Practical aspects of measuring acoustics in German open plan offices

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Summary
Despite all research and scientific outcome, room acoustics are often not being considered in the planning phase of open plan offices. Due to an increasing number of noise abatement consulting requests, IFA is performing a project on room acoustics in open plan offices in Germany. In order to obtain an overview of the acoustic situation in these rooms, measurements are carried out by means of the measurement standard DIN EN ISO 3382-3. Ratings are performed according to the latest draft of the national standard VDI 2569, which defines three room acoustics classes A, B and C. VDI 2569 uses parameters determined by the measurement standard DIN EN ISO 3382-3 to allocate a room acoustics class. In the course of 2017, IFA carried out measurements in 13 open plan offices across different branches. The necessary parameters were collected with a commercial software and evaluated using a self-made software tool according to VDI 2569. Nearly none of the measured rooms reached any of the possible room acoustics classes. This article will also highlight the practical pitfalls and difficulties associated with planning and performing a measurement in accordance with both guidelines.

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1. Introduction

Classification of room acoustics in all kind of rooms is very important. People, who work all day in an insufficient acoustically designed room, are heavily stressed. 50% of German employees work in an office [1]. 41% of all offices are designed for three or more employees [1]. Considering this data, a classification of office rooms regarding their room acoustic properties is essential. Acoustical parameters to quantify an open plan office are given in the international standard DIN EN ISO 3382-3 [2]. A rating of an open plan office can be performed by the latest draft of the national supplement VDI 2569 [3]. This standard defines three room acoustics classes (short: *rac*) A, B and C in dependence of the determined parameters according to DIN EN ISO 3382-3 [2]. Though, planning and performing measurements in accordance to both standards is difficult, because of a variety of restrictions.

During the year 2017 IFA carried out measurements in 13 open plan offices. The results of the measurements will be presented alongside with the pitfalls and difficulties associated with planning and performing a measurement in accordance with both guidelines. To this end, a overview of both standards is necessary before. In addition, a discussion about the parameters used for rating the acoustic quality of open plan offices according to VDI 2569 [3] follows.

2. Standards

2.1. DIN EN ISO 3382-3

This is a brief overview of the measurement standard from 2012 [2]. It gives guidance in performing measurements in open plan offices. According to the standard there are the following single number quantities representing the acoustical quality of an open plan office [2]:

- STI in the nearest workstation;
- distraction distance, r_{D}, in m;
- privacy distance, r_{P}, in m;
- spatial decay rate of A-weighted sound pressure level of speech, $D_{2,\mathrm{S}}$, in dB;
- A-weighted sound pressure level of speech at 4 m, $L_{p,\mathrm{A,S,4m}}$, in dB;
- average A-weighted background noise, $L_{p,\mathrm{A,B}}$, in dB.

Table I. Examples of target values for evaluation of measurement data, Annex A [2].

Acoustic conditions	$D_{2,\mathrm{S}}$ [dB]	$L_{p,\mathrm{A,S,4m}}$ [dB]	r_D [m]
Poor	< 5	> 50	> 10
Good	≥ 7	≤ 48	≤ 5

Table II. Limit of single number qunatities assigned for grades of sound propagation (*gsp*) [3].

gsp	$D_{2,\mathrm{S}}$ [dB]	$L_{p,\mathrm{A,S,4m}}$ [dB]
1	≥ 8	≤ 47
2	≥ 6	≤ 49
3	≥ 4	≤ 51

These quantities can be determined by using different measurement techniques such as pink noise and MLS (*maximum length sequence*), accompanied by diverse conditions. The measurements according to this standard have to be performed in furnished rooms in the absence of the employees. Measurements have to be performed at least at four positions along a measurement line. Six to ten measurement positions are recommended. The measurement line has to cross over workstations within a range of 2 to 16 m and the first measurement position shall be located at the nearest workstation on the measurement line. Furthermore, each open plan office zone has to be considered for itself. The loudspeaker and microphone positions have to be located at workstations, minimum 2 m from reflecting surfaces, e. g. walls, and 50 cm from tables. DIN EN ISO 3382-3 [2] suggests at least 2 measurement lines. An evaluation of the measurement results is given exemplarily by Annex A of the standard (see Table I).

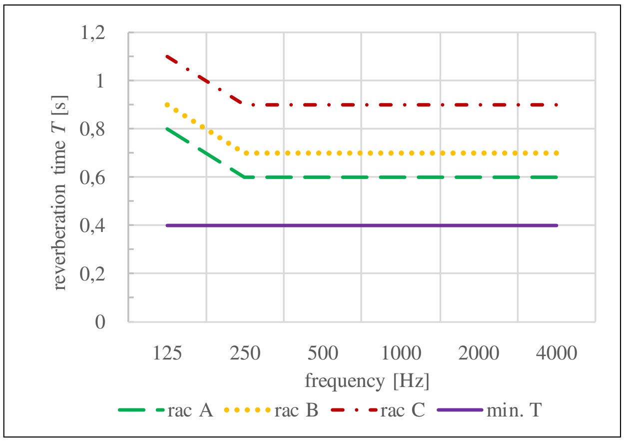

Figure 1. The reverberation time has to be inside the shown limits and above the minimum value of 0.4 s to reach one the room acoustics classes (*rac*) [3].

2.2. VDI 2569

The national supplement relating to the international standard DIN EN ISO 3382-3 [2] is VDI 2569 [3]. Currently available in the draft version of 2016, this guideline allows an evaluation of office spaces in terms of their acoustic quality. Measurements according to DIN EN ISO 3382-3 [2] are obligatory. The reverberation time has to be measured additionally [4]. To classify open plan offices, the following single number quantities are used [3]:

- reverberation time, T, in s;
- sound pressure level of in-situ noise, $L_{\mathrm{NA,Bau}}$, in dB ('Bau' for *bauseitig*, German for in-situ);
- A-weighted sound pressure level of speech at 4 m, $L_{p,\mathrm{A,S,4m}}$, in dB;
- spatial decay rate of A-weighted sound pressure level of speech, $D_{2,\mathrm{S}}$, in dB.

The first two single number quantities are global parameters, the last two are line dependent parameters. Further, more limitations regarding the measurement conditions are added. The number of independent measurement paths depends on the number of workstations. Measurements along at least three measurement paths have to be conducted. With increasing number of workstations more measurement paths have to be chosen, preferably divisible by three. The first measurement point along a measurement path has to lay in front of a sound screen. Changes in direction from measurement position to measurement position within a measurement path should not exceed 30 degrees. Architectural separations, like walls and stairwells, within a measurement path should be avoided. However, sound screens and acoustic separations, even if they are as high as the ceiling, are allowed along a measurement path. These are just some examples of the additional measurement conditions.

The acoustical evaluation of open plan offices is based on the single number quantities mentioned above. According to VDI 2569 [3] it is possible to achieve one of three room acoustics classes from A (first) to C (last). Further, it is possible not to reach any of these room acoustics classes. To classify a measurement path, a grade of sound propagation is assigned. According to the room acoustics classes, there are three grades of sound propagation 1 to 3 (short: *gsp*). The limits defined for the grades of sound propagation are summarized in Table II. To reach for example room acoustics class C, $^2/_3$ of the measurement paths have to reach the third grade of sound propagation and $^1/_3$ of the paths the second grade. Additionally the reverberation time has to lay inside specific limits shown in Figure 1. The conditions for reaching one of the room acoustics classes are summarized in Table III.

Table III. Conditions: room acoustics classes for open plan offices [3]. The reverberation time has to be checked additionally according to Figure 1.

Room acoustics class	Classification of measurement paths in gsp	Recommendation in dependence of utilization	$L_{\mathrm{NA,Bau}}$
A	2/3 in gsp 1 1/3 at least in gsp 2	Good for call center, communication-intensive use	≤ 35 dB
B	2/3 at least in gsp 2 1/3 at least in gsp 3	Good for distribution, construction, administration; suitable for call center	≤ 40 dB
C	1/3 at least in gsp 2 2/3 at least in gsp 3	Suitable for distribution, construction, administration	≤ 40 dB

3. Method

3.1. Planning of measurements

The difficulties in planning a measurement according to both guidelines are multiple. First of all nearly in none of the measured open plan offices the requested number of independent measurement paths according to VDI 2569 [3] were reached. Especially in the lateral direction of the offices it is challenging to find five workstations in a path: one workstation for the sound source and the following four for the minimum number of measurement points. Often the first measurement position is in the back of a workstation, because of a sound screen dividing opposing workstations. This is only possible if there is no cabinet in the back of a workstation. The most difficult restriction is to find microphone and loudspeaker positions which have at least a distance of 2 meters to reflecting surfaces. Most workstations at the measured open plan offices have cabinets and walls or glazing in immediate proximity. A measurement path that complies with both directives is almost unachievable. Moreover, most floor plans do not show the height of cabinets or any sound screens. In some cases the real room occupancy differs from the available floor plan. Despite these limitations, the selection of measurement lines can influence the results at same office conditions.

3.2. Performed measurements

The impulse response was measured with a MLS-signal in the offices (1) to (8) and the single number quantities were derived from that (see Table IV). The remaining offices were measured with pink noise and STIPA signal to determine the single number quantities required by DIN EN ISO 3382-3 [2]. The rating according to VDI 2569 [3] was performed with a self-made online software tool. $L_{\mathrm{NA,Bau}}$ as an architectural quantity was not available at any of the measured offices. The background noise $L_{p,\mathrm{A,B}}$ was measured with operating air conditioning systems in offices (3) to (5) (Table IV). The remaining measurements were carried out without the presence of air conditioning noise, either because there was no air conditioning or it was already switched off centrally. None of the measured offices are equipped with a masking system. The measurements were performed preferably at evening and night hours, since the working process could not be interrupted. Only office (8) - as a showcase office - was measured at daytime.

3.3. Evaluation and simulation

After all measurements were performed, an evaluation according to DIN EN ISO 3382-3 [2] was carried out. The single number quantities for the offices (9) to (13) had to be calculated by hand. The single number quantities for the remaining offices were calculated by the same commercial software which was already used for the measurements. With these measurement results and appropriate information about the acoustical components in the office, room acoustics simulations were started. First the real conditions were reproduced. After the measurement values of the various measurement paths were approximated with acceptable accuracy, different acoustic optimisations were tested in the simulation. The room acoustics simulation of the offices with the recommended optimisations serve as a verification for the consultation. All companies involved in this project received a detailed consultation report with the measurement results and improvement proposals.

4. Results

Measurement results with the relevant single number quantities and the evaluation according to VDI 2569 [3] are shown in Table IV and V. Four offices out of 13 reached a room acoustics class. Two reached room acoustics class B (offices (1) and (11)) and the offices (9) and (10) reached room acoustics class C. Although in all four cases the reverberation time fell below the recommended minimum in some of the evaluated octaves. The remaining nine offices, even though they do not reach any of the room acoustics classes, have acceptable reverberation times (except (4)). In most cases the values for the distraction distance are about or higher than 10 meters (specified

Table IV. Overview: measurement results of 13 German open plan offices with two or more measurement paths.

Office	Number of workstations	Room area [m^2]	$D_{2,\mathrm{S}}$ [dB]	$L_{p,\mathrm{A,S,4m}}$ [dB]	$r_\mathrm{D}/r_\mathrm{P}$ [m]	gsp
(1)	50	524	8.8	49.1	11.3 / 19.5	3
			7.3	48.0	12.8 / 24.6	2
			6.7	47.4	13.2 / 25.4	2
(2)	31	425	5.8	51.4	12.1 / 22.4	-
			5.2	52.0	15.6 / 29.5	-
			4.0	52.8	18.1 / 35.4	-
(3)	41	422	6.6	51.4	5.5 / 12.1	-
			4.5	53.7	7.9 / 16.8	-
			6.8	51.8	6.6 / 11.2	-
(4)	28	355	3.4	50.3	6.2 / 18.0	-
			3.6	51.4	6.3 / 16.4	-
			3.2	53.5	10.3 / 25.9	-
(5)	35	383	5.8	49.3	6.1 / 14.2	3
			6.8	49.8	3.2 / 12.5	3
			4.4	47.3	2.7 / 10.4	3
			6.4	49.9	2.4 / 12.3	3
(6)	17	253	7.2	52.8	11.7 / 21.3	-
			6.5	50.9	11.9 / 24.3	3
			5.4	51.5	15.2 / 30.3	-
(7)	13	144	6.3	49.9	10.4 / 18.6	3
			7.7	53.1	14.1 / 27.1	-
(8)	30	359	4.5	51.9	17.6 / 32.2	-
			4.3	50.9	14.5 / 28.6	3
(9)	20	202	8.4	49.7	14.2 / 24.4	3
			6.7	46.0	9.1 / 19.0	2
(10)	20	208	5.2	45.8	15.9 / 32.5	3
			6.3	43.7	14.6 / 29.6	2
(11)	32	312	5.4	46.2	12.7 / 22.8	3
			7.3	45.9	16.5 / 31.2	2
			6.3	43.5	17.1 / 34.6	2
(12)	18	185	4.8	53.5	15.6 / 29.4	-
			5.2	53.9	18.3 / 35.7	-
(13)	11	102	4.3	54.9	- / -	-
			3.0	54.3	14.4 / 29.7	-

as *poor* in [2], see Table I), except the offices (3) to (5). These offices had an air conditioning noise at about 42 to 46 dB(A) in average. The remaining offices had a background noise level < 40 dB(A).

A change in the number of measurement positions is able to change the grade of sound propagation. For example, the third measurement path in office (1) has $D_{2,\mathrm{S}} = 6.7$ dB. It was determined out of six measurement positions. With $L_{p,\mathrm{A,S,4m}} = 47.4$ dB it is rated to the second grade of sound propagation. Removing the last two measurement positions, which are located in direct view of the sound source, leads to $D_{2,\mathrm{S}}$ of 8.1 dB and the first grade of sound propagation ($L_{p,\mathrm{A,S,4m}} = 47.5$ dB). In this case it would not change the room acoustics class, but it shows the possibility of choosing an *intelligent* path.

In nearly every measured office there are less measurement paths possible than specified in [3]. The restrictions in both guidelines do not allow more paths. The offices (9) and (10) both with two measurement paths instead of the required five (or six) paths, have a grade of sound propagation of 2 in one path and a grade of sound propagation of 3 in the other. Because of room symmetry it is possible to use the same path several times. This decision can change the rating between room acoustics classes, in this case B and C.

5. Discussion

In most cases, the assignment of a grade of sound propagation to a certain path fails due to the values specified in VDI 2569 [3] for $L_{p,\mathrm{A,S,4m}}$. Apart from offices (4) and (13), all offices have $D_{2,\mathrm{S}} \geq 4\,\mathrm{dB}$ and therefore are acceptable for the third grade of sound propagation or better.

However, a rating according to $L_{p,\mathrm{A,S,4m}}$ and $D_{2,\mathrm{S}}$ alone is not expedient [5]. Since there is a lack on information about the intelligibility of speech, an STI-dependent parameter should be included. Particularly as the intelligibility of speech is a level-independent factor and is basically responsible for the decrease in performance of the employees in an office workplace [6]. As shown in [7][8], the STI is an effective predictor for disturbance by speech. Especially the quantity r_D can be used as a predictor for noise disturbance at an office workplace [5]. Since this STI-based variable strongly depends on the background noise level, the $L_{p,\mathrm{A,B}}$ should be taken into account, too. In as much as $D_{2,\mathrm{S}}$ is not correlated with the disturbance by speech [5], an inclusion of further parameters is important.

On the one hand the variable $L_{p,\mathrm{A,S,4m}}$ gives more information to the expert, on the other hand variables r_D and r_P are easier to comprehend for the consulted client. A rating using the single number quantities $D_{2,\mathrm{S}}$, $L_{p,\mathrm{A,S,4m}}$ *and* r_D in dependence on $L_{p,\mathrm{A,B}}$ could better estimate the acoustic quality and also extend the comprehensibility by non-acousticians.

Limits for all four parameters and their dependent room acoustic classes should be quantified by a big sample of various open plan office measurements. Furthermore, the size of the measurement uncertainty for the different parameters needs to be specified. In [5] some reference values for the uncertainties of $D_{2,\mathrm{S}}$, $L_{p,\mathrm{A,S,4m}}$, $L_{p,\mathrm{A,B}}$ and r_D can be found. The evaluation of the reverberation time can be useful for smaller office rooms, since reverberance is already a factor included in the sound pressure level of speech in four meters.

In summary, as the speech intelligibility is strongly connected to the cognitive performance, the rating of acoustic quality also should strongly depend on it.

6. Conclusions

This work shows the practical aspects of measuring open plan offices in accordance to both guidelines DIN EN ISO 3382-3 [2] and VDI 2569 [3] available in Germany. The restrictions and pitfalls in measuring, but also in evaluating and rating an office, are emphasized. When all requirements and boundary conditions of the two guidelines are followed, it is in most cases not possible to reach the required number of measurements paths, which prevents a meaningful rating of the offices. Evaluating offices with only the two single number quantities $D_{2,\mathrm{S}}$ and $L_{p,\mathrm{A,S,4m}}$ per measurement line and a global reverberation time should be reviewed. It is moreover proposed to add STI-based parameters to the rating, since these are known to assess speech intelligibility and therefore to represent the decrease in performance more reliably.

Acknowledgement

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Table V. Overview: Reverberation time and classification of measured open plan offices according to VDI 2569. «min» in column *Room acoustics class of reverberation time* stands for falling below the minimum value of 0.4 s in some of the octaves.

Office	Reverberation time T [s]						Room acoustics class	Room acoustics class
	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	of reverberation time	according to VDI 2569
(1)	0.60	0.51	0.30	0.26	0.26	0.25	A / min	B
(2)	0.83	0.59	0.39	0.39	0.43	0.45	B	none
(3)	0.66	0.70	0.59	0.53	0.52	0.43	C	none
(4)	0.99	0.96	0.85	0.75	0.68	0.58	none	none
(5)	0.45	0.42	0.41	0.48	0.58	0.50	A	none
(6)	0.61	0.42	0.35	0.37	0.41	0.40	A / min	none
(7)	0.52	0.37	0.32	0.32	0.34	0.35	A / min	none
(8)	0.69	0.45	0.36	0.34	0.37	0.36	A / min	none
(9)	0.39	0.35	0.31	0.28	0.34	0.39	min	C
(10)	0.37	0.38	0.31	0.31	0.42	0.45	A / min	C
(11)	0.35	0.34	0.33	0.33	0.56	0.59	A / min	B
(12)	0.80	0.65	0.46	0.44	0.50	0.57	B	none
(13)	0.72	0.53	0.41	0.33	0.37	0.42	A / min	none