI = 0.2 moves to a longer distance.

For a good acoustical design the goal is a short distraction distance, preferably below 5 m as recommended in Annex A of ISO 3382-3. Although this might be obtained with a very long reverberation time, this is clearly an unacceptable solution.

Another possibility is a very high background noise level, nearly 50 dB if the reverberation time is 0.4 s. This corresponds to the first category of open-plan offices in NF S 31-199 [4] where the assumed noise from human activity is between 48 dB and 52 dB.

Another way to approach the goal is to introduce noise screens between the workstations. This reduces the distraction distance, see Figure 3. The effect of the screens is most pronounced in low background noise.

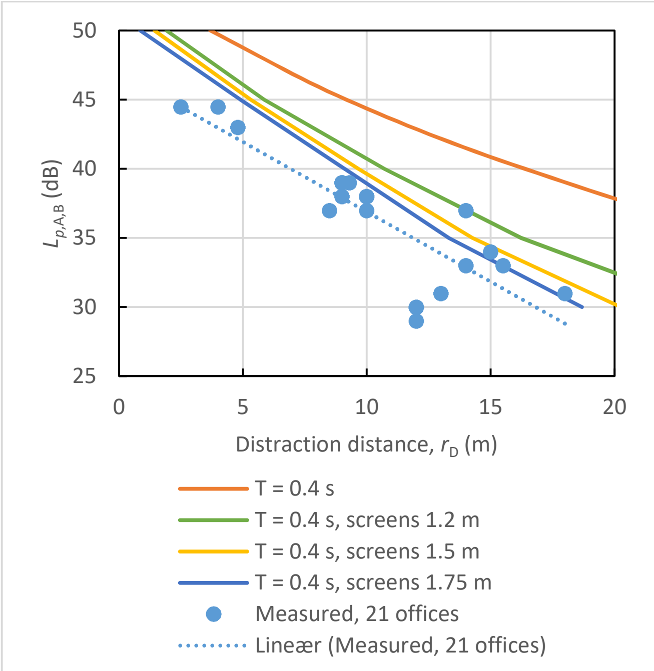

Figure 3: Relation between distraction distance and background noise level. Full lines: Simulations without and with screens of various heights. Dots: Measured data from Haapakangas et al. [7].

Figure 3 also shows the results from the 21 Finnish offices reported in [7]. In general, these measured results suggests screens that are high and closer together than those applied in the simulated offices. However, the relationship between background noise and distraction distance in the simulations has a slope, which is similar to the slope of the linear regression line through the measured data. The slope is approximately -1 dB per m (R^2 = 0.69).

The effect of screens is illustrated in Figure 4, which combines the two parameters distraction distance and spatial decay rate of speech. It is seen that increasing the reverberation time (RT) leads to a decrease of both r_D and $D_{2,S}$. Introduction of screens and increasing the screen height leads to a decrease of r_D and increase of $D_{2,S}$. With high screens, the RT has strong influence on $D_{2,S}$, but rather limited influence on r_D.

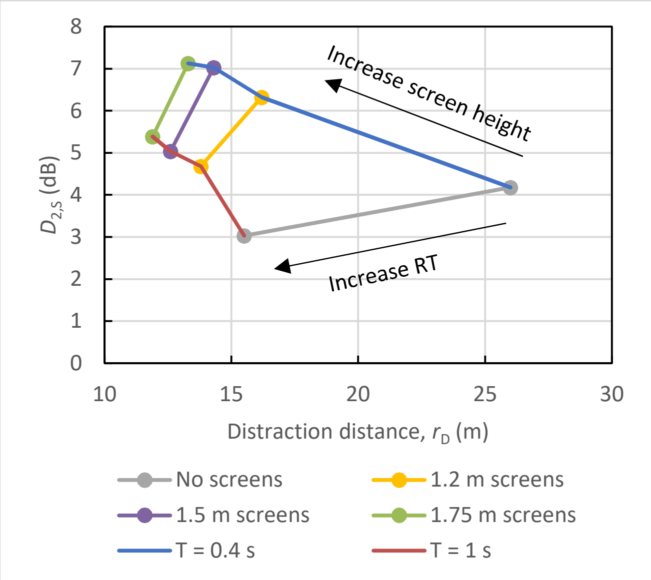

Figure 4: Relation between distraction distance and spatial decay rate $D_{2,S}$ in simulations with different reverberation times (RT), with and without screens. The background noise level is 35 dB with speech spectrum.

Figure 5 is similar to Figure 4, but here the results are shown for three different levels of the background noise. The decrease of r_D with increasing background noise is very pronounced. In high background noise and with screens, RT influences $D_{2,S}$, only, not r_D.

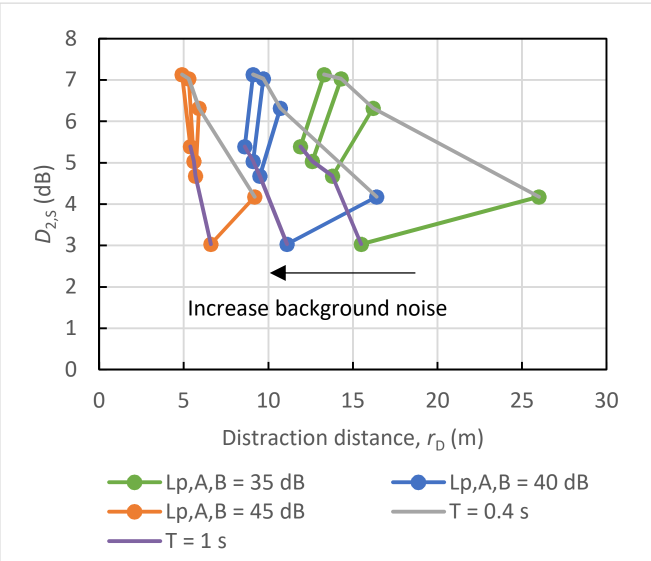

Figure 5: Relation between distraction distance and spatial decay rate $D_{2,S}$ for different levels of background noise, different reverberation times, with and without screens.

Figure 6 shows the results of the simulations in a diagram, which combines the two parameters distraction distance and SPL of speech at 4 m. Increasing screen height is efficient to reduce r_D, but has very limited influence on $L_{p,A,S,4m}$. Increasing RT has a strong influence on $L_{p,A,S,4m}$, and the level exceeds 50 dB if T > 0.4 s in this example. This diagram explains why it is necessary to optimise the reverberation time; it should neither bee too long nor too short.

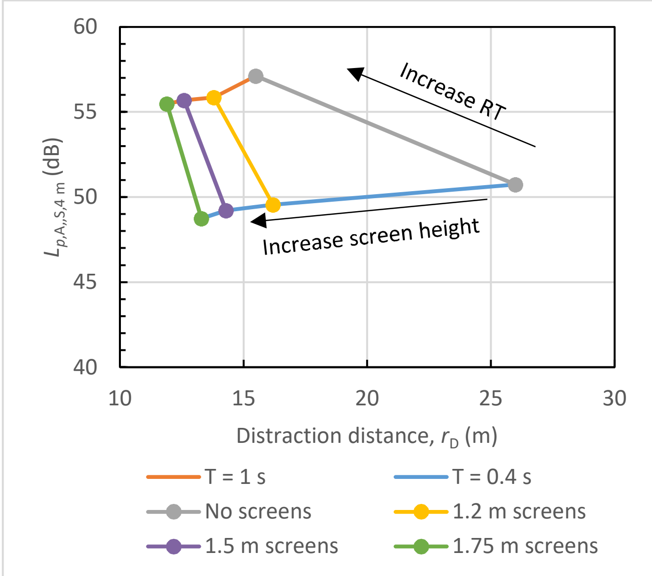

Figure 6: Relation between distraction distance and SPL of speech at 4 m in simulations with different reverberation times, with and without screens. The background noise level is 35 dB with speech spectrum.

Discussion

Annex A of ISO 3382-3 contains guidelines for evaluating the acoustic parameters in offices. Conditions are good if $r_D \leq 5$ m, $D_{2,S} \geq 7$ dB and $L_{p,A,S,4\ m} \leq 48$ dB. Conditions are poor if $r_D > 10$ m, $D_{2,S} < 5$ dB and $L_{p,A,S,4\ m} > 50$ dB.

Figure 7 is in a diagram that displays $D_{2,S}$ against r_D. The data from open-plan offices, in which the % HD by speech was reported, Haapakangas et al. [7] are plottet. Most offices are neither poor nor good according to the guidelines. $D_{2,S} > 6$ dB in most offices and the whole picture is scattered. The relevance of the suggested limits is not obvious.

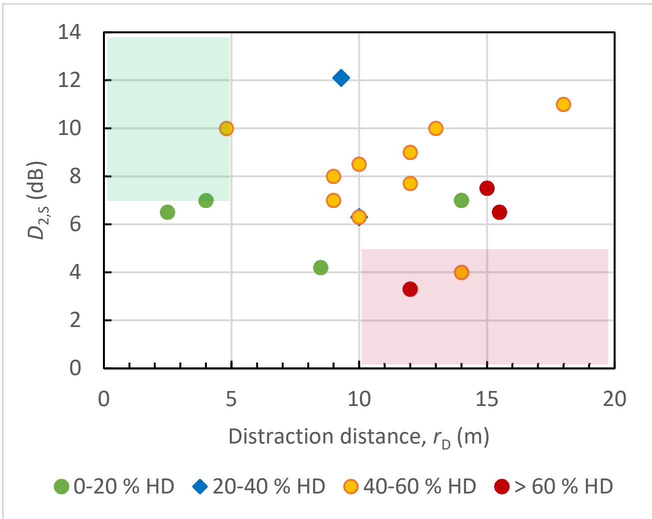

Figure 7: Relation between distraction distance and spatial decay rate $D_{2,S}$ in measured data from open-plan offices, Haapakangas et al. [7]. The colour of the dots indicate the % HD by speech. The shaded areas refer to "good" (light green) and "poor" (purple) in Annex A of ISO 3382-3 [1].

In Figure 8 the same data are displayed in a diagram with $L_{p,A,S,4\ m}$ and r_D as the acoustic parameters. This diagram makes more sense, because there is a tendency that the offices with the worst subjective rating are in the upper left corner.

However, the correlation between the subjective rating and r_D is not very obvious. The offices with best rating (0-20 % HD) have r_D between 2.5 m and 14 m. This can be the result of very different background noise in the measured offices. As remarked previously (Figure 3) there is a rather strong correlation between and r_D and background noise. Actually, some of the best-rated offices had short r_D, but also quite high background noise.

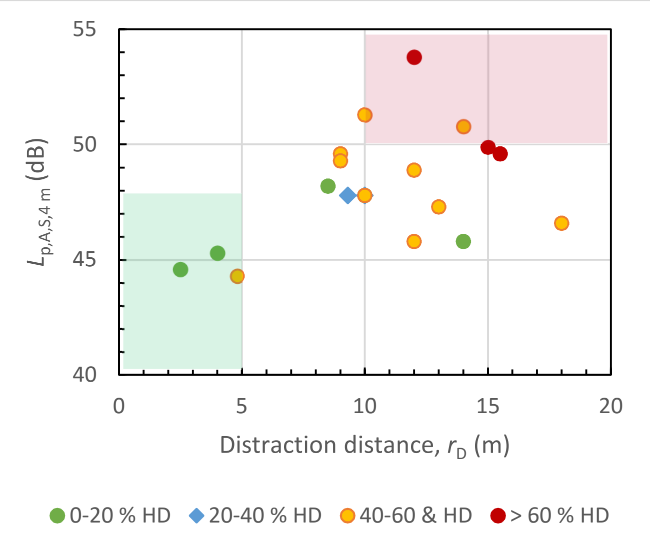

Figure 8: Relation between distraction distance and SPL of speech at 4 m $L_{p,A,S,4\,m}$ in measured data from Haapakangas et al. [7]. The colour of the dots indicate the % HD by speech. The shaded areas refer to "good" (light green) and "poor" (purple) in Annex A of ISO 3382-3 [1].

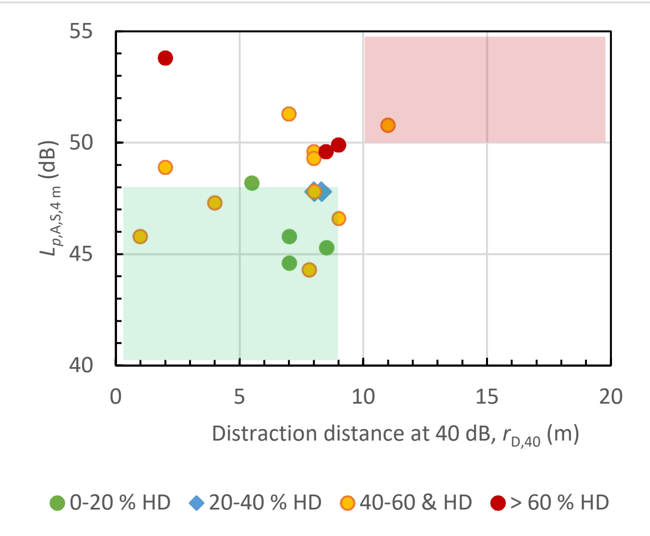

Figure 9: Relation between distraction distance adjusted to 40 dB background noise level and SPL of speech at 4 m $L_{p,A,S,4\,m}$ in measured data from Haapakangas et al. [7]. The colour of the dots indicate the % HD by speech. The shaded areas are suggested for "good" (light green) and "poor" (purple).

To overcome this dependency of the background noise, it is suggested to 'normalise' the distraction distance in such a way, that it represents a realistic background noise from human activity. Using the correlation from Figure 3, the adjusted distraction distance at 40 dB background noise from speech, $r_{D,40}$ can be roughly approximated by:

$$r_{D,40} \approx r_D - \left(40 - L_{p,A,B}\right) \quad \text{[m]} \qquad (1)$$

This leads to the diagram in Figure 9. It is suggested that the corresponding limit for 'good' conditions is $r_{D,40} \leq 9$ m.

Normally, Equation (1) should not be used. The STI results of measurements as well as simulations should be calculated directly using the 40 dB speech noise spectrum, see Figure 1.

Conclusion

Among the acoustic parameters, the spatial decay rate $D_{2,S}$ seems to have no relevance. However, the SPL at 4 m is an important design parameter together with the distraction distance. Since the latter is strongly dependent on the background noise level, it is suggested to 'normalise' the distraction distance to a well-defined level of background noise that may better represent the noise from human activities.

References

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