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HOW RELIABLE ARE ISO 3382-3:2012 MEASUREMENTS FOR PREDICT OF THE EMPLOYEE SATISFACTION WITH THE ACOUSTICS IN OPEN-PLAN OFFICES? PRELIMINARY RESULTS OF MULTIPLE MEASUREMENTS AS WELL AS IN-SITU SURVEYS

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ABSTRACT

As in many countries, German offices are changing. Smaller offices are increasingly giving way to open office landscapes for maximum space efficiency. The changed office environment has measurable effects on the employees, who are supposed to work as productively as possible on the one hand, and should be as satisfied as possible with their work environment on the other.

In order to quantify the current level of employee satisfaction with building physics parameters, the Fraunhofer Institute for Building Physics IBP carried out in-situ surveys in offices of several German companies. The results show significantly different ratings when comparing the satisfaction with building physics parameters such as acoustics and lighting, with acoustics being one of the parameter with the biggest dissatisfaction in all offices. In addition to the surveys, several of the offices in which the participants worked, were measured acoustically according to ISO 3382-3:2012 and ISO 3382-2:2008. On the basis of preliminary results, it is discussed, if acoustic measurements according to ISO 3382-3:2012 are a reliable predictor for employee satisfaction with acoustics in open-plan offices.

1. INTRODUCTION

17 million Germans are employed in offices [1]. Only 58% work in single or two-person offices, the other 42% in larger office forms. If it were up to the employees, office landscapes would look differently: 95% of all office workers would choose a one- or two-person office if they had the choice [2]. Concerns about open office structures are currently being further increased by Covid-19. Nevertheless, companies are planning larger office landscapes - mostly for economic reasons [3]. The open office forms pose many problems, e.g. regarding acoustics. In order to specify the problems and develop solutions, the Fraunhofer Institute for Building Physics IBP conducted employee surveys (n = 659) and had room parameters evaluated according to their importance. Acoustics took first place ahead of parameters such as air quality or temperature [4]. Other studies have come to similar results. According to a survey by the bso, 21% of the employees frequently or very frequently feel disturbed by noise in the office [2].

The European OFFICEAIR study showed that 47% of all employees complain about noise like talking colleagues or printers [5]. In a study by the Hans Böckler Foundation, as many as 75% of those questioned even stated that noise was a disruptive factor in the office. Other studies indicate that the time lost due to acoustical disruptions increases significantly with offices size [6]. Noise is not only subjectively perceived as a major problem by employees in open office environments - studies show that it has a big impact on health. The vegetative nervous system of humans is negatively affected from a noise level of 60 dB(A), the mental state and cognitive performance are affected from 30 dB(A). Speech noise in particular has a negative impact, it leads to a reduced working memory performance, starting at a level of 35 dB(A) [7]. The use of room acoustic measures can only achieve limited improvements. Although attempts are being made to reduce not only the reverberation time, but also speech intelligibility of the office staff, room acoustics can only be influenced to a very limited extent if an open office structure is to be maintained. For measuring the acoustic quality of offices, ISO 3382 suggests the acoustical parameters T_{20} (reverberation time), $D_{2,s}$ (spatial decay rate of speech), $L_{p,A,S,4m}$ (A-weighted sound pressure level of speech at a distance of 4m), STI (speech transmission index), as well as r_D (distraction distance), that is calculated on the basis of the measured STI result and $L_{p,B}$ (background noise level).

As many parameters are defined in ISO 3382-3:2012, it should be examined which parameters are able to best represent human perception and are a suitable predictor of employee satisfaction with acoustics in open-plan offices. Some studies have already been considered, such as by Seddigh et al., who showed that adding room absorption decreases the disturbances caused by acoustics [8], or Newsham et al., who compared the measured Speech Intelligibility Index with survey responses in nine buildings, but found no significant relation [9]. Haapakangas et al. analysed 21 offices in Finland and compared acoustical measurement results with the percentage of highly disturbed persons in the office. They found, that r_D was the best predictor of perceived noise disturbance in open-plan offices best ($r = 0.54^*$), followed by $L_{p,A,S,4m}$ which also showed a correlation of $r = 0.47^*$, whereas no correlation could be found when comparing $D_{2,s}$ [10]. In Germany with its special office landscapes (e.g. no sound masking is used in most offices), no

comparison of acoustical measurement results and employee satisfaction has so far been conducted. Therefore, this comparison will be done by using survey and measurement data of eight open-plan offices. The results will be compared with the measurements and survey data of 21 open-plan offices by Haapakangas et al. [10].

The question how reliable ISO 3382-3:2012 measurement results are as a predictor of employee satisfaction with acoustics in open-plan offices will be discussed.

2. METHOD

Eight open-plan offices in Germany were examined. The measurements took place between the year 2015 and 2020. Only the open areas of the open-plan offices were evaluated. Smaller rooms, as for example telephone booths, were not considered. The offices all had around 30 working places. Web-based in-situ surveys of the employees working in the offices as well as measurements were executed. In some companies, the employees of several structurally identical offices answered the survey. Detailed background information about the offices are given in Table 1.

Office	Participants	Business	Year
1	58	Insurance	2019
2	166	Insurance	2019
3	51	Insurance	2018
4	37	Insurance	2018
5	39	Insurance	2018
6	24	Insurance	2018
7	33	Sales	2015
8	33	Sales	2015
Total	441		

Table 1. Information about the offices that were considered in this study.

If employees had just moved into the offices, the surveys started after an acclimatization time of at least two weeks. The following questions were used in the survey (translated from German):

- How satisfied are you overall with the acoustic conditions (noise level, speech and non-speech noises in and outside the office, intelligibility of interlocutors) at your workplace?
- How satisfied are you with your workplace regarding the possibility of having undisturbed conversations without being heard by other people or listening to their conversations?
- How intelligible are conversations from a greater distance at your workplace?
- How satisfied are you overall with the indoor climate conditions (temperature, air quality, air movement) at your workplace?
- How satisfied are you overall with the lighting conditions (light intensity, visual comfort of the lighting, daylight) at your workplace?
- How satisfied are you overall with your work?

In addition to these question items, further questions were used that are not presented in this paper. The questions could be answered on a seven-point (-3 completely dissatisfied, -2, -1, 0, +1, +2, +3 completely satisfied) or a five-point (-2 completely dissatisfied, -1, 0, +1, +2 completely satisfied) scale. In addition to the survey, measurements according to ISO 3382 were carried out in all eight offices. $L_{p,A,S,4m}$, STI and r_D , $D_{2,S}$, $L_{p,B}$ as well as T_{20} were measured. The measurement was run with B&K Dirac 6.0 and signal MLS. In all following statistical evaluations, the significance level $\alpha = 0.05$ was chosen.

3. RESULTS

3.1 Survey results on overall satisfaction with building physics parameters

By comparing the satisfaction with building physics parameters across offices 1-6, acoustics was the parameter with the biggest dissatisfaction, as shown in Figure 1. Statistically significant differences could be found between the building physics parameters ($F(2, 1148) = 180.24, p < .01$). Statistically significantly more people were dissatisfied with acoustics than with climate or lighting conditions. This trend was also shown in many other research projects, compare e.g. [11].

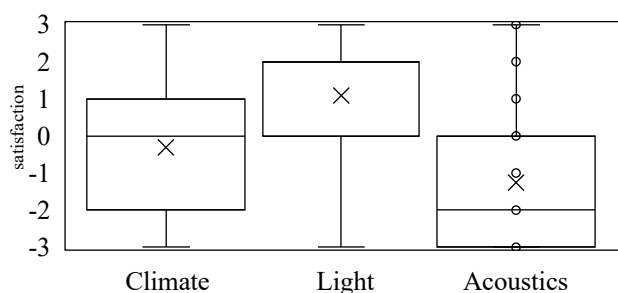


Figure 1. Comparison of overall satisfaction (-3: very dissatisfied, 3: very satisfied) with climate, lighting and acoustics, averaged over all offices.

3.2 Survey results on acoustics

The survey results on acoustics are shown in the following figures. Some questions were only asked in offices 1-6. The overall satisfaction with acoustics was statistically significantly different between the offices, as shown in Figure 2 ($F(5, 251) = 19.91, p < .001$). The satisfaction was relatively low in most offices. Only in office 1, satisfaction was rated neither particularly low nor particularly high.

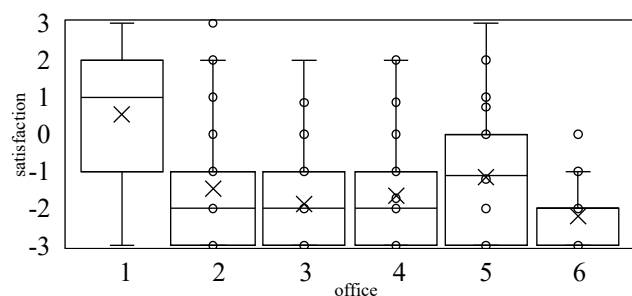


Figure 2. Overall satisfaction (-3: very dissatisfied, 3: very satisfied) with acoustics.

Also, the overall satisfaction with acoustical privacy showed statistically significant different ratings between the offices ($F(7, 425) = 8.94, p < .001$), see Figure 3. Satisfaction with acoustical privacy was low in all offices. In offices 7 and 8, a five-point scale was used and transformed to a seven-point scale.

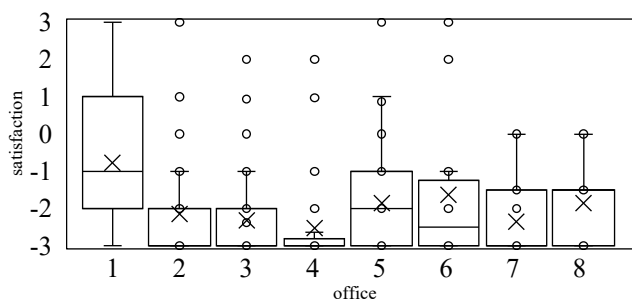


Figure 3. Satisfaction (-3: very dissatisfied, 3: very satisfied) with acoustical privacy.

Regarding speech intelligibility, the question was rated on a scale from 0 “not intelligible” to 100 “very intelligible” and showed significant differences between the offices ($F(5, 355) = 11.07, p < .01$), as shown in Figure 4.

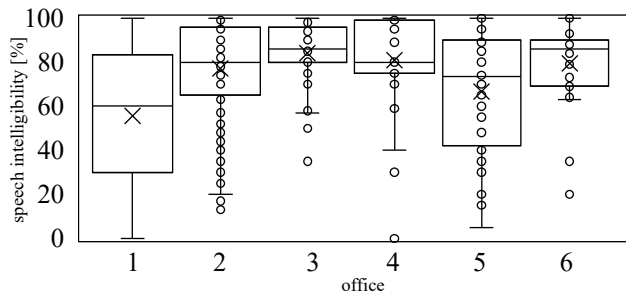


Figure 4. Speech intelligibility from workplaces not next to the recipient.

Overall satisfaction with the working task showed no statistically significant differences between the offices ($F(5, 188) = 2.02, p = .08$) with a median between 0 and +1.5. Therefore, it can be assumed that the survey results regarding the satisfaction with acoustical and building physical parameters are not related to different levels of satisfaction with the working task in the offices.

3.3 Measurement results

As in most German open-plan offices, sound masking was not used in any office. Therefore, background sound levels were low (25-35 dB(A)) in all measurements. T_{20} measurement results for all offices are shown in Figure 5. The other results of the ISO 3382-3:2012 path measurements are represented in boxplots in the following figures for a better understanding of the deviation between the measurement results in every office. $L_{p,A,S,4m}$, $D_{2,S}$, $L_{p,A,B}$ and T_{20} were measured in all eight offices, whereas r_D was only measured in offices 1-6.

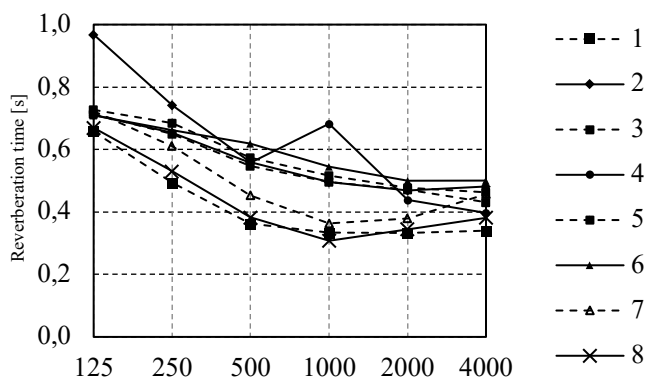


Figure 5. Results of the T_{20} measurements in the offices.

Figure 6 shows the $L_{p,A,S,4m}$ measurement results of the different offices. Comparing the results showed statistically significant differences between the offices regarding $L_{p,A,S,4m}$ ($F(7, 74) = 6.96, p > .01$).

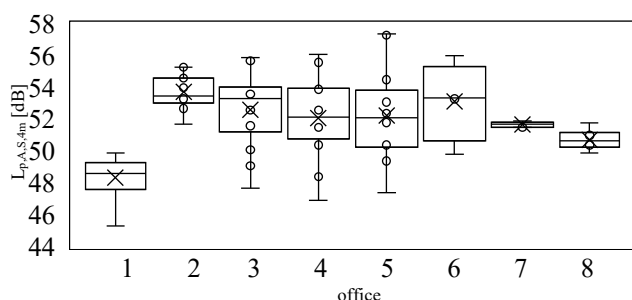


Figure 6. Results of the $L_{p,A,S,4m}$ measurements.

Figure 7 shows the $D_{2,S}$ measurement results of the different offices. The measurement results showed statistically significant differences between the offices regarding $D_{2,S}$ ($F(7, 74) = 14.40, p > .01$).

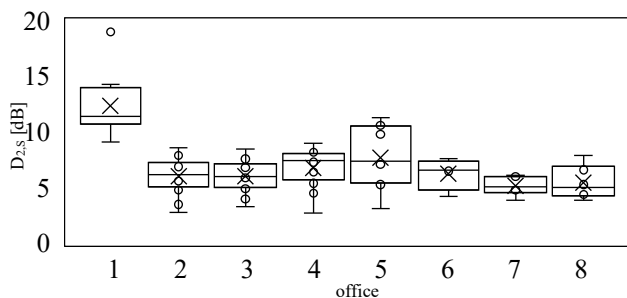


Figure 7. Results of the $D_{2,S}$ measurements.

Figure 8 shows the r_D measurement results of the different offices. r_D was only measured in offices 1-6. The measurement results showed no statistically significant differences between the offices regarding r_D ($F(5, 64) = 1.34, p = .26$).

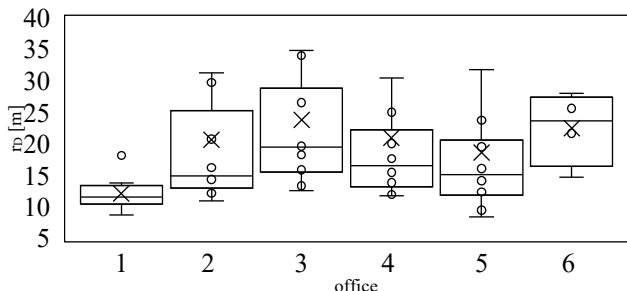


Figure 8. Results of the r_D measurements.

3.4 Comparison of survey and measurement results

In offices 7 and 8, only the question relating to acoustical privacy was asked. Therefore and due to the fact that a high correlation between the subjective ratings of overall satisfaction with acoustics and satisfaction with acoustical privacy could be found ($r = 0.76^*$), the comparison of the acoustical measurement results (mean values) and satisfaction with acoustical privacy (mean values) is shown in Figures 9, 10 and 11. Acoustical measurement results and survey data highly correlate regarding all measurement parameters. Correlation is highest ($r = 0.89^*$) when comparing r_D and subjective results, followed by the comparison of $D_{2,S}$ and subjective results ($r = 0.79^*$) and the comparison of $L_{p,A,S,4m}$ and subjective results ($r = -0.68$). However, no statistically significant correlation could be found by comparing $L_{p,A,S,4m}$.

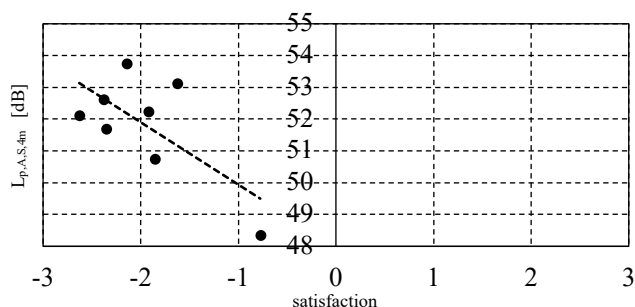


Figure 9. $L_{p,A,S,4m}$ measurements (mean values) against satisfaction (-3: very dissatisfied, 3: very satisfied) with acoustical privacy ($r = -0.68$, $p = .06$). $R^2 = 0.46$.

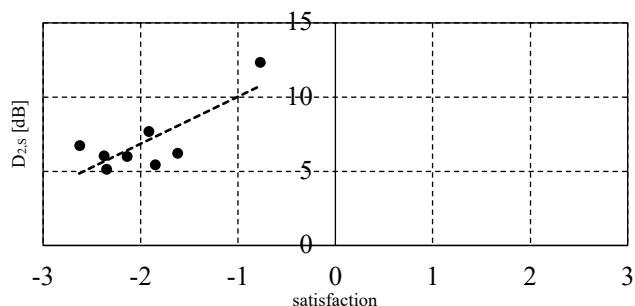


Figure 10. $D_{2,S}$ measurements (mean values) against satisfaction (-3: very dissatisfied, 3: very satisfied) with acoustical privacy ($r = 0.79$, $p = .02$). $R^2 = 0.63$.

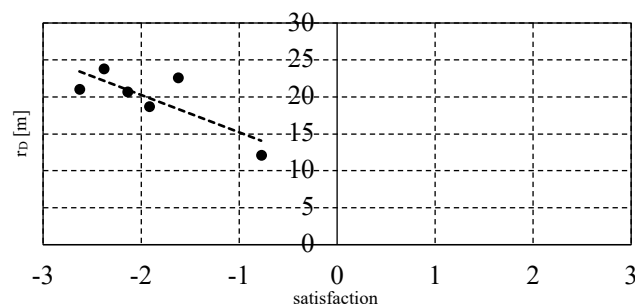


Figure 11. r_D measurements (mean values) against satisfaction (-3: very dissatisfied, 3: very satisfied) with acoustical privacy ($r = 0.89$, $p < .01$). $R^2 = 0.64$

Only eight offices are presented in this study, which could be used for comparing acoustical measures and subjective ratings. In addition, only one data point (office 1, as shown in Figures 9, 10 and 11) showed great differences in both

acoustical and subjective measures compared to the other offices.

4. DISCUSSION

Since only data from eight offices was collected, the results were compared with the previously published results of Haapakangas et al. [10]. In the present study very low background noise levels were measured and no sound masking was used in any office. Therefore, the measurement results can be used to complete the data frame and to validate the suggested model. The average values of the ISO 3382-2:2012 path measurement results of the present study are presented in Table 2 in combination with the results of the office survey. As recommended by Haapakangas et al. [10], the gathered survey data was recoded into a binary variable (0 low disturbance, 1 high disturbance). When using the seven-point scale, responses from -3 to -1 were categorized in 1 “high disturbance”, responses from 0 to +3 were categorized in category 0 “low disturbance”. When using the five-point scale, responses from -2 to -1 were categorized in category 1, responses from 0 to +2 were categorized in category 0.

Office	r_D	$D_{2,S}$	$L_{p,A,S,4m}$	Paths	HD Noise [%]	HD Acoustical Privacy [%]
1	12,1	12,4	48,4	11	28	59
2	20,7	6,0	53,7	13	75	88
3	23,8	6,1	52,6	14	85	94
4	21,0	6,8	52,1	14	86	97
5	18,7	7,7	52,2	14	74	86
6	22,6	6,3	53,1	4	92	83
7	-	5,2	51,7	6	-	91
8	-	5,5	50,7	6	-	79

Table 2. ISO 3382-3:2012 measurement results and percentage of highly disturbed (HD) employees.

By comparing the $L_{p,A,S,4m}$ measurements and the percentage of persons highly disturbed by noise, a higher correlation ($r = 0.71^*$) could be found after adding the results presented in this study to the data frame presented by Haapakangas et al. than without (0.47^*). The results are shown in Figure 12.

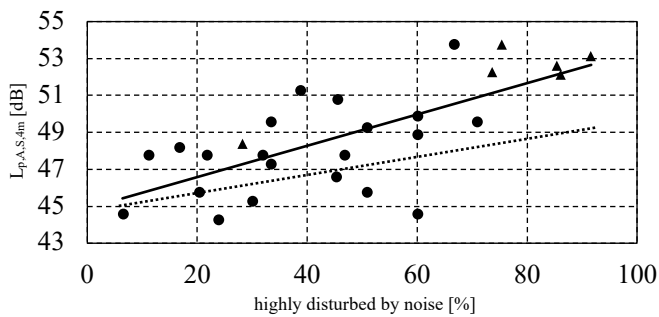


Figure 12. $L_{p,A,S,4m}$ (mean values, Mueller et al. (triangles) and Haapakangas et al. (dots)) against %HD by noise ($r = 0.71$, $p < .01$). $R^2 = 0.50$. Dotted: original trend line by Haapakangas et al. without results of this study.

By comparing the $D_{2,s}$ measurements and the percentage of persons highly disturbed by noise, a similar low correlation ($r = -0.09$) could be found with the results presented in this study than without ($r = -0.04$). The results are shown in Figure 13.

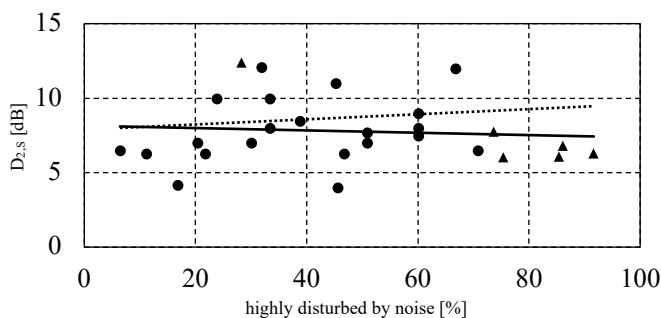


Figure 13. $D_{2,s}$ (mean values, Mueller et al. (triangles) and Haapakangas et al. (dots)) against %HD by noise ($r = -0.09$, $p = .67$). $R^2 = 0.01$. Dotted: original trend line by Haapakangas et al. without results of this study

By comparing r_D measurements and percentage of persons highly disturbed by noise, a very high correlation could be found that is even higher when adding the results presented in this study ($r = 0.79^*$) than without ($r = 0.54^*$). The results are shown in Figure 14.

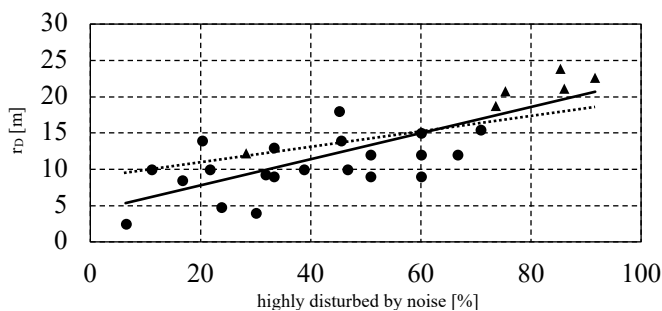


Figure 14. r_D measurements (mean values, Mueller et al. (triangles) and Haapakangas et al. (dots)) against %HD by noise ($r = 0.79$, $p < .01$). $R^2 = 0.63$. Dotted: original trend line by Haapakangas et al. without results of this study.

Comparing the results in relation to the results of Haapakangas et al., r_D still seems to be most reliable predictor of the employee satisfaction with acoustics in

open-plan offices, as already stated by Haapakangas et al. [10]. The correlation between %HD and $L_{p,A,S,4m}$ is similarly high, but the uncertainty is higher than with r_D . $D_{2,s}$ is still not able to predict employee satisfaction.

5. SUMMARY

Also in German open-plan offices, acoustics leads to the biggest dissatisfaction compared with other physical parameters. Measurements and surveys were conducted in eight offices and compared with results previously reported by Haapakangas et al. [10]. In summary, two of the acoustical parameters in ISO 3382-3:2012 are able to predict employee satisfaction well: r_D and $L_{p,A,S,4m}$. To keep percentage of employees highly disturbed by noise below 20%, the mean value of $L_{p,A,S,4m}$ should be kept below 47 dB and the mean value of r_D should be kept below 8 m. This was also suggested by Rindel based on the results by Haapakangas et al. [12]. These target values are in contrast to German occupational safety (according to ASR A3.7 [13] the level reduction requirement applies and therefore no sound masking should be used) and to the endeavour of architects to create the most aesthetic, open office space without high screen walls between the workplaces. Without these two measures, however, the target values required for employee satisfaction often cannot be met.

To determine the expected percentage of employees highly disturbed by noise in open-plan offices the Eqn.

$$\%HD_{\text{Noise},rD} = 1.8 * \frac{1}{n} \sum_{i=1}^n r_{D,i} + 42 \quad (1)$$

based on data in Figure 14 is recommended.

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