Room Acoustic Design in Open-Plan Offices

Erling Nilsson, Björn Hellström

10ème Congrès Français d'Acoustique
Lyon, 12-16 Avril 2010

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Erling Nilsson[1], Björn Hellström[2]
[1]Saint-Gobain Ecophon AB, Box 500 SE-260 61 Hyllinge, Sweden
[2]Tyréns, SE-118 86 Stockholm, Sweden

In a Nordic cooperation project the acoustical conditions in open-plan offices was investigated. Measurements have been carried out in five open plan offices accompanied with an inquiry gathering the subjective judgments by the staff. A program for the acoustical measurements was designed specifying how to perform the measurements and which type of parameters to measure. The acoustical parameters included in the measurements are Reverberation time T_{20}, Early Decay Time (EDT), Clarity (C_{50}), Speech transmission index (STI), Speech intelligibility index (SII), Privacy Index (PI), Rate of spatial decay of sound pressure levels per distance doubling (DL_2), Excess of sound pressure level with respect to a reference curve (DL_f), background noise levels in occupied and unoccupied offices. In two of the offices a refurbishment program was carried out. Measurements as well as questionnaire were accomplished after refurbishment. The effect on room acoustic parameters DL_2 and DL_f and on subjective judgments by the staff will be presented in this paper.

1 Introduction

The extensive use of open-plan solution for offices has highlighted the problems related to the acoustical conditions in these environments. The variety of the architectural design, the planning of working areas and the activities going on has also been challenging for the acoustic evaluations. In Europe the purpose of using an open plan structure is often to create flexible solutions which support communication between employees and working teams but also gives possibility for concentrated work. In these environments it is normally not a realistic goal or even the intention to create high speech privacy between workplaces. Instead the organisation of work places should support communication between working members in the same team but depress speech sound from neighbouring groups working with other projects. This implies that preventing sound propagation over long distances is important. Nevertheless, irrelevant speech is the major source of disturbances in OPO and it's well recognized that it has a detrimental effect on cognitive performances [1, 2]. In a modern flexible OPO the creation of a functional workplace is a complex process were the acoustical planning only is a part of a series of considerations that has to be handled. The open-plan office should support both communication and concentrated work. Thus, for an OPO to be an efficient and comfortable workplace there a number of factors besides the acoustic treatments that has to be fulfilled like

- sufficient number of sound insulated rooms for concentrated work and meetings
- flexible solutions for computer and mobile phone with wireless connections
- education of staff of purpose with OPO and how to behave to decrease annoyance
- planning of workplaces to simplify communication between team members and minimize disturbance between different groups
- acoustic planning for the activity going on

In [3] a method to approach room acoustic design is presented. The main principle in this approach is taking into account the multidimensional character of human's perception of sound, the type (shape, volume, distribution of absorption) of the room and the activity that is planned for the room. This threefold of factors interacts and has to be considered in the acoustic design to secure an appropriate acoustic environment. A consequence of the human perception of sound is that normally several room acoustic descriptors have to be used for a relevant evaluation of the room acoustic. Only using reverberation time will often be insufficient and sometimes even misleading [4]. Due to the shape, size and distribution of sound absorbing material it is appropriate to distinguish between different room types. Excluding large industrial spaces and performance room like concert halls and theatres and restrict the analysis to ordinary rooms there are at least three groups of rooms that have to be analysed in different ways. The reverberant rooms were the diffuse field assumption is valid are room types were the late reverberation time (T_{20} or T_{30} according to ISO 3382-1) work as a global parameter and characterize the acoustical conditions sufficiently well. However, this room type is unusual in practise. A more common room type is the room with an absorbent ceiling. In these room types the diffuse field assumption is normally not fulfilled and the reverberation time alone is not enough to characterise the acoustic conditions. Room acoustic descriptors related to different sensations like steady-state sound levels, speech clarity and reverberance have to be evaluated separately. Another room type is rooms with extended forms like open-plan spaces and corridors. Typically for these room types are that room acoustic parameters varies over distance from source and are not useful as global descriptors of the interior environment. For these spaces measures related to sound propagation seems to be more appropriate for room acoustic characterisation [5, 6]

The aim of this work is to suggest appropriate objective measures for a simple and practical evaluation of open-plan offices. The purpose of the measures is to secure that the overall basic acoustic conditions in an open-plan office are sufficient for the activities going on. The intention is that the measures reflect the interior fittings of the space and reflect critical parameters regard to the design and planning of the office. These critical parameters can apply to the choice of material and outer layer for the room's surfaces and furnishings, general room layout and/or the use of the workstations.

A measurement methodology for evaluating the room acoustics in large office space in a meaningful way can also lead to work environmentally sound solutions. This will benefit both employers and workers leading to greater efficiency, less absenteeism and increased job satisfaction. It can also help to increase accessibility for individuals with hearing loss. A good acoustic environment minimizes the risk that office workers have to leave work early because of significant pressure from an unsuitable working environment.

2 Method

2.1 Measurement specification

The acoustical parameters included in the measurements are Reverberation time T_{20}, Early Decay Time (EDT), Clarity (C_{50}), Speech transmission index (STI), Speech intelligibility index (SII), Privacy Index (PI), Rate of spatial decay of sound pressure levels per distance doubling (DL_2), Excess of sound pressure level with respect to free field (DL_f), background noise levels in occupied and unoccupied offices. In this paper we will focus on the parameters DL_2 and DL_f. The meaning of these measures is illustrated in figure 1. Reverberation times and speech transmission index were measured at workplaces while DL_2 and DL_f were measured at two different paths, one along the workplaces and one in the diagonal direction of the room. This illustrated in figure 2.

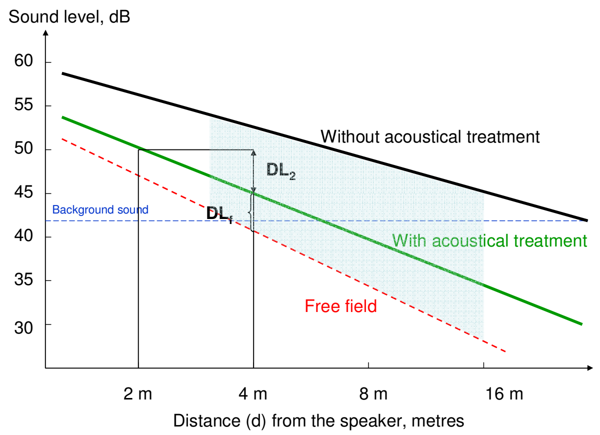

Figure 1. Example of sound propagation curves in an open-plan office with and without acoustical treatment. DL_2 measure the decrease of sound level per doubling of distance. DL_f measure the difference between the SPL of the sound source in the room and corresponding value in free field.

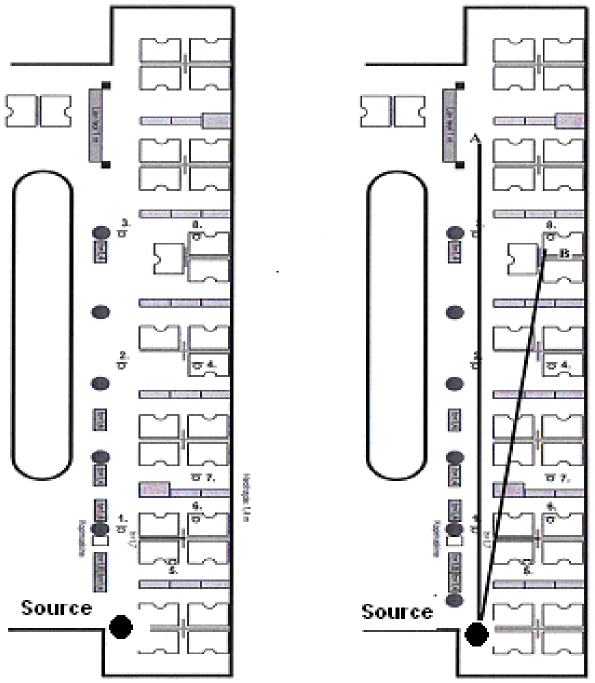

Figure 2. The open plan office with measuring positions (left) and measuring paths for the sound distribution curves (right)

2.2 Inquiry

The measurements of objective room acoustic parameters were accomplished by an inquiry among the staff. The purpose of the questionnaire was to identify critical criteria with regard to the subjective impression of the working environment. Moreover, the results from the questionnaires were compared with measured room acoustic parameters. The inquiry and the room acoustic measurements were performed both before and after the refurbishment of the open-plan offices. Before implementation, the questionnaire was tested on experts on acoustics, as well as on a number of people who work in open-plan offices. The completed questionnaire comprises of sixty questions, and takes at most twenty minutes to answer.

2.3 Acoustic treatment

In general terms the refurbishment in the two offices consist of partly or totally new suspended ceilings corresponding to $\alpha_w>0.9$. As a complement to the acoustic ceilings patches of free hanging sound absorbing units were installed over the workplaces. This is illustrated in figure 3. In one of the offices sound absorbing screens were placed between the workplaces. In both offices, wall absorbers were mounted on one of the walls. The basic idea behind the acoustic design was to prevent speech propagation between different working teams.

Figure 3. Free hanging absorbing units above workplaces

Before refurbishment		
Office	DL_2 (dB)	DL_f (dB)
1	5.2	7.4
2	5.8	6.8

After refurbishment		
Office	DL_2 (dB)	DLf_f (dB)
1	9.9	-0.1
2	6.7	1.0

Table 1: Sound propagation measures DL_2 and DL_f before and after refurbishment

3 Results

3.1 Measurement of DL_2 and DL_f

Speech is the most disturbing sound signal in an open-plan office. How to increase the attenuation of speech between different working groups is consequently a question of major importance in the acoustical planning. To quantify the attenuation of sound during propagation measures like DL_2 and DL_f are appropriate. These parameters are defined in ISO 14257 [7]. In this investigation A-weighted pink noise was used as a sound source. Knowing DL_2 and DL_f and specifying a target value for acceptable speech level L_c at a work place, the distance needed between the person talking and the workplace is given by

$$d_c = 10^{0.3(L_{speech} + DL_f - L_c)/DL_2} \qquad (1)$$

where d_c is the distance of comfort, L_{speech} is the level of speech and L_c is the acceptable speech level at the work place. DL_2 and DL_f will depend on the chosen evaluation interval. In many offices a suitable interval appears to be from 3 to 16 meters. DL_2 is given by the regression line over this region and DL_f is given by the average value over the same distance. The validity of equation 1 is limited to the evaluation interval.

This (comfort) distance gives an indication of how to proceed in the acoustical design work concerning absorbing materials, screens, furnishing etc. and act as a useful tool for the architects.

DL_2 and DL_f have been measured in two offices both before and after refurbishment. The values have been evaluated over the range 3 to 16 meters. The results are presented in table 1. As appear from table 1 the acoustical treatment has affected both DL_2 and DL_f. Since DL_2 has increased and DL_f has decreased after treatment this imply that for distances larger than 3 meter from the source, the speech level will decrease faster as a function of distance and the speech level in each position has diminished. As a consequence and according to equation 1 the distance to reach an acceptable speech level has been shortened.

In table 2 equation 1 has been used to calculate the distance needed to reach a sound pressure level of 35 dB(A) from a sound source producing a sound pressure level of 55 dB(A) at 1 meter. The calculation is carried out for the two offices in table 1 and for the cases before and after refurbishment.

Before refurbishment	
Office	Distance to reach 35 dB(A) when the speech level is 55 dB(A)
1	> 16 meter
2	> 16 meter

After refurbishment	
Office	Distance to reach 35 dB(A) when the speech level is 55 dB(A)
1	4 meter
2	5 meter

Table 2 : Calculation of distance of comfort

3.2. Questionnaire

The questionnaire comprises 60 questions. Most of the questions are divided into five multiple-choice questions. The number of respondents regarding the answer of the questionnaire before and after the acoustic treatment was 14, respectively 10 in office 1. In office 2 the corresponding numbers was 16, respectively 7. For the sake of clarity we will only refer to the question how the staff considers the acoustic environment from a general point of view before and after the refurbishment. The results are presented in figure 4 and 5.

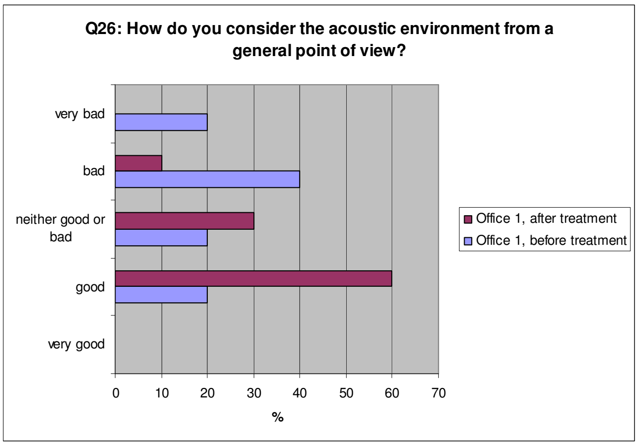

Figure 4. Subjective judgements before and after refurbishment for office 1.

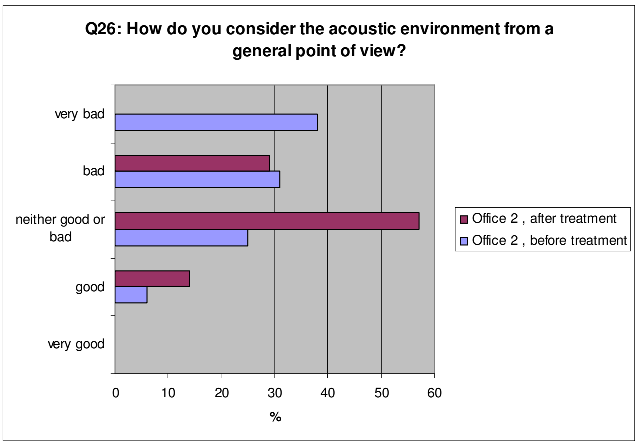

Figure 5. Subjective judgements before and after refurbishment for office 2.

4 Conclusions

There is a need for complementary parameters for the acoustic evaluation of open-plan offices. Ordinary room acoustic parameters like reverberation time are not sufficient for a relevant characterization of the acoustic environment in open-plan spaces. The influence of the interior design on sound propagation over distance is a crucial factor for the overall impression of the acoustic environment and its suitability as an efficient work place. Measures related to sound propagation like DL2 and DLf are therefore appropriate for open-plan spaces. In two open-plan offices a refurbishment program has been performed. It has been shown that DL2 and DLf are sensitive for the acoustic treatments carried out and also reflect the improvement of the subjective judgment concerning the acoustic environment in general. Moreover, these measures can be converted into a (comfort) radius indicating the distance needed to achieve a certain reduction of the sound level from a sound source. This application could serve as a practical tool for the acoustical planning of open-plan offices.

Acknowledgments

This project was partly financed by the Nordic Innovation Center which is greatly acknowledged.

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