DOI: 10.61782/fa.2023.0869

forum acusticum 2023

CONSIDERATION ON OPEN PLAN OFFICE ACOUSTICS ASSESSMENT – CLASSIFICATION BASED ON ACTIVITY AND OCCUPANTS' PERCEPTION

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ABSTRACT

In recent years, new standards and guidelines regarding the acoustics in open plan offices have been published. These standards and guidelines often consider the room acoustics conditions, but do not go into much detail concerning the perception of the office occupants. In addition, changes in the work situation due to the pandemic and the post-pandemic return to the office create a new acoustic scenario for employees in open plan offices, e. g. an increased number of video calls, flexible working hours and daily changing occupancy. These facts also lead to more shared desk offices. As a result, a clear and expedient consideration of acoustics and its classification based on the activity performed, is important to reduce mental stress in open plan offices.

Based on surveys and measurements in existing open plan offices and recent literature, the consideration of occupant perception for the reduction of mental stress is inevitable. However, the actions to improve the room acoustics and the overall situation need to consider the physical measurement data.

This work presents an approach for capturing the auditory mental stress in open plan offices.

Keywords: *noise, office, mental stress, perception, standard*

1. INTRODUCTION

The WHO constitution defines *health* as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" [1]. A main goal for all employers must be keeping their employees healthy. To fulfil this aim, the employer operating offices – and especially open plan offices – must obtain the knowledge on how to build and equip them. Therefore, numerous standards, recommendations and also national regulations are available. A main reported issue in Indoor Environmental Quality (IEQ) of open plan offices concerns the dissatisfaction with the acoustic design (sound privacy and noise level e.g. [2]). Moreover, in the post-pandemic situation a different working environment with a higher rate of desk sharing offices awaits the occupants. A study by the consulting company *Drees & Sommer* from July to October 2022 with 230 participants employed at twenty different organisations shows, that already 66% of respondents work in offices with desk sharing and another 9% of the respondents companies will introduce the concept in near future [3]. Even though, this design scheme inherits a higher sick leave rate [4]. Nevertheless, the post-pandemic situation in offices cannot be fully classified scientifically, as it continues to evolve - introducing even further aspects such as flexible and mobile working possibilities. A search in Web of Science (*All fields*: OFFICE and PANDEMIC and ACOUSTICS, and *Year published*: 2020-2023; search April 2023) shows only fifteen results for this topic. Even just four of them are dealing with acoustics in detail, although not always with office acoustics: [5–8]. Thus, an extensive description on office acoustics and occupants' perception in post-pandemic offices is needed. Though, the quantities and methods must be discussed.

2. QUANTITIES AND METHODS

Different standards, guidelines and regulations use a variety of quantities to describe the quality of open plan of-

fices. Additionally, classification schemes do not fully consider the occupants' perception, but are rather driven by an evaluation of room acoustic parameters. Moreover, different approaches demand for particular methods of assessment. In occupational safety and health a quick and easy-to-use method is needed for the description of the acoustic environment in offices.

The following parameters and methods can be considered when planning and designing open-plan offices:

- ISO 3382-3 single number quantities $D_{2,\mathrm{S}}$, $L_{p,\mathrm{A,S},4\,\mathrm{m}}$, r_{C} and r_{D} as a targeted method for the room acoustic characterisation [9],
- attenuation of speech $D_{\mathrm{A,S}}$ as described in ISO 22955 [10], considering especially Table 6 for activity-based office zones and its proposed revision in [11],
- STI and STI-matrix [12], as speech intelligibility is a main distractor in offices [13],
- reverberation time, as demanded by numerous standards, guidelines and regulations.

These parameters are not only applicable a priori, but are suitable for the description of acoustics in existing offices. Whether or not reverberation time is applicable in large open plan offices is beyond the scope of this paper.

The acoustic environment of existing offices can be expressed by the following parameters, which are highly dependent on the occupancy during the day of measurement:

- Sound pressure level at a certain workplace during a particular activity or time,
- *Percentile level differences* $L_{\mathrm{AF},10\%} - L_{\mathrm{AF},90\%}$ to describe the decrease in performance during working hours [14]; the higher the difference, the higher the annoyance and lower the performance,
- *Liveliness* [15, 16] classifies sound environments into four groups: *quiet*, *tranquil*, *lively* and *turbulent*; this method allows to quantify varying conditions during working hours for a given workplace and enables to communicate about it with non-acousticians,
- Further psycho-physical quantities, as for example fluctuation strength [17, 18].

These merely represent a selection of possible parameters and methods for the description of the acoustic situation in open plan offices. Nevertheless, only some parameters are connected with the occupants' perception, as for example r_{D} [19]. Most of the quantities consider different approaches for target values or are seen as descriptive parameter-sets. A main goal of all these approaches should be to provide workplaces based on the needs of the employees working in those offices.

An effective way of obtaining occupants' perceptions of working conditions is to use questionnaires. A questionnaire as measurement method points out whether there is an issue concerning acoustics or other IEQ-factors. ISO 22955 [10] for example provides a questionnaire with this aim in its annex D.

3. AN APPROACH

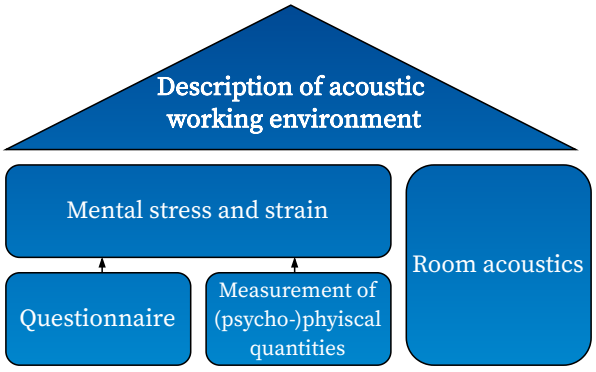

Figure 1. Model for the extensive description of the working environment in open plan offices.

To receive an extensive description of the acoustic working environment, different aspects should be considered. In the beginning, capturing the mental stress and strain is important, to describe the occupants' view on the working conditions. This includes two steps: a report about the perception, at best using a validated questionnaire. Additionally, an instrumental description using (psycho-)physical measurands (e.g. as mentioned in the second list in Section 2). A link or connection between those quantities and the perception could be set up. Based on those quantifications, a clear and higher-level view on the working conditions arises. However, any changes and modifications based on revealed problems should be quantified. Therefore, a room acoustics description of the office is necessary and inevitable. A summary of these steps is shown in Fig. 1.

Unfortunately, this approach is time-consuming and only suitable for research purposes. Companies with open

plan offices and no acoustic expertise could neither carry out such an extensive study, nor is it essential to have one in every office.

Rather, it is important to design the offices at the planning stage according to the needs of the activities to be carried out. A exemplary flow chart is provided by ISO 22955 [10, Annex B] to support this approach. Though, different aspects of ISO 22955 cannot be controlled directly by improvement measures, e.g. the workstation noise level $L_{\mathrm{Aeq},T}$. Further, the STI as parameter is not part of the design approach in this standard, even if it is an important measure for disturbance by speech.

The approach in existing offices should be kept more simple. Irrespective of complaints, a questionnaire - separate for each office space, but with a sufficient number of respondents - in the form of an assessment of the work environment could be helpful in finding out the occupants' point of view. Based on the responses, various further investigative steps can be initiated, so that an improvement can be achieved in an iterative process. This could be, for example, measuring the room acoustics in accordance with ISO 3382-3 and a redesign for different activity zones, or either a reorganisation based on the acoustic needs of organisational departments and units. In any case, in the opinion of the authors, room acoustics adapted to the activity performed is indispensable.

4. FIELD STUDY

Based on the approach presented in the previous section and summarised in Figure 1, the authors conducted investigations in four companies with a total of seven office spaces (starting in 2019, compare [20]). Due to a lack of feedback on the questionnaire in one company, only four offices from three companies could be consulted based on employee needs. With this low number of data points, it is still inappropriate to derive scientific knowledge from the questionnaire results of three companies in conjunction with the associated measurement of room acoustics and psycho-physical quantities.

Therefore, a descriptive overview of the ISO 3382-3 measurement results of four offices in three companies is given in Table 1. In addition, Table 2 displays the results of the ISO 22955 questionnaire, which was translated into German.

The office of company A is a multi-space office with acoustic ceiling sails, sound screens (height: 1.55 m) and enclosed offices for phone calls or concentrated work in the middle of the room. The office is operated on a desk sharing basis for an IT department of an insurance company. Company B - a fintech service provider - and its two offices are occupied by many different departments with various activities. The offices - each one for itself - are separated by screens and partitions (height: 1.2 m and 1.6 m) and are equipped with an acoustic ceiling. Company C, a large international enterprise, operates a private 24/7 call centre for emergency calls and was occupied by ten agents during the measurements. Therefore, it was not possible to exclude all the noise generated by the occupants and the background noise level is indicated as "$>$ 40 dB" in Table 1. Only a few partitions existed to divide the four different zones, which are equipped identically with an acoustic ceiling and mainly with group desks for three employees.

The ISO 3382-3 results represent different acoustic conditions in the different companies (Table 1). For example, the distance-based parameter pair r_{C} and r_{D} give a good indication for the description of room acoustic quality. Whereas r_{C} is about 6.7 m in office A, it is better in the offices in company B with about 4.0 m. Office C retains the worst comfort distance of these offices at around 9.2 m. The distraction distance is only comparable between A and B, as it is dependent on the background noise level. Thus, company B is again in a better position in this comparison with an r_{D} of about 8 to 8.6 m, while office A has values around 13 m at a comparable background noise level.

The occupants were asked to complete the questionnaire online, within three to four weeks of the measurements. The questions regarding the working environment are an important part of this survey. A five-point scale is used for this questions with ratings from 1 "*very unsatisfactory*" to 5 "*totally satisfactory*". To summarise the results, the ratings of 1 and 2 are cumulated to describe the percentage of unsatisfied respondents with a certain working environmental factor.

Taking into account the results of room acoustic measurements, the questionnaire does not show an obvious connection between those and the occupants' perception in the three companies. Overall, the control of the working environment is an important aspect. The *options for controlling noise* and the *possibility of controlling the temperature* are listed in the Top 3 of each company. The call centre staff (company C) have a need to personalise their workstations (94.1% unsatisfied), whereas this is a secondary issue in the shared desk office (A, 48.8% unsatisfied). The *possibility of holding private conversations* as well as the *noise environment* are complained about by

Table 1. Results of ISO 3382-3 measurements in four offices. Indication of spatial decay rate of speech $D_{2,\mathrm{S}}$, speech level at 4 m distance $L_{p,\mathrm{A,S,4\,m}}$, comfort distance r_{C}, distraction distance r_{D} and A-weighted background noise level $L_{p,\mathrm{A,B}}$. [a]Ten call centre agents were present during the measurements. Therefore, the $L_{p,\mathrm{A,B}}$ and r_{D} are not reliable.

Office	**A**	**B.1**	**B.2**	**C**
Number of measurement paths	2	3	3	4
Number of workstations	30	30	39	60
Area [m^2]	359	333	544	450
$D_{2,\mathrm{S}}$ [dB]	4.9 ± 0.9	7.0 ± 0.2	7.4 ± 0.1	5.1 ± 0.6
$L_{p,\mathrm{A,S,4\,m}}$ [dB]	48.8 ± 1.3	45.1 ± 0.4	44.3 ± 0.5	51.0 ± 1.3
r_{C} [m]	6.7 ± 0.6	4.0 ± 0.1	3.7 ± 0.2	9.2 ± 1.0
r_{D} [m]	12.8 ± 1.0	8.0 ± 0.5	8.6 ± 0.6	*7.6 ± 4.5*[a]
$L_{p,\mathrm{A,B}}$ [dB]	30.0	31.2 ± 1.0	30.0 ± 0.3	> 40[a]

employees of companies A and B (see Table 2).

The room acoustic measurement took place during a night, as the offices are usually unoccupied at this time. The psycho-physical measurands (second list in section 2) were only collected during a single day's measurement. Therefore, their indication could be misleading. These types of results only represent a specific tendency for the day measured. Influencing factors, such as e. g. occupancy rates, can have a huge impact on these measurements, so only a long-term measurement can provide evidence. Such measurements are time-consuming and should be planned precisely for future studies. For example, an overview of various quantities with a high number of measurements is presented in [21].

5. DISCUSSION

Numerous standards, guidelines and regulations with different approaches and various quantities are available for the design and classification of open plan offices. None of them follows a holistic approach or is suitable for every office. Therefore, an iterative approach is needed to improve existing offices and reduce mental stress emerged by the acoustical working environment. A questionnaire to capture the working environment and to highlight existing issues is an adequate first step. Based on the responses, the next steps could be planned individually. An instrumental assessment of the acoustic situation is inevitable to perform improvement measures.

Still, a fast and easy-to-use method is missing for the description of the acoustic working environment in open plan offices, for the reason of a complex and multi-dimensional optimisation problem. Moreover, the evolving post-pandemic situation and the increased use of desk sharing concepts leads to further working situations, that have not yet been considered and that need to be looked at more closely. Existing assessment regulations and guidelines are classifying open plan offices for diverse usage scenarios. Though, field investigations are missing to prove the concept, as for example for the German guideline VDI 2569 [22]. Further research is needed to improve the overall working situation in open plan offices, especially in consideration of occupants' perception, health, comfort and well-being.

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Table 2. ISO 22955 questionnaire results for the working environment (GABO Questionnaire, Annex D [10]). Indication of percentage unsatisfied respondents (ratings 1 and 2 on a five-point scale, where 1 means "*very unsatisfactory*" and 5 means "*totally satisfactory*") with the mentioned working environment. Representation of the three highest values in one company by bold print (Top 3). Second part of the table shows general information: total number of participants answered the questionnaire; n as number of participants answers usable in the evaluation; response rate based on the relation between n and the total number of workstations (see Table 1).

Company	A	B	C
Noise Environment	**68.8%**	**62.5%**	38.9%
Possibility of concentrating in your workplace	50.0%	41.7%	55.6%
Lighting quality	6.3%	20.8%	27.8%
The physical position of your workstation	12.5%	4.2%	29.4%
Possibility of holding private conversations	**81.3%**	**62.5%**	66.7%
Your options for controlling noise	**75.0%**	**79.2%**	**77.8%**
Furniture at your workstation	12.5%	12.5%	35.3%
Possibility of seeing outside	18.8%	16.7%	11.8%
Cleanliness of your workstation	6.3%	12.5%	35.3%
Equipment available at your workstation	6.3%	20.8%	23.5%
Possibility of controlling the temperature	**68.8%**	**62.5%**	**83.3%**
Air flow at your workstation	25.0%	**62.5%**	44.4%
Possibility of personalising your workstation	43.8%	16.7%	**94.1%**
Possibility of working out of the view of others	50.0%	58.3%	72.2%
Total number of participants	19	26	22
Included in evaluation n	16	24	18
Response rate (n /number of workstations)	53%	35%	30%

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