Open Plan Office Acoustics: A Case Study in a Real Office

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Introduction

Day by day, work places must implement and develop technological advances more rapidly, adapting to changes in organizational dynamics and to workers' needs [1]. Thus, open plan offices have emerged to solve the need for flexibility, offering greater interpersonal access and easier communication among their occupants than traditional enclosed plan offices.

Although the organization of the work environment through open plans benefits its users in terms of rapid exchange of information and gains in productivity, it has disadvantages from the standpoint of privacy and the ability to concentrate. Therefore, correct acoustic treatment of the environment is essential. According to ref. [2], the need for acoustic planning for such spaces is on the rise, in view of the increasing number of spaces designed according to the open plan concept.

Materials and Method

The object of this study was an open plan office in a large Brazilian company located in the city of Curitiba, state of Paraná. Approximately 150 employees work in this office, which has a volume of about 2690 cubic meters. The room is built of the following materials: brick walls, ceramic tile floor, and fiberglass ceiling, and it contains several dividing walls and plywood desks with upholstered chairs. The desks are separated by small screens of varying heights, the highest of which is 1 meter from the floor up. The windows are made of aluminum fitted with ordinary glass panes.

In the present work, acoustic measurements were taken of the sound pressure level (SPL), reverberation time (RT) and speech transmission index (STI). The measurements were divided into two stages. In the first stage, they were taken during normal working hours to determine the SPL acoustic data. The second stage was carried out after working hours to measure the RT and the STI.

The SPL was measured using a Brüel Kjaer 2260 acoustic analyzer. The SPL measurements were taken in the octave frequency band of 63 to 8000 Hz and the A-weighted sound level (LA_{eq}). The SPL was measured at ten points in the open plan office. After taking the measurements, the data were transferred to a computer and the spatial mean of all the measured points was calculated. All the SPL measurements were carried out according to the Brazilian NBR 10151 [3] and NR 17 [4] standards.

The RT was measured using Dirac 3.1 software. In addition to this program, installed in a notebook, the following equipment was used: a soundcard (Fareface 800), power amplifier (Brüel Kjaer 2716), dodecahedron sound source (Brüel Kjaer 4296), and an acoustic analyzer (Brüel Kjaer 2260). Log-sweep noise excitation was used, since it offers advantages over other types of noise excitation in obtaining a better signal-to-noise ratio. The positions and number of sound source points and microphones used followed the ISO 3328 [5] standard.

The STI was measured using practically the same equipment as that used to measure the RT. The only difference was the substitution of the dodecahedron sound source for a mouth simulator (Brüel Kjaer 4227) and the inclusion of an octave frequency band equalizer (Behringer FBQ 800). These changes in equipment were done in accordance with the IEC 60268-16 [6] standard. To measure the STI, the signal was first equalized and calibrated as indicated in [6]. For the positioning of the sound source and microphone, the IEC 60268-16 [6] standard establishes only that they should be in the speaker and listener position. Since all the workers in the office are speakers and listeners, a source position and ten receiver positions were defined to evaluate the interference of this speaker on the listeners in his proximity. All the other speakers were considered background noise and later inserted into the measurement. This was done by inserting the ambient noise measured during working hours into this measure of the SPL in the octave frequency band of 63 to 8000 Hz. The STI was measured using the Maximum Length Sequence (MLS) signal with weighting factor for male speech.

Results and Discussion

Table 1 presents the A-weighted sound level values.

Measurement point	Leq (dBA)	Measurement point	Leq (dBA)
1	62.0	6	60.3
2	59.0	7	62.1
3	60.0	8	62.2
4	60.4	9	61.3
5	61.1	10	61.0
mean			61.0

Table 1 – A-weighted sound level

The mean value of the A-weighted sound level measured in the office was LA_{eq} =61dB. This value is lower than the limit established by the NR 17 [4] and NBR 10152 [7] standards for office environments, which is 65 dB(A). However, the NBR 10152 [7] standard establishes that the limit value for acoustic comfort in offices is 45 dB(A). The values measured in the office exceeded this level.

Three sound source positions (F1, F2, F3) were selected for the RT measurements, and for each of them, three microphone positions were determined (F1P1, F1P2, F1P3, F2P1, F2P2, F2P3, F3P1, F3P2, F3P3), making a total of 9 receiver positions. The values obtained at each point are given in Table 2.

Measurement point	RT (s) per octave frequency band (Hz)					
	125	250	500	1000	2000	4000
F1P1	0.74	0.64	0.47	0.51	0.63	0.67
F1P2	0.69	0.73	0.64	0.72	0.75	0.77
F1P3	0.71	0.59	0.47	0.53	0.69	0.81
F2P1	0.54	0.42	0.33	0.41	0.51	0.62
F2P2	0.59	0.44	0.40	0.46	0.60	0.73
F2P3	0.69	0.63	0.51	0.63	0.66	0.79
F3P1	0.78	0.73	0.64	0.75	0.73	0.82
F3P2	0.60	0.60	0.48	0.62	0.67	0.74
F3P3	0.76	0.58	0.51	0.59	0.63	0.78
mean	0.68	0.60	0.49	0.58	0.65	0.75

Table 2 – Measured Reverberation Time

As can be seen in Table 2, the mean RT for the frequency of 500 Hz is 0.49 s, which falls below the limit indicated by the German VDI 2569 [8] standard. According to this standard, panoramic offices should present a RT of less than or equal to 0.5 s at the frequencies of 500, 1000 and 2000 Hz. At the frequencies of 1000 and 2000 Hz, the RT values measured in this office were 0.58 and 0.65 s, respectively, which exceed the values established by the German standard. This finding indicates the need for greater sound absorption at these frequencies.

Table 3 lists the values of the speech transmission index with and without the background noise.

Measurement Point	STI	
	Without background noise	With background noise
1	0.90	0.48
2	0.76	0.28
3	0.81	0.32
4	0.85	0.37
5	0.81	0.37
6	0.69	0.22
7	0.74	0.28
8	0.74	0.28
9	0.48	0.08
10	0.55	0.08

bad	poor	fair	good	excellent

Table 3 – Speech Transmission Index without and with background noise. The colors correspond to the subjective scale [6].

The STI values shown in Table 3 indicate a considerable difference between the values measured without background noise and the values including this noise. The noise pressure level of the human voice at a distance of one meter is approximately 67 dB(A), and the average ambient noise in this office is 61 dB(A). Due to the proximity between the values of the signal and of the background noise, speech intelligibility is strongly reduced when the background noise is inserted into the measurement.

Figure 1 shows the STI values including the background noise, according to the location of the receiving point in the office.

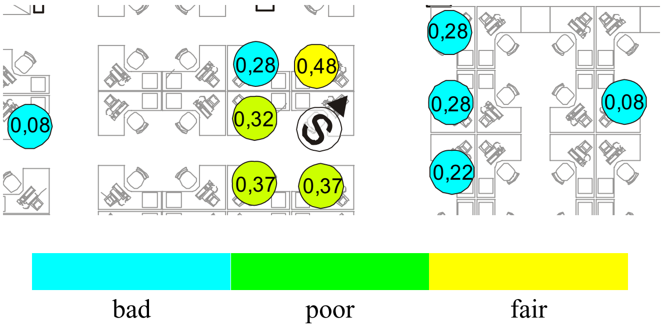

Figure 1 – STI measuring point with their respective values (including background noise). S represents the sound source, and f indicates the direction of the source. Colors correspond to the subjective scale [6].

As can be seen in Figure 1, the STI values varied significantly according to the receiver position in relation to the sound source. This was expected, since the STI was measured using a directional source with a relatively low sound intensity.

The highest STI value in the real situation, i.e., including background noise, was 0.48. This value is considered fair by the IEC 60268-16 [6] standard, so in this office a speaker communicates fairly well with a listener at the work station next to his and the one in front of him. As Figure 1 indicates, the points that presented STI values of 0.32 and 0.37 (green points) also represent listeners located at work stations adjacent to the source, through not facing it, and they therefore presented poor speech intelligibility, according to [6]. On the other hand, the blue points represent work stations further away from the source. The two most distant points from the source presented an STI value of 0.08, so interference from the direction of the sound source was not observed at these points. This finding is consistent with the statement of [9], according to whom the direction of the speakers is considered only in the near field, since sources in the far field are considered multidirectional because the sound pressure level is dominated by multiple reflections.

Conclusions

Based on the aforementioned measurements, the noise pressure level of the open plan office evaluated in this study lay within the limit established by Brazilian legislation, but was higher than the limit established for acoustic comfort in such spaces. In terms of reverberation time, the office presented inadequate values according to the German standard, although it showed high sound absorption at the frequency of 500 Hz. As stated in this paper, STI values are highly dependent on the position of the receiver in relation to the sound source. The direction of the sound source also exerts an influence, which is detected mainly in the field near the source. Moreover, the STI values declined sharply when ambient noise was included in the measurements, indicating the influence of this parameter on speech intelligibility.

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