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AN EXPERIMENTAL, NUMERICAL AND SUBJECTIVE APPROACH FOR OPEN PLAN OFFICE ACOUSTICS

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ABSTRACT

The concerns related to the acoustical conditions in open plan offices have been raising for several years. The ISO 3382-3 standard for the measurement of acoustical parameters in open plan offices establishes a procedure for the experimental evaluation of these spaces. However, the difficulties in its application in specific office setups and particularities of different types of teams and work environments implies a broader approach using the opinions of the users to validate or dismiss some conclusions based on the measurements or numerical simulations alone.

This paper describes the methodology and results obtained while studying the acoustical environment in 4 open plan offices. Numerical simulations of the existing situation were calibrated with the results of measurements using the ISO 3382-3 standard, on which several solutions were implemented to achieve the minimum quality in acoustical criteria, namely $D_{2,S}$, $L_{p,A,S,4m}$ and r_D. Simultaneously, a questionnaire to all users was made to help understand the specific problems and adjust the solutions to solve them. The results show that if a survey were not implemented the design of countermeasures based on measurements and numerical simulations alone would have been partially ineffective.

1. INTRODUCTION

The perception of the quality of the physical office environment depends on ambient features in workplace, such as temperature, noise, air quality and light [1][2][3]. The physical environment of an office is determinant to promote a healthy working environment [3]. As office employees spend a significant proportion of their time at work, the physical environment has a significant effect in their well-being but also in their behavior, perception, working performance and productivity [3][4].

The current trend of the increase in the number of open-plan offices in favor of enclosed private workstations [5][6], where acoustics, privacy and other proxemics issues outperform [7] [8], leads towards the importance of acoustic office design. Several studies identified noise and lack of privacy as the key sources of dissatisfaction in open-plan office layouts, acting as ambient stressors in the work environment [1][9].

Although open-plan office layout facilitates communication and interaction between co-workers, which support teamwork effectiveness, it does not mean that it improves individual work efficiency and organizational productivity [7]. In fact, research points out the irrelevant speech as the most annoying element on open plan office context [7], that is "the perception of the speech distracting for the single worker compared to activity that he is carrying out, especially based on their own semantic content" [5]. Office noise events affect typical office tasks, like typing or reading, which have a negative effect on productivity's workers [10]. However, in the case of speech and conversation, noise annoyance is not related with the level of speech, but with the speech intelligibility, which decreases working memory and receptive reading. In addition, ringing telephone affects the cognitive performance [10].

The range of activities that are required in an open-plan office, such as communication between team members but also concentrated work, sets the need of thinking about the acoustic office design and find solutions that ensure a suitable acoustic environment.

In this research, 4 open-plan offices located in Maia, Portugal, were studied with the purpose of minimizing the discomfort reported by its users, by means of questionnaire surveys, numerical simulations and acoustic measurements.

Concerning offices, Portuguese building acoustic regulations only states a target value for the Reverberation Time RT ($V \geq 100$ m^3) [11]. Despite of this parameter still the most used for study of room acoustic, scientific literature shows that this parameter is not enough to evaluate the acoustics conditions in open-plan office [12] [10] [6]. Thus, acoustics measurements were based on standards EN ISO 3382-3, which establishes other parameters for the evaluation of acoustical quality of open-plan offices [13].

The aim of this research is to provide insights in acoustic office design taking into account the workers' opinion and considering that there is no standard formula for acoustic office design.

2. CHARACTERIZATION / CASE STUDY SITES

Four open-plan offices were investigated. These spaces included multiple teams, as described:

- Office A → Shared Service Center Team (55 workers) and Information Technology Team (44 workers), 480 m^2;
- Office B → Logistics, Chemical and Quality Team (29 workers), the Purchase Team (7 workers) and

other Information Technology Team (24 workers), 291 m^2;

- Office C → The Marketing and Product Development Team (19 workers) and the Sales Team (23 workers), 252 m^2;

- Office D → The Human Resources Team (8 workers), the Audit Team and the Credit Management team (10 workers) and the Finance Team (16 workers), 219 m^2.

The four open-plan offices are located in the same building and linked by a central corridor without doors. The building is located on a business development area, protected of outside noise.

The case study sites have the same interior materials: the ceiling has no acoustic treatment, the walls are masonry and the floor has carpets in all extension. None of the case study office has dividing panels between the collaborators or teams.

Based on our observation of the sites and considering the history of complains and the managers' feedback, a list of main sources was identified, namely: colleagues of the same team chatting, colleagues of other teams chatting, phone calls, movements of people, toilets, kitchen, phone ringing, typing, office equipment, fan noise/ventilation systems and outside noise.

3. METHODOLOGY

3.1 Research approach

The current study is based on a subjective assessment related to the workers' opinion, along with and an objective analysis covering numerical simulations and acoustics measurements.

3.2 Acoustics Measurements

Acoustics measurements were based on standard EN ISO 3382-3, 2012 [13].

The first step was to determine the measurement paths for each office analyzed. The measurements must be carried out along a line which cross over workstations and where each of workstation comprise a point of measurement, minimum 4 points [13]. This procedure resulted in 3 paths of measurement for office A, 2 for office B and 4 for office C and D, represented on **Figure 1**. Due configuration of office D, the number of points of measurement for each path was 3.

Distraction distance (r_D), spatial decay rate of speech (D_{2S}) and A-weighted sound pressure level of speech ($L_{p,A,S}$) were evaluated.

Measurements were made after the office hours.

Figure 1. Open-plan office layout.

3.3 Questionnaire survey

3.3.1 Sample characteristics

A questionnaire was distributed in order to gather data about the office occupants' opinion regarding their office environment.

The questionnaire was self-administered to office employees who occupied the 4 open-plan offices through an email link. The link remained active for 7 days, between the 14th and 20th of November 2019. In total 235 people received the online questionnaire. The return was 83% (194 responses). Confidentiality was assured.

Most of respondents were between the ages of 41 and 50 (41,8%), followed by 31-40 (21,6%), under 30 (19,6%) and above 50 (17%). 52,6% were female and 47,4% male. The office employees completed a five-part questionnaire themselves.

The first part of the questionnaire was regarding to demographic variables such as age, gender and workplace position.

Part 2 covered satisfaction assessment with office aspects like temperature, lighting, ventilation, privacy, acoustics, and office layout, using a five-star scale.

In parts 3 and 4, respondents answered through/thru a 5-point linear scale ranging from 1 (not at all) to 5 (extremely). Part 3 comprised questions about sound environment assessment and part 4 was regarding the level of annoyance caused by sound sources previously identified.

The last part contained questions about effects on office productivity and wellbeing.

The survey took about 6 minutes on average to be filled. The information collected was used as basis for discussion about build solutions, along with acoustic measurements and numerical simulations.

3.4 Numerical simulation

Room acoustics analysis of open spaces has been carried out through ray-tracing software, CATT-Acoustic v9/TUCT2. The model was developed considering a simplified geometric approximation of the real space under analysis, maintaining the lines and general volume.

Numerical models were calibrated according to the measurement results, in order to perform the correlation between the results of the possible room acoustic treatment scenarios and their effect after implementation. Calibration was performed respecting the global acoustic trend of offices' parameters, namely sound pressure level and speech intelligibility.

Figure 2 shows models concerning each office analyzed.

In total, 29 room acoustic treatment scenarios were simulated to find the minor and less expensive intervention according to the workers' complaint.

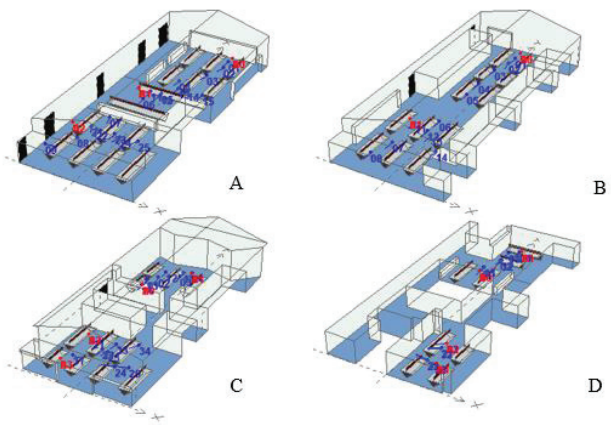

Figure 2. Perspective view of the numerical models used.

4. RESULTS

The measured distraction distance, r_D, A-weighted sound pressure level of speech, $L_{p,A,S}$, and Spatial decay rate of speech, $D_{2,S}$, are shown in following figures.

The results obtained for the 3 parameters fall outside of the intended range according to ISO 3382-3 Standard.

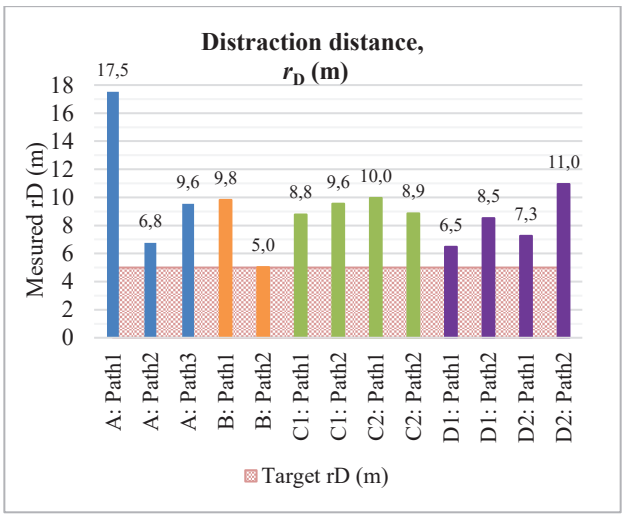

Figure 3. Results of distraction distance measurements.

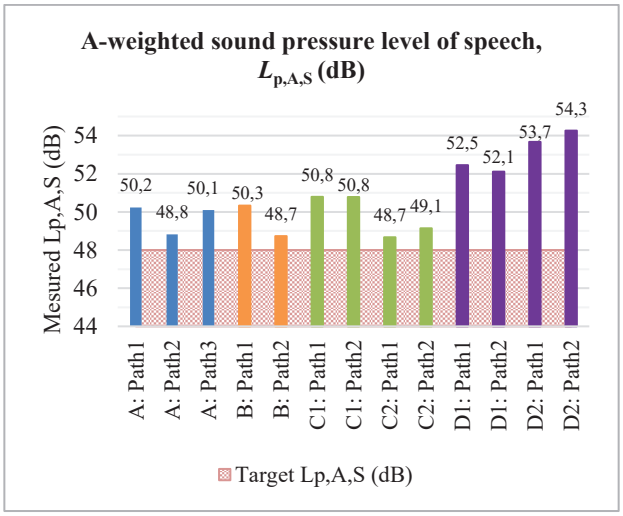

Figure 4. Results of A-weighted sound pressure level of speech measurements.

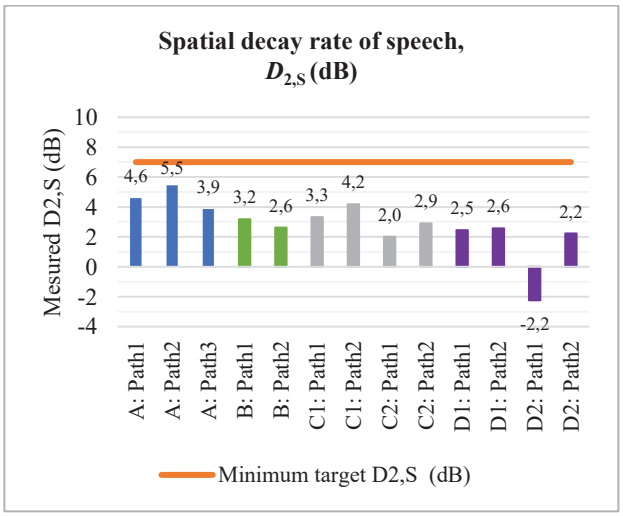

Figure 5. Results of spatial decay rate of speech measurements.

In **Figure 6** the perception of interviewees on their general working environment is shown where a five-stars scale is used. Privacy and acoustics were pointed out as the less satisfied factor about office, suggesting that the workers are generally not satisfied with the office acoustic environment.

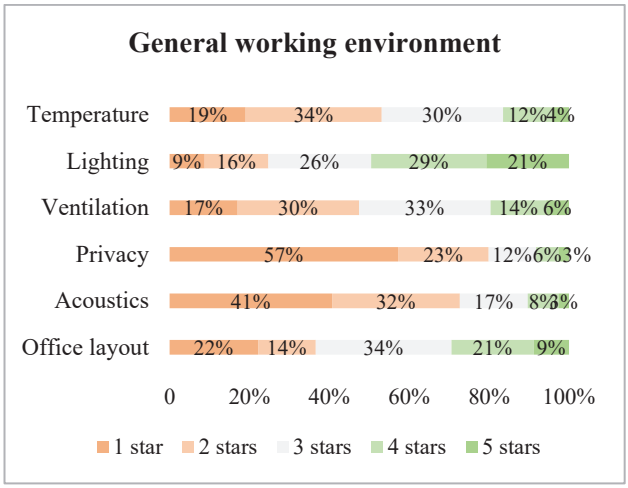

Figure 6. Evaluation of the general working environment.

Figure 7 and **Figure 8** depicts the perception of sound level inside office and noise annoyance level due acoustic office environment, respectively.

It can be seen that the acoustic environment of Office A is pointed out as the noisiest and the more annoying, fact that is coincident with the bad results obtained on acoustics measurements regarding to distraction distance.

On the other hand, the results of $L_{p,A,S}$ and D_{2S} measurements obtained in Office D are the further away from the target values, despites the relative satisfactory evaluation of workers of Office D regarding sound office level and noise annoyance. This can be explained by the number of workers that work on the same space: 34 employees in an area of 219 m^2 (Office D) *vs* 60 workers in an area of 291m^2 (Office B).

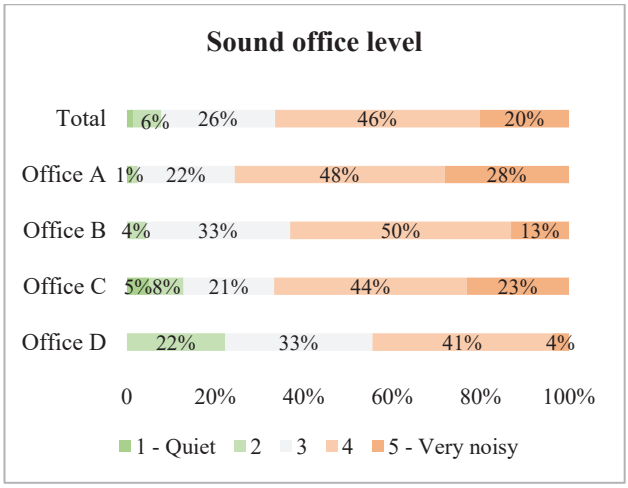

Figure 7. Perception of sound level inside the office.

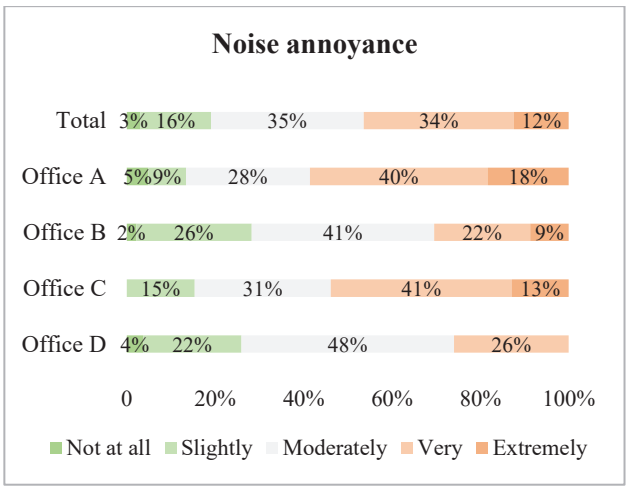

Figure 8. Noise annoyance degree due acoustic office environment.

Figure 9 is about the evaluation of understanding conversations over distances of more than 5 meters. It is interesting to note that the results of Office C are the highest, where 57% of the employees understand these conversations very or extremely, although the results of $L_{p,A,S}$ measurements in this office were the closest to the target value (according ISO 3382-3 Standard).

The analyses of **Figure 10** demonstrate that the Office C is where more workers talk on the phone when they are working which explain the mentioned results.

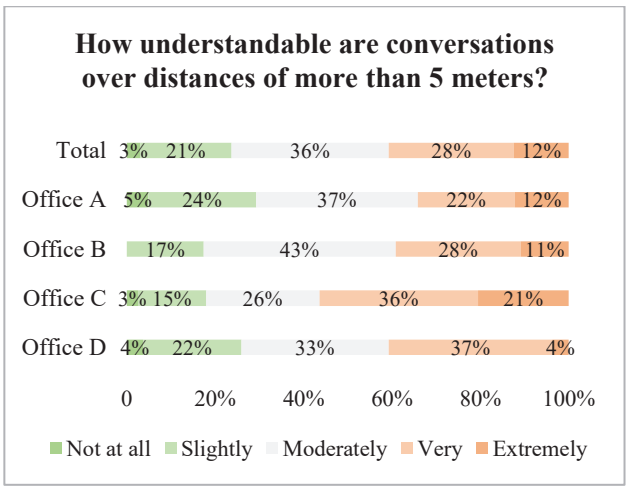

Figure 9. Evaluation of understanding conversations over distances of more than 5 meters.

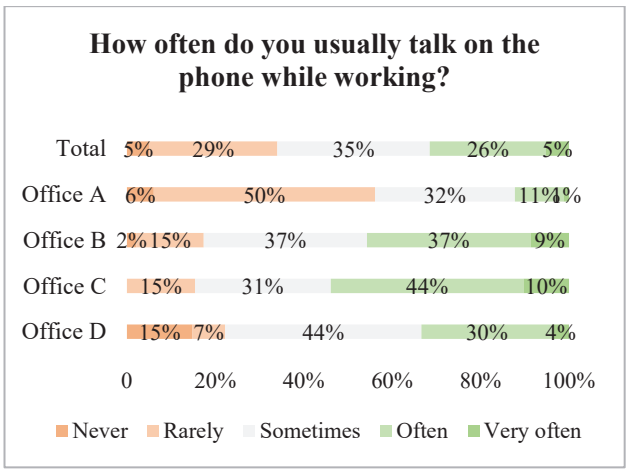

Figure 10. Frequency of talking on the phone while working.

5. CONCLUSIONS

Based on questionnaire survey, acoustic measurements and numerical simulation of four typical open-plan offices, it has been highlighted the importance of context data obtained, either in a subjective or objective analysis, and the needed of take a holistic view of the situation in acoustic office design

In conclusion, it is the author's opinion that an objective evaluation should be complemented with questionnaires to the workers to analyze if their opinions agree with the measurement results. Consequently, this provides further knowledge into the type of complaints that can help improve the acoustical measure decision process.

6. FUTURE RESEARCH

A future study could describe the acoustic office design implemented and analyze the impact of these build solutions on workers satisfaction thru an equivalent questionnaire survey. This study could also compare the results obtained before and after construction works, concerning the workers opinion and acoustic measurements.

It would be interesting to detail the room acoustic treatment scenarios considered and how the information collected was used as basis for discussion about build solutions.

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