Technical Note

Study of the Acoustic Suitability of an Open Plan Office Based on STI and DL\textsuperscript{2} Simulations

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Many business offices around the world are organized as open plan offices. Therefore, studies about the acoustic comfort of the people who work in them have become increasingly important. The focus of this work is the acoustic evaluation of an open plan office combining several architectural characteristics and levels of ambient noise. This evaluation was performed through a computational model calibrated from a real office. The rate of spatial decay of sound pressure levels per distance doubling (DL\textsuperscript{2}) and the speech transmission index (STI) were simulated for the acoustic evaluation of the office, allowing for the determination of the radius of distraction (rD). These parameters were simulated for 6 situations using different floor and ceiling covering materials and inserting or withdrawing screens between workstations. In addition, STI and rD were simulated under two conditions of ambient noise. The results indicated that the DL\textsuperscript{2} and rD are adequate acoustic parameters for the acoustic evaluation and improvement of an open plan office. The DL\textsuperscript{2} was strongly influenced by the presence or absence of screens between workstations and by the ceiling covering material. The rD was more sensitive to changes in ambient noise.

Keywords: open plan offices, acoustic evaluation, acoustic improvement.

1. Introduction

The open plan office design, or “bürolandschaft”, was created by the Schnelle brothers in Germany in about 1955 (DUFFY, 1980). This type of office was based on some fundamentals which relate the principles of design to those of organization.

In the 1970s and early 1980s, occupants of open plan offices reported the lack of privacy and the distraction caused by the noise produced by coworkers (PEJTERSEN et al., 2006). Even when objective measurements demonstrated that the background noise of conversations in the room was not excessively high (approximately 50 dB), this noise distracted the workers (VAN DER VOORDT, 2004).

HONGISTO et al. (2007) stated that it is not the sound level of speech but its intelligibility that determines its distraction effect. Speech is the sound source that causes the highest distraction, since it occurs unpredictably, its intensity is variable and it has the highest possibility of information content among the sounds that occur in the office. In a study performed by KJELLBERG et al. (1996), the degree of distraction of workers proved to be more closely related to sound events, noise control capacity and noise predictability than to the actual noise levels.

According to EGAN (1988), speech privacy is influenced by three factors: source, environment and receiver. With regard to workspaces, the acoustic environment of open plan offices can be incremented technically by three main factors: 1) the room’s absorption, which reduce reverberation and early reflections; 2) barriers, which control direct sound; and 3) artificial masking of the sound, which provides a uniform sound environment and reduces the distraction caused by adjacent workstations (HONGISTO et al., 2004).

Speech privacy and the distraction caused by the speech of coworkers can be described by the speech intelligibility between workstations. ASSÉLIEAU (2007) argues that speech intelligibility should be good locally in order to promote conversation among members of the same group. However, as the distance from the speaker increases, speech intelligibility should become poorer.

Speech intelligibility can be attained through objective and subjective methods (BRACHMANSKI, 2007;
2. Material and methods

The acoustic parameters STI and DL\textsubscript{2} were obtained from a calibrated computational model of a real office. The computational model was calibrated by a comparison between the RT data measured \textit{in situ} and the data produced by the computational simulation of the office in real conditions. According to Golas and Suder–Debska (2009), an important question, when computational simulations are employed, is whether the computational model does reflect the current state of the studied room. After the model was calibrated, changes were made in the architectural characteristics and ambient noise in order to verify the behavior of the acoustic parameters STI and DL\textsubscript{2} in response to the changes.

2.1. Object of study

The object of study here was an open plan office in a large multinational company (Figs. 1, 2):

![Fig. 1. Internal view of the office under study.](image)
The main architectural features of this office are described in Table 1.

Table 1. Main architectural characteristics of the office under study.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Area [m²]</td>
<td>613.03</td>
</tr>
<tr>
<td>Volume [m³]</td>
<td>1716.48</td>
</tr>
<tr>
<td>No. of workstations</td>
<td>147</td>
</tr>
<tr>
<td>Area/workstation [m² workstation]</td>
<td>4.17</td>
</tr>
<tr>
<td>Ceiling height [m]</td>
<td>2.80</td>
</tr>
<tr>
<td>Ceiling material</td>
<td>0.49</td>
</tr>
<tr>
<td>Flooring material [(1)]</td>
<td>85%[(2)]  0.18</td>
</tr>
<tr>
<td>(+) 15% [(2)]</td>
<td>0.01</td>
</tr>
</tbody>
</table>

(1) Mean $\alpha$ between the octave bands from 125 to 4000 Hz.

(2) Percentage of total floor area covered with material with $\alpha = 0.18$ or $\alpha = 0.01$.

As can be seen in Fig. 1, the office in question did not have dividing panels between the workstations. The ceiling was finished in mineral wool board and the floor was covered with carpeting in the desk area (85% of the total area) and by ceramic tiles in the corridors (15% of the total area). The desks were made of particle board covered with high pressure laminate.

2.2. Computer simulations

The computer simulation was performed using the ODEON Version 9.0 software package. This software uses the hybrid method, which calculates the early reflections using a combination of the image source method and ray tracing, while the late reflections are calculated by a special ray tracing process that generates diffuse secondary sources. This simulation requires a three-dimensional model of the room.

To ensure the reliability of the simulation, it was very important to use suitable calculation parameters. Most of the calculation parameters were defined by the Odeon 9.0 software itself, leaving the choice of the essential parameters such as the surface materials ($\alpha$), surface scattering coefficients ($\delta$), definitions of the source and receiver (location and characteristics), among others.

The scattering simulation method is a calculation procedure that must be defined by the user of the program. Odeon 9.0 offers three options: 1) Lambert, 2) without scattering, and 3) total scattering. If the scattering method chosen is the Lambert method, all the directions of the early reflections will be calculated using the scattering coefficients indicated for the surfaces on the list of materials. If the method is defined as without scattering, scattering is not considered, so all the reflections will be calculated as specular. Lastly, if the total scattering method is selected, 100% of the scattering will be applied to all the surfaces, but this method is not recommended (Christensen, 2003). For Rindel (2000), the attribution of surface scattering coefficients in computer simulations has proved to be essential in obtaining reliable results. Thus, Lambert’s scattering method was chosen for all the simulations in this study.

2.2.1. Simulations with interventions

For the STI simulations with architectural and ambient noise modifications, the source was located in one position, the workstation of a speaker, and the receivers in a 0.50 m $\times$ 0.50 m grid. After the simulation, the radius of distraction ($r_D$) was calculated from the grid. This parameter was chosen because, unlike the STI, it generates a single value which is independent of the position of the receiver in the room. However, in addition to the discussion about the $r_D$, the grid of the STI was also analyzed, since it provides important data about the behavior of sound inside the room.

The Odeon 9.0 software calculates the $DL_2$ for each frequency band from 63 Hz to 8 kHz, and the $DL_2, Co$, which is the A-weighted rate of spatial decay for the frequency bands 125 Hz to 4 kHz. The data generated in this study were analyzed using only the $DL_2, Co$ because it presents the results of noise reduction per distance by means of a single number. In this simulation, the source and receivers were positioned at a height of 1.20 m, which is equivalent to the average height of a sitting person. The ISO 14257 standard (2001) determines that there should be a minimum distance of 1.5 m between the receivers and vertical objects or surfaces. On the other hand, for the source, this distance should be 3.00 m. These parameters of the standard were observed in the simulations. The variation of distance between the source and receivers may follow a constant or logarithmic increment. In addition, the standard recommends that the receivers be located in
the middle region, i.e., at a distance of 5 to 16 m from the source. Therefore, 12 receiver points were used, Fig. 3, at distances of 5 to 16 m from the source, with a constant distance increment of 1 m.

![Fig. 3. Simulation of the DL2 using Odeon 9.0 software. P1 represents the sound source and points 1 to 12 indicate the receivers.](image)

The source utilized in the simulation of the DL2 was of the omnidirectional pointwise type (International Organization for Standardization, 2001). The STI was simulated using a source with directivity resembling that of the human mouth (International Electrotechnical Commission, 2003). The frequency spectrum and the sound power are predetermined by the manufacturer, according to the specifications of the ISO 14257 (2001) and IEC 60268-16 (2003) standards.

The architectural modifications employed in the simulations of the office involved the materials covering ceiling and floor surfaces and the presence or absence of office partitions. Modifications in ambient noise were also made, albeit only for the STI simulations. Six simulations of the DL2 and twelve simulations of the STI were made since in each physical condition of the environment the STI was simulated at two levels of ambient noise. These noise levels are equivalent to the average sound pressure levels found in real offices. Table 2, below, describes the modifications made to the office in the six simulated situations. In Table 2, \( \alpha \) represents the mean value of the absorption coefficient between the one-third octave bands from 125 to 4000 Hz.

In the six physical situations of the environment, the STI was simulated with two levels of background noise, 64.1 dB(A) and 55.4 dB(A). These combinations of materials, situations of partitions and sound pressure level are commonly found in real offices.

3. Results and discussion

The combination of the constructive elements of ceiling and floor materials and presence/absence of partitions resulted in six simulated situations, which are referred to as A, B, C, D, E, and F. For each of these situations two sound pressure levels (SPL) were inserted, 64.1 and 55.4 dB(A), for the STI simulation, from which the rD was obtained, resulting in twelve values of rD. Table 2 describes the simulated situations, while Table 3 lists the values obtained for the rD and DL2. In Table 3, the first line of rD values indicates the results obtained in the simulations with 64.1 dB(A) of SPL and the second line presents the values obtained in the simulations with 55.4 dB(A) of SPL.

<table>
<thead>
<tr>
<th>Acoustic parameter</th>
<th>Situations</th>
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<tr>
<td>rD (m)</td>
<td>A B C D E F</td>
</tr>
<tr>
<td>DL2, Co</td>
<td>3.11 3.18 2.29 4.40 4.33 2.83</td>
</tr>
</tbody>
</table>

The values of rD listed in Table 3 indicate that when the ambient noise is high, 64.1 dB(A), the ceiling and floor covering material do not interfere in the speech intelligibility. Moreover, at these noise levels, the insertion of partitions caused no interference of the rD value. When the ambient noise was reduced to 55.4 dB(A), there was a significant increase in speech intelligibility, increasing the values of rD. At this noise level in the simulations without partitions, i.e. situations A, B and C, the floor and ceiling covering material did not interfere in the values of rD, which remained unchanged at 2.50 m in the three situations. Inserting partitions in situation D caused the rD to remain the same as in the situations without partitions. However, there was a significant difference with regard to the workstations with higher intelligibility in situations A and D, as can be seen in Figs. 4 and 5. In Fig. 4, situation A, note that the workstations most affected by the speaker’s speech are in front of him, while in Fig. 5, situation D, the highest intelligibility in the workstations is behind and to the sides of the speaker.
In situations E and F, with a background noise of 55.4 dB(A), there was a reduction of the rD in relation to the values found for the room in the situations without partitions and in situation D. This reduction can be explained by the decrease in intelligibility due to the reduction in sound absorption when compared with situation D, and dulling of the speaker’s voice by the partitions when compared with situations A, B and C.

According to Hongisto et al. (2007), for an office to be considered acoustically excellent, the values of rD should be lower than 5 m. Therefore, according to this classification, the office can be classified as acoustically excellent in all the simulated situations.

With regards to the $\text{DL}_{2}$, as Table 3 indicates, this parameter is strongly influenced by the floor and ceiling finishing materials and the insertion/removal of partitions between workstations. The highest $\text{DL}_{2}$ was found in situation D, i.e., with acoustic materials covering both floor and ceiling, as well as the presence of partitions between workstations. The lowest $\text{DL}_{2}$ was found in the opposite situation, C, with reflective material covering the floor and ceiling and without partitions between workstations. Based on these data, it can be stated that to achieve a high sound reduction with distance, the office environment should have considerable sound absorption and partitions between workstations.

If the simulated values of $\text{DL}_{2}$ were compared to the values specified by the French standard, NF S31-080 (Ondet, Suer, 1995), the office in situations D and E would be suitable for activities requiring high performance from the workers. The office in situations D and E is characterized by the presence of partitions between workstations and considerable acoustic absorption in the ceiling and floor (situation D) or only the floor (situation E). When the partitions are removed from the model in situations A and B while maintaining the same ceiling and floor materials as in situations D and E, the office can be considered suitable for activities requiring efficient performance, according to the French standard. On the other hand, in situations C and F, which are characterized by the absence of acoustic material on both ceiling and floor, the office is considered adequate only for activities requiring standard performance, regardless of whether it has partitions (situation F) or not (situation C).

4. Conclusions

Based on the simulated data, the rD and $\text{DL}_{2}$ proved to be suitable parameters for the acoustic evaluation of open plan offices in the various simulated situations of acoustic conditioning and ambient noise. Moreover, the calibrated computational model proved to be an excellent tool for studying the acoustic conditioning of an open plan office. This finding was also reported in studies carried out by Zannin et al. (2009).

The advantage of the rD over the STI lies in the fact that it characterizes the speech intelligibility in an office by means of a single number. However, the rD does not allow one to observe the workstations most affected by a speaker’s speech, as can be seen from the STI maps in Figs. 4 and 5. Therefore, the spatial organization of work groups in an open plan office requires an analysis of STI maps, ensuring not only that the space is organized to provide reasonable intelligibility among group members but also speech privacy between work groups.
An analysis of the values of rD indicates that this parameter is strongly dependent on the environment’s sound pressure level. When the noise in the room is high, at a value close to 65 dB(A), the rD values are low. At this SPL, the change in floor and ceiling finishing materials and the insertion/removal of partitions did not affect the values of rD, since the radius of distraction is very small. Reducing the value of the SPL to approximately 55 dB(A) led to a significant increase in speech intelligibility and therefore an increased rD.

The DL\textsubscript{2} parameter was strongly influenced by the presence/absence of partitions. In the situations with partitions, the simulated DL\textsubscript{2} values were higher than those simulated in the other situations. Moreover, the DL\textsubscript{2} decreased considerably when the acoustic material on the ceiling and floor was removed, both in the situation with partitions (situation F) and in that without partitions (situation C). These results are similar to those obtained from acoustic measurements in earlier studies conducted by Virjonen et al. (2009).

As for the data recorded in the literature for comparison with the values found in this work, the values stipulated for the DL\textsubscript{2} by the French standard appear to be compatible with those reported here for the six simulated situations. However, in terms of the rD, the classification proposed by Hongisto et al. (2007) seems inadequate for classifying the simulated situations of this office since, according to those authors, all the simulated situations of this office would classify it as acoustically excellent based on the values of rD obtained (rD < 5 m). This difference may be attributed to the method employed to obtain this parameter, since the earlier studies (Hongisto et al., 2007; Virjonen et al., 2009) were based on measurements while the present study was based on acoustic simulations.

References

20. Passero C.R.M, Zannin P.H.T. (2010), Statistical comparison of reverberation times measured by the integrated impulse response and interrupted noise methods, computationally simulated with ODEON software,


