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How ISO 3382-3 acoustic parameter values are affected by furniture, barriers and sound absorption in a typical open plan office

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ABSTRACT

ISO 3382-3 offers a set of acoustic parameters to describe acoustic conditions in open plan offices such as speech transmission index, spatial decay rate of speech and background noise level. In this research, these parameter values were measured in a typical open plan office while varying furniture, barriers and sound absorption. In many open plan offices a high acoustic quality may be desirable, requiring significant amounts of barriers and (additional) sound absorption. Acoustic designs of open plan offices can be tested using modelling or measurements. In practice one may get very similar design questions such as: 'Do we need screens and how high do they need to be?'. Measured results from offices are available in international literature, but direct comparison is difficult because of different building dimensions, floor plans and furniture elements. This research presents results from measurements in a single open plan office that is representative for many Dutch offices. Furniture, barriers and sound absorption were varied to study the feasibility of achieving certain parameter values. The results from this study give insight in the acoustic design that is necessary to achieve a certain acoustic quality in the open plan office.

Keywords: Open plan office, ISO 3382-3

1. INTRODUCTION

The acoustics in open plan offices is influenced by the building and its furniture elements. A generally good starting point is a sound absorbing ceiling and carpet on the floor. And, possibly, the floor plan and furniture arrangement can be optimized to avoid acoustically unfavorable combinations of functions. As a third step, table dividers and free standing barriers might be used to reduce transfer of sound between workstations or areas. Sound absorption can also be integrated into the screens or applied to walls. In this study, a large set of measurements have been obtained in a typical open plan office while varying screens and absorption. Examples are shown in figure 1 with table dividers and side panels (left) and additionally with free standing barriers between groups of tables (right).



Figure 1 – examples of measured variations of screens in an open plan office

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2. LITERATURE

2.1 Studies on office acoustics

Some research papers have studied acoustic solutions in a number of different offices by means of measurements based on ISO 3382-3 methods, such as Virjonen et al. (1), Keränen and Hongisto (2), Yadav et al. (3), Selzer and Schelle (4) and Haapakangas et al. (5). Most papers present room properties and the acoustic solutions in the measured offices in tables, including room size and height, ceiling absorption, barrier height, etc. Still, without knowing the actual office layouts it is hard to comprehend why some offices perform better than others. Specifically, the Finnish Institute of Occupational Health (1,2,5) has measured rather extreme values for acoustic quality descriptors. Just one example is available in figures 1 and 2 in Virjonen et al. (1), where 'office 11' seems to have rows of bookcases and single workstations between them. Even though this office might have a very high spatial decay rate of speech, one can question whether such an office can be considered as 'open plan'. On the other hand, it is well understood that open plan offices without any acoustic barriers have a low spatial decay rate of speech resulting in irrelevant speech being too intelligible and rooms being too noisy.

Some researchers have systematically investigated the changes in acoustic conditions while varying room absorption and furniture elements. Two studies by Bradley and Wang (6) and Schmich et al. (7) show results from such investigations under laboratory conditions with only two adjacent workstations. In the test rooms, reflections from walls were suppressed heavily by sound absorption and only ceiling and floor reflections influenced the measurements. Even though these studies give great insight on which elements contribute most to the reduction of the sound level on the other side of a set of workstations, the absolute measured values cannot be used for practical situations because of the lack of room reflections. A study by Keränen (8) did take into account the effect of reflections from walls in a 9 x 9 m^2 room with 4 groups of 3 workstations, while using the ISO 3382-3 descriptors to study the effect of screens and wall absorption. However, still these measurements were not representative for a typical open plan office where multiple groups of workstations continue along a line. There is a lack of systematic research on acoustic solutions in real offices.

2.2 Acoustic descriptors and guidelines

Four single number ratings are proposed in ISO3382-3: the decay rate of speech (level reduction when doubling the distance), $D_{2,S}$, the A-weighted sound pressure level of speech at a distance of 4 m, $L_{p,A,S,4m}$, the distraction distance, r_D (above which the Speech Transmission Index, STI, falls below 0.50), and the average A-weighted background noise level, $L_{p,A,B}$. Detailed explanation of these parameters is given in Virjonen et al. (1) and in the ISO standard. The relation between these parameters has been discussed by Wenmaekers and Hak (9).

Specifically, the Speech Transmission Index is not only influenced by the acoustics of space by the smearing of sound but also by the ratio of speech level and background noise level, see Wenmaekers and Hak (10). In current paper, three levels of background noise have been considered that cover the typical range of levels in offices. The spectrum is based on the NR = 30 dB curve for the relevant frequency range 125 to 8000 Hz to simulate typical noise from HVAC systems, see table 1. Note that active noise masking might be necessary to achieve the higher noise levels 40 and 45 dB(A), while a quiet office may have a 35 dB(A) background noise level.

Table 1: background noise levels based on NR curve 30 dB

	125	250	500	1000	2000	4000	8000
NR27 = 35 dB(A)	45	37	31	27	24	22	20
NR32 = 40 dB(A)	50	42	36	32	29	27	25
NR37 = 45 dB(A)	55	47	41	37	34	32	30

Currently, guidelines exist in Finland (11), Germany VDI 2569, see (12) and France NF S 31, see (13) for (some) of the acoustic parameters. Figure 2 shows the distribution of measured data for the speech level related parameters $D_{2,S}$ and $L_{p,A,S,4m}$ for Finnish and German guidelines. The French guidelines use $D_{2,S} \geq 7$ or 9 dB and speech level reduction at the opposite desk $D_n \leq 4$ dB or $D_n \geq 6$ dB. It is clear that a large part of the data falls into the lower categories and only few offices meet the highest requirements. Also, only the offices measured by the Finnish Institute of Occupational Health seem to reach $D_{2,S}$ values above 9 dB. It is striking that the German guidelines have chosen lower values. Perhaps because these are more realistic? Nevertheless, also very few measured offices reach the highest category of the German guidelines.

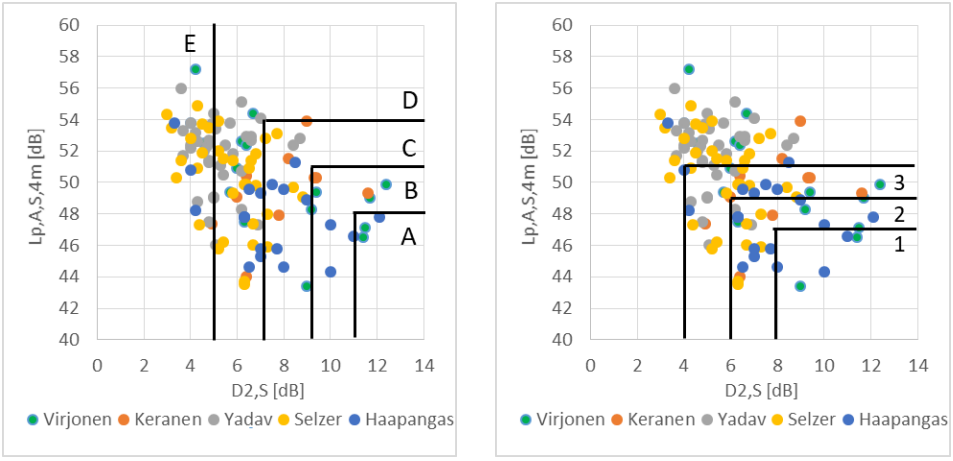


Figure 2: measured data from (1,2,3,4,5) compared to guidelines from Finland (left) and Germany (right)

Even though $D_{2,S}$ and $L_{p,A,S,4m}$ are useful parameters for describing the acoustics of the open plan offices, research by Haapakangas (5) indicates that these parameters do not correlate with the percentage of people that are highly disturbed by (speech) noise. The parameters that relate to speech intelligibility, STI and distraction distance r_D, did show a correlation with highly disturbed people. The Finnish guidelines describe 5 different classes for r_D. Figure 3 shows the distribution of measured data for the speech intelligibility related parameters r_D and $L_{p,A,B}$ and the r_D classes. Again, very few offices achieve the highest class and most offices are in the lower categories. Also, it is shown that in general a higher background noise level results in a lower distraction distance but with large variations.

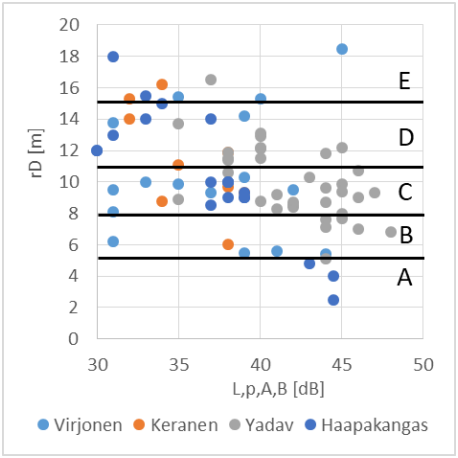


Figure 3: measured data from (1,2,3,4,5) compared to guidelines from Finland

We can conclude that the different guidelines allow the possibility of achieving an office design that can meet the different quality levels (A-E and 1-3). Offices in the highest categories A-B and 1 seem to be rare, while offices in the middle classes (C and 2-3) are found in all available literature sources. Also, it is clear that most offices fall into the lower categories (D-E or <3).

2.3 Research goal

Few guidelines exist how to actually achieve a certain quality level or category using ISO 3382-3 parameters. What solutions can the user expect when he asks for a certain quality level? Are the necessary acoustic measures realistic or even desired from other viewpoints than acoustics? Surely, high screens will improve acoustic quality but does it match the expectation of the user within the open plan office concept?

To get more insight, an experiment was conducted in a single office while gradually increasing the amount of acoustic measures such as screens and absorption. The office and the acoustic measures were chosen to be representative for modern offices and office furniture in The Netherlands. Results show what measures are needed for the given office to achieve the different quality levels. They can serve as examples for other office designs or as benchmarks for simulations of other office layouts. Also, it is shown that some of the higher quality levels are not (easily) reached with realistic measures.

3. METHOD

3.1 Measurement procedure and equipment

Measurements have been performed following ISO 3382-3 over two measurement lines, one along the wall and one along the aisle with the sound source in front of the wall. An omnidirectional sound source (B&K 4292) and an omnidirectional microphone were connected to a laptop with measurement software Dirac 6 (B&K 7841) via a triton usb device (AE) and amplifier (B&K 2734). The sound source was calibrated in a reverberation room using the 'system calibration' function in Dirac. The microphone was calibrated in Dirac using a reference tone (B&K 4231). Source and receiver typically had a 1.2 m height, except for experiments with a workstation for standing where the source had 1.5 m height. The source-receiver distance was derived from the impulse response measurements of the room with only tables using the Dirac software.

3.2 Room and furniture

A vacant office was selected that was available for two weeks to perform the measurements. Floor plan and dimensions are shown in figure 4 on the next page. The room is typical for many Dutch open plan offices as it has a long and narrow floor plan to provide daylight and with closed rooms to subdivide the long space. The space between table groups is approximately 2 x 0,9 m which is the typical space required to reach the workstations. When the barrier between workstation groups is applied, the same distance is preserved, even though it is common to provide more space (1.2 m between workstation and barrier), such that measurements with and without barrier can be directly compared.

Within the group of four workstations, table dividing panels can be placed and side panels on the side of the wall and aisle and in the middle, see figure 4. The distance between workstations and the side wall is 0.5 m and extensions for the table dividing panel and free standing barrier are available to close the gap.

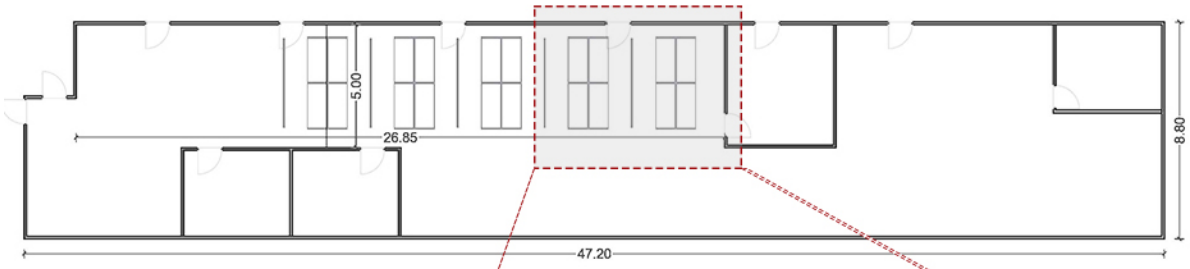
3.3 Room materials and furniture elements

The room has a sound absorbing ceiling with 20 mm Rockfon panels on a > 500 mm cavity. The floor is covered by carpet and the walls are acoustically reflective (glass and gypsum board). Except for the 20 workstations (5 groups of 4 workstations) the room was completely empty. As a result, it might be more reverberant and reflective than a fully furnished office, which makes the results from the experiment pessimistic.

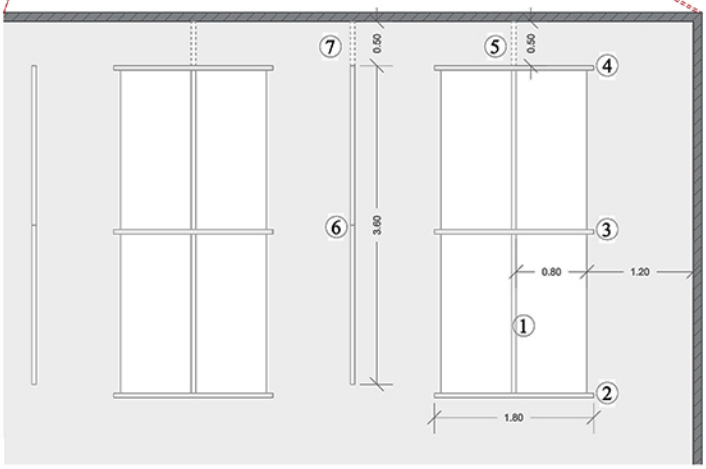
Table dividing panels and free standing barriers were constructed from 25 mm chipboard, which is relatively heavy for office screens but guarantees that sound transmission through the screen is negligible. In most cases, the table dividing screens run to the floor and have a 1.2 m or 1.5 m height which is typical for a solution that allows seeing each other while being seated or standing respectively. The free standing barriers between groups of workstations are 2 m high.

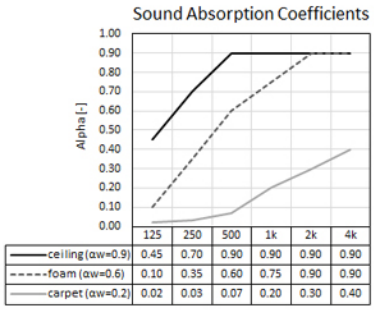
Sound absorption could be applied separately to the screens on each side of the chipboard. As sound absorption, 30 mm melamine foam was applied only to the upper 1.3 m height of the screens were it is most effective. Thicker sound absorption on either side of a core was not considered to be common in standard office screens. In one case, 60 mm melamine foam was used as a screen without the core. In another case, sound absorption was also applied to the back wall behind the sound source.

The sound absorption coefficients of the materials are shown in the graph in figure 4.



1. table dividing panel
2. side panel aisle
3. side panel middle
4. side panel internal wall
5. extension panel divider
6. free standing barrier
7. extension panel barrier





	125	250	500	1k	2k	4k
ceiling (αw=0.9)	0.45	0.70	0.90	0.90	0.90	0.90
foam (αw=0.6)	0.10	0.35	0.60	0.75	0.90	0.90
carpet (αw=0.2)	0.02	0.03	0.07	0.20	0.30	0.40

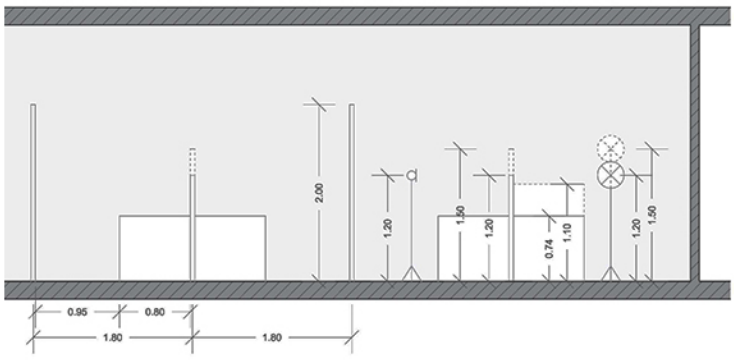


Figure 4: floorplan and section with dimensions
graph with sound absorption coefficients

4. RESULTS

27 iterations of changes in the screens setup were tested to understand the relevance of combinations of solutions while taking over 500 impulse response measurements. Figure 5 shows the measurement results for four variations of the setup that made a considerable improvement compared to the empty tables and each other. The variations are as follows:

v1: only the tables in the room
v2: tables with 1.2 m high table dividers made of 60 mm thick sound absorption without a core
v3: tables with 1.5 m high table dividers made of 30 mm thick sound absorption of each side of a core together with reflective side panels
v4: as v3 combined with a 2 m high free standing barrier between groups of tables, the upper 1.3 m of the barrier is covered with 30 mm of absorption on each side of the core. On the same height, sound absorption is applied to the back wall behind the sound source.

Figure 5 shows the A-weighted speech level ($L_{p,A,S}$) as a function of distance, the speech transmission index (STI) as a function of distance with a 40 dBA background noise level, reverberation time T30 per frequency and the distraction distance for each variation for three background noise levels 35, 40 and 45 dBA . In the legend of the graphs, results for single number ratings are presented.

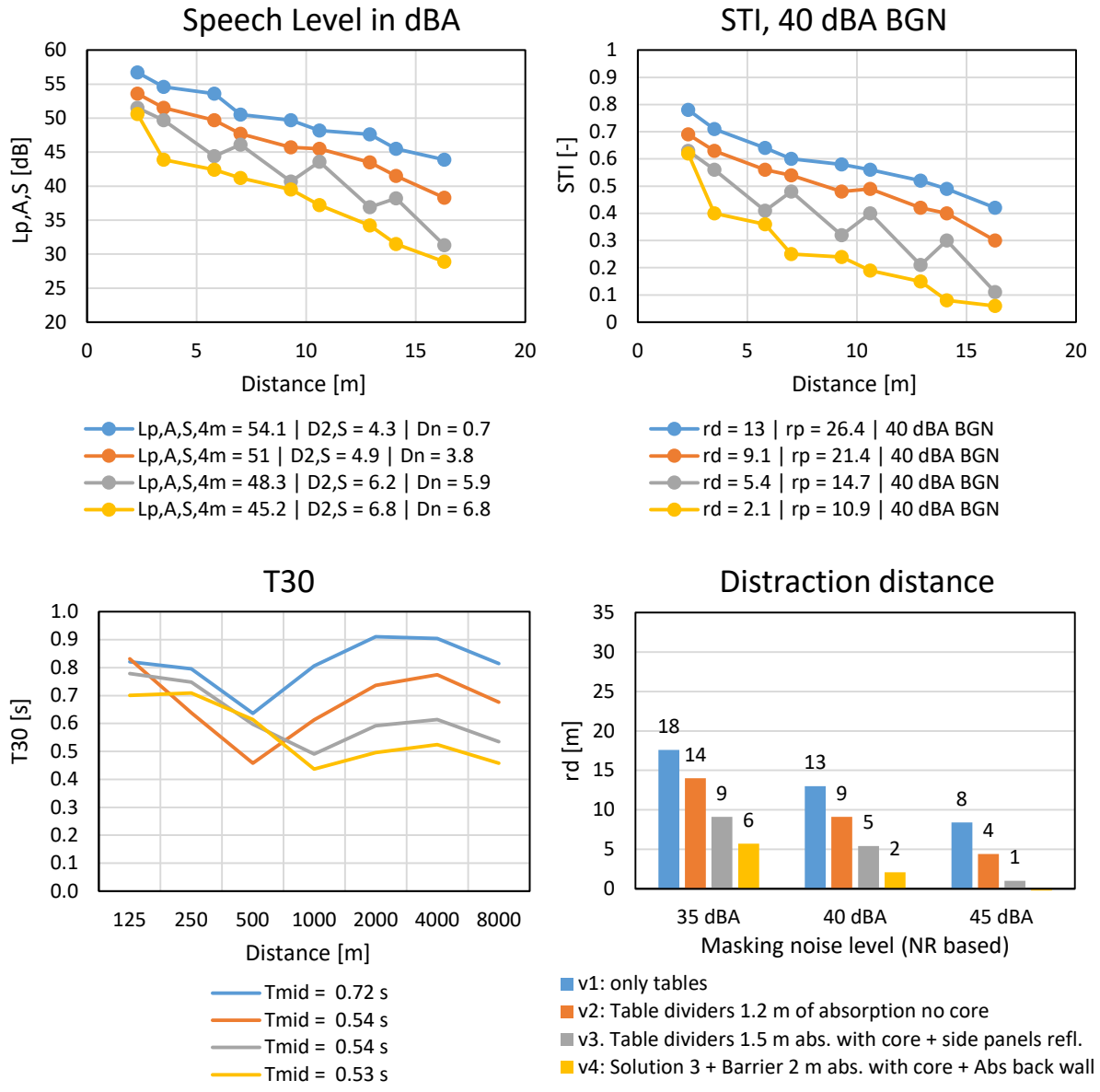


Figure 5: measurement results for four different variations of furniture setups

4.1 V1: Only tables

The results with empty tables confirm that without any screens the acoustic parameters related to speech levels are in the worst categories as described in section 2.2 (Class E or Step <3). The distraction distance is too long when background noise is low. Nevertheless, with a 45 dBA background noise level (which requires active sound masking), it seems possible to achieve 'Class B' from the Finnish guidelines (r_D > 8 dB).

4.2 V2: Table dividers

A first step of improvement is made by applying the table dividing panels. Measurements show little difference in screen height 1.2 m or 1.5 meter. Neither does a standing table with source height 1.5 m result in significant change in parameter values compared to a sitting table with source height 1.2 m. However, if the 1.5 m high dividing panel is only above table level, the opening under the table has a large impact and this type of screen is therefore not recommended. The setup with reflective table dividing panels was found to 'sound' very unpleasant and is therefore not considered as an appropriate solution.

Because the measurement results for various heights and finishes of the table dividing panels are comparable, the most suitable solution is a 1.2 m screen with 60 mm of absorption without a sound insulating core. With this solution, 'Step 3' from the German guidelines is met, while in the Finnish Class system still the poor class 'E' is reached for speech level parameters. However, a 'Class C' distraction distance is achieved with 40 dBA background noise level or even 'Class A' with 45 dBA.

4.3 V3 Table dividers and side panels

The next step of improvement is made by applying side panels, see figure 1 left. These panels block sound that is travelling around the screen in the horizontal plane. Near a wall, the side panels block the reflection of sound via this wall, which can also be solved by extending the table dividing panel to the wall. Experiments with applying sound absorption to the wall on the side of the aisle did not show considerable improvement. Also, applying sound absorption to the side panels on the side of the table did not give considerable improvements. This means that the side panels can be reflective on both sides. Listening experiments confirmed that the absorption on the table dividing panel is sufficient to provide a pleasant 'sound' even when speaker with one's head between the panels.

Looking at the acoustic parameter results, this setup can fulfill 'Step 2' from the German guidelines but still only 'Class D' from the Finnish guidelines regarding speech levels. Class C, B and A distraction distance is achieved with 35, 40 and 45 dBA background noise level respectively. With a $D_{2,S}$ of 6.2 dB, the lowest requirement of the French guidelines of $D_{2,S} \geq 7$ dB is still not met, while with a D_n of 5.9 dB the French guideline of $D_n \geq 6$ dB is almost met which corresponds with results in figure 1 from reference 13.

4.4 V4 Adding a free standing barrier

Looking at the speech level and STI as a function of distance, a clear zig-zag shape can be observed in variation v3. It is clear that the position directly behind a screen benefit most from it. Therefore, the next logical step is to introduce free standing barriers between groups of workstations, see figure 1 right (note that the absorption shown on the side panels is not necessary). However, the first experiment with a reflective barrier showed a worsening of acoustic conditions. Sound is being reflected back to the source, arriving at work stations in front of the barrier. It is clear that the barrier has to be sound absorbing to take away this effect, as well as the back wall behind the loudspeaker.

A significant speech level reduction was achieved by adding the barriers. However, the rate of speech level decay over distance hardly changed. As a result $D_{2,S}$ increased slightly from 6.2 dB to 6.8 dB. It was found that sound travelling via the horizontal path along the side panels and barriers is limiting the decay rate. When the barriers are extended to the internal wall, a $D_{2,S}$ of 8.2 dB is achieved from the measurement line next to this wall.

With the measured results close to the wall, including the barrier to wall extension, the German 'Step 1' is achieved. A next quality level is reached for the Finnish guidelines with 'Class C' for speech level parameters and the French requirement for $D_{2,S}$ > 7 dB is met. For the distraction distance, the highest Finnish quality level 'Class A' is achieved for nearly all background noise levels.

No attempts were made to further improve the setup because this was not considered being realistic. It should be noted that it is common to have 30 cm more space between the barrier and the work station, which might have a (small) negative effect on the measurement results.

5. DISCUSSION AND CONCLUSION

The results from this research show that it is possible to design acoustic solutions that can fulfill the German guidelines regarding speech level and the Finnish guidelines regarding distraction distance. In an office with the German 'Step 1' quality, it seems that the distraction distance is low enough to nearly meet $r_D \leq 5$ m ('Class A' Finnish guidelines) under all background noise conditions 35-45 dBA. With a 'Step 2' or 'Step 3' quality, this 'Class A' distraction distance is only achieved with a higher background level up to 45 dBA.

The highest Finnish and French guidelines for the speech level parameter $D_{2,S}$ have not been reached (≥ 9 dB). It is questionable whether this is possible in realistic scenarios that fit the typical architecture of (Dutch) open plan offices. Besides, such high $D_{2,S}$ has proven to be unnecessary because a low distraction distance can already be achieved with $D_{2,S} \leq 8$ dB even in a quiet office.

Looking at the pictures in figure 1, it is clear that the acoustic solutions have a big impact on the design and cost of the open plan office. Depending on the type of work and the type of office, careful selection of criteria is needed to match users' needs and expectations.

ACKNOWLEDGEMENTS

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