Investigations on room acoustical parameters for open-plan offices

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Introduction

In [1] the authors reported on hearing tests of auralized room situations of various open-plan offices. One result of these investigations was the fact that in open-plan offices, which are used for R&D-like tasks, the short-term memory performance is influenced much more by the sound insulation of the workstations than by sound absorption. This is due to the fact that in R&D-like open-plan offices the total noise level is often very low and that individual speakers can be heard very clearly, especially when speech intelligibility is high because of high sound absorption. This effect is called the irrelevant speech effect (ISE) [2]. Workstations in open-plan offices therefore need a high sound insulation. Sound insulation does not necessarily affect reverberation time. Therefore the planning of open-plan offices needs other quantities beyond reverberation time. In order to choose quantities suitable for planning five open-plan offices together with eleven modifications of the interior acoustics measures have been measured. Of almost all the workstations a binaural room impulse response (RIR) to a few, individually selected, representative working positions was measured with an artificial head. A miniaturized dodekaeder of a known, since monitored, sound power level was used as a loudspeaker. All together more than 700 RIR have been measured. From the RIR many acoustic parameters have been calculated [3].

Room acoustic parameters

For the sound *absorption* (A/V-ratio) the most common measurable quantity is of course the reverberation time T. For clarity reasons we restricted ourselves to mean values of reverberation times T_{20} in the frequency range between 200 Hz and 2 kHz. In fact reverberation time is dependent on the distance between the sending and the receiving position [4] and on the sound insulation whether sound directly reaches the receiving position (line-of-sight) or not in certain open-plan offices. For the *sound insulation* of the workstations the spatial decay of sound level $L_p - L_W$ was calculated (s. fig. 1). In order to get the most realistic values for this quantity the sound power level L_W for a male person according to DIN EN 60268-16 was considered and the resulting sound pressure level at each workstations was weighted according to the isophone curves in ISO 226. A similar procedure was chosen by Hongisto [5]. In order to derive a single number quantity, the difference between the spatial decay of sound level $L_p - L_W$ and the corresponding value for the free field curve at the specific distance for each sending-receiving (S-E) combination was calculated. The latter quantity is called the excessive sound pressure level DL_f; for a comparison of the open-plan offices the arimethic mean of the DL_f-values for each measured position of a specific room situation was calculated.

For the *speech intelligibility* the quantity definition D_{50} (ger. Deutlichkeit) was used. In fact it was planned to use the speech transmission index *STI*, but evaluating the *STI* of the measured RIR gave different results when calculated by different commercial programs. Up to now the discrepancy has not been resolved. The definition D_{50} is clearly correlated with syllable intelligibility. If D_{50} reaches 50 %, the syllable intelligibility is approx. 70 %, the speech intelligibility can then be considered to be very high. The disadvantage of using D_{50} instead of the *STI* is the missing sensitivity to masking effects in the presence of background noise.

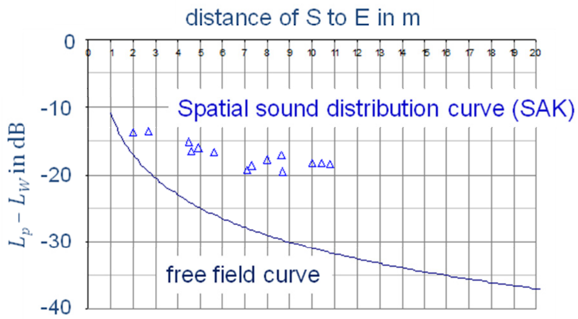

Figure 1: Spatial decay of sound level of one measured room situation. In addition the free field curve is shown. The difference between L_p-L_W and the value for the free field curve is called the excessive sound pressure level DL_f. A single number for DL_f for a specific room situation was calculated by the arimethic mean of the DLF-values for each measured position of this room situation.

In figure 2 the values for the parameters T_{20}, D_{50} and DL_f for one of the measured open-plan offices in its original form (No.1) and after various modifications of its interior are shown. In modification No.2 the absorbing ceiling was changed, which had a higher absorption coefficient in the low and mid frequency range. For modification No.3 absorbing curtains had been added. In modification No.4 the reflecting partition walls had been exchanged by absorbing ones.

It is a well-known fact that reverberation time T_{20} and definition D_{50} strongly correlate, since the higher the equivalent sound absorption area, the higher speech intelligibility is. This does ring true for the excessive sound pressure level DL_f. Modification 4 of the open-plan office shows a dramatic drop in DL_f when the partition walls get absorbing instead of reflecting, whereas the other parameters are just weakly affected. This example proves the necessity of additional parameters, especially characterizing the effect of screens and partitions on transmission paths.

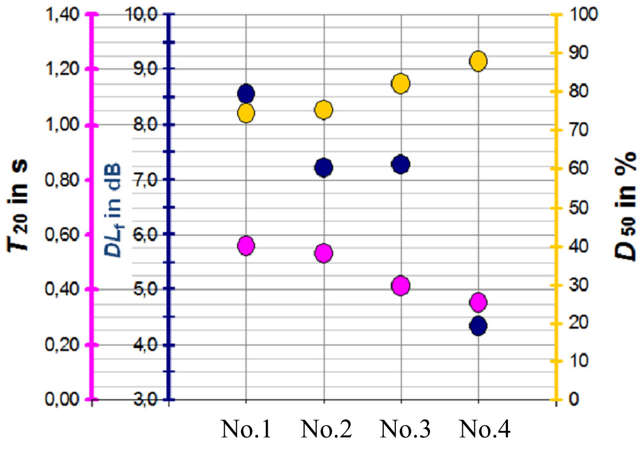

Figure 2: Distribution of the parameters T_{20} (left scale), D_{50} (right scale) and DL_f for one of the measured open-plan offices in its original form (No.1) and after various modifications of the interior acoustic measures.

Distribution of the parameter values

Figure 3 shows the two-dimensional scatter plot of definition D_{50} versus the spatial decay of sound level $L_p - L_W$. The plot shows two different accumulations. The dark circles represent transmission paths, which at least partly suffer from a direct sound field due to a line-of-sight. The faint circles represent transmission paths, which had at least one screen or partition betweeen sending and receiving position.

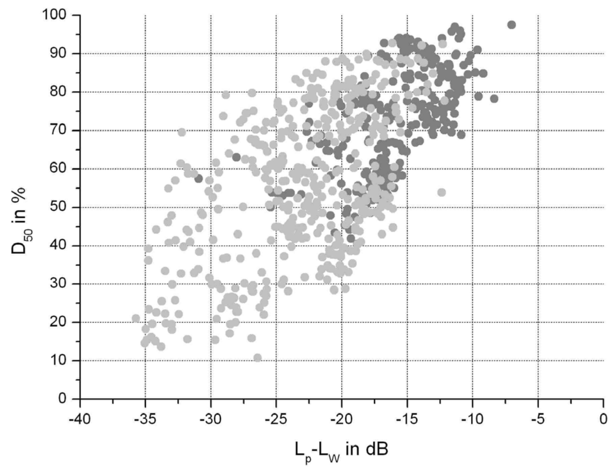

Figure 3: 2D-scatter plot of spatial decay of sound level versus definition including all room situations measured.

Of course transmission paths with a direct line-of-sight have smaller values of $L_p - L_W$. Small values of definition can be achieved by a high value of $L_p - L_W$, which of course has its reason in a long and certainly not straight-line like transmission path. For a definition of less than 50% the spatial decay of sound power has to exceed 20 dB; nonetheless spatial decay of sound power of more than 20 dB does not necessarily imply a low value for the definition. These investigations only ring true for a situation without any backgorund noise. In the presence of background noise of e.g. level of 40 dB, a speaker with a sound power level of 65 dB(A) would be masked at working areas which have an $L_p - L_W$ of -25 dB. In this case the speech intelligibility would be much lower than represented by a definition of 50 %.

Figure 4 shows shows the two-dimensional scatter plot of the definition D_{50} versus reveberation time T_{20} . The two accumulations have the same meaning as in fig. 3. If the planning criteria for open-plan offices of high acoustic comfort is fixed to a reverberation time of 0.5 s, which corresponds to a A/V-ratio of bigger than 0.32, almost no transmission path fulfills a criteria for the definition to be less than 50 %. Workstations with a definition of less than 50 % are in offices, which show reverberation times higher than T_{20} >= 0.6 s.

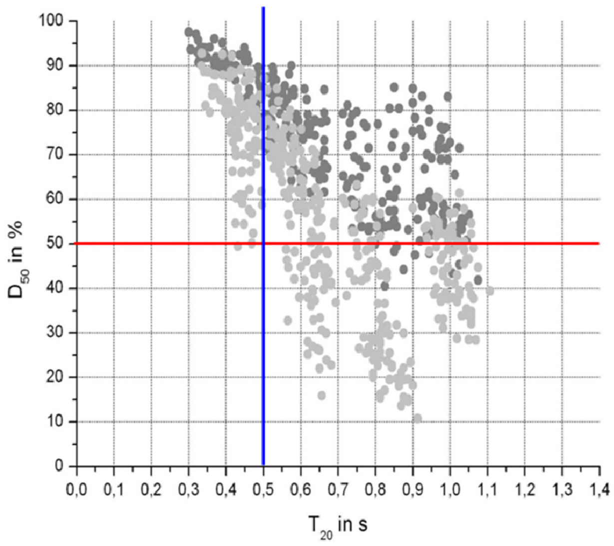

Figure 4**:** 2D-scatter plot of reverberation time versus definition including all room situations measured.

References

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