Background noise level to determine the speech privacy in open plan offices

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Summary

The acoustic comfort for people working in open plan offices is mainly determined by the level of speech-privacy at their workplace. This speech privacy is determined by the strength of the disturbing noise source, the sound reduction between source and receiver and the background noise level at the workplace. This background noise may be caused by external sources like traffic noise, the noise by HVAC devices and the noise caused by the other people in the open office space. In many cases, in well insulated buildings with moderate or low level HVAC sound levels, the noise from working people is the most important contributor to the background noise. At the same time this contribution is very difficult to predict in a design stage. Knowing these background levels is important since design decisions depend on them, like decisions regarding lay out of the plan, necessity of sound reduction screens, providing a number of concentration rooms or even introducing a sound masking system. So for acoustical design of open plan office environments, a prediction method is needed to estimate the background noise caused by working people in open plan offices.

A prediction model has been developed based on source data of different activities, sound transfer calculation and statistical combination of data. The sound pressure level produced by human activities is based on measurements of these activities. Workers at certain positions in the open plan office can be assigned an activity and a time distribution of this activity. Together with the sound transfer from source to receiver, the statistical distribution of the sound from all the working people in the open office at each receiver position can be calculated. The prediction model was validated for two different offices.

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1. Introduction

In the appreciation of acoustic comfort in open plan offices, the ability to communicate with colleagues and to work concentrated on a task are important qualities. The level of speech privacy that is achieved at the workplaces is therefore important. The speech privacy at each workplace is determined by the strength of the disturbing noise source, the sound reduction between that source and the workplace and the background noise level at the workplace.

The sound reduction between source and receiver is influenced by acoustic finishes of the space (e.g. ceiling, carpet), distance, obstruction by closed rooms and shielding by screens. The background level is caused by HVAC devices, external sound like traffic and the noise created by the activities of people in the office. The background level in offices should not be too loud because this can lead to annoyance and fatigue. Studies on acceptable ventilation noise levels were done by e.g. Bradley and Gover [1]. In many cases the noise from working people is the most important contributor to the background noise which can cause a positive masking effect (e.g. Jones and Macken [2]).

Open plan offices are of course not new but the layout and use have changed over time. The ‘classic’ open office from the seventies and eighties is a large open office space (not a cubicle office) with a high density of people evenly spread over the office floor. All workers have their own workplace within this office. In the more recent offices, starting in the mid-nineties and indicated as “activity based working offices” smaller groups of workplaces are created in an open environment and combined with small closed office spaces and meeting rooms. Even more important is that the workplaces are not occupied by a single person any more, but related to an activity (activity related work). In these modern offices, workplaces are then designed for a specific task like informal meeting, work related meeting, individual concentrated work, or as single or multi-user lounges.

Concerning the speech privacy, the background noise level in the ‘classic’ large open plan office is created by all the people in the same acoustic office space. This level is usually high enough to provide adequate speech privacy. In the new office plans with smaller groups of people in the open areas, the background level caused by people can be significantly lower making speech privacy and acoustic comfort much more critical.

Every office and organization is unique but whatever the office layout is, it is always essential that the right speech privacy is achieved at the different workplaces. Knowing the background levels is important since design decisions depend on them. These are decisions regarding lay out of the plan, necessity of sound reduction screens, providing a number of concentration rooms etc. So for acoustical design of open plan office environments, a prediction method is needed to estimate the background noise caused by working people.

The design of open plan offices should be more customized for the work process of this specific organisation. To study background noise levels and the optimal office layout it is important to analyse the way people work. It has to be studied whether they work in teams or on individual basis and what the main activities are (e.g. communication or concentration). Then the different functions and clusters can be located at the best positions with a suitable speech privacy in the office layout.

People enter an office floor in an acoustically dynamic environment, e.g. at the elevators, pantry, informal lounge. This is the point where they informally meet. From this dynamic point the main routing leads towards a more formal meeting environment and/or individual work environment where speech privacy is more important. This layout, with an acoustical zoning plan, is an example of a good acoustic design. These acoustical lay out concepts however do not always find its way into office layouts.

In the dynamic environment a lower speech privacy is accepted than in the working environment. Whether we focus on the dynamic or the work environment, the background level caused by people is always of important influence on the speech privacy and should be considered in the prediction.

The speech privacy can be expressed in terms of the Speech Transmission Index (STI), Articulation Loss of Consonants (ALcons) or the Articulation Index (AI). In the program of requirements of open plan offices, measurable single number acoustic quantities are introduced that assure the acoustic quality of the space. The recent ISO 3382-3:2012 [3] standard can be used for this purpose. This standard defines the spatial decay rate of speech $D_{2,S}$, the distraction distance r_D and the privacy distance r_P. The standard describes how to measure or calculate these single number quantities and gives examples (Annex A) of what target values can be used.

Measurements of the r_D and the r_P are in basis done in empty offices. The ISO standard recognises that noise from people talking can sometimes cause a positive masking effect [2] but evaluation of the acoustic conditions with people talking is not within the scope of this ISO 3382-3.

The background sound level caused by people can, and will often be, higher than the sound levels due to ventilation. This means the speech privacy is generally underestimated if the contribution of people is not included in the background level. Without information on the background level caused by people it is impossible to know the real speech privacy during office hours. As indicated in the ISO standard, the STI can be determined by using a simulated background noise from human activities.

It is clear that it is important to study on the background noise levels caused by people and find a model to predict these values. This paper describes a prediction model that calculates the background levels for the specific lay out of the office and the specific activity profile of an organization.

2. Prediction model

In the research described in this paper a method is developed to calculate the background level (L95) in an open plan office, for specific calculation points, to be chosen at any position in the office layout.

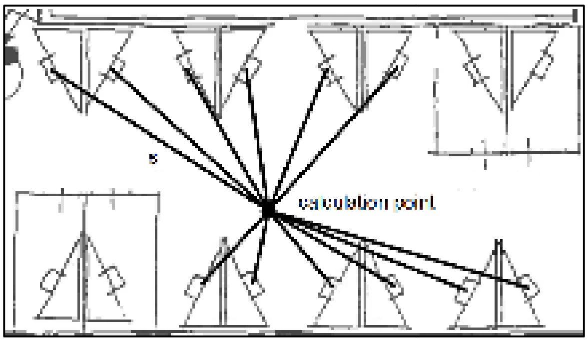

Figure 1. Every workplace is a source on a distance s_n from the calculation point.

Every person in the office is a source and can be modelled as a sound source at a fixed position in the office with a time distribution of different activities (figure 1).

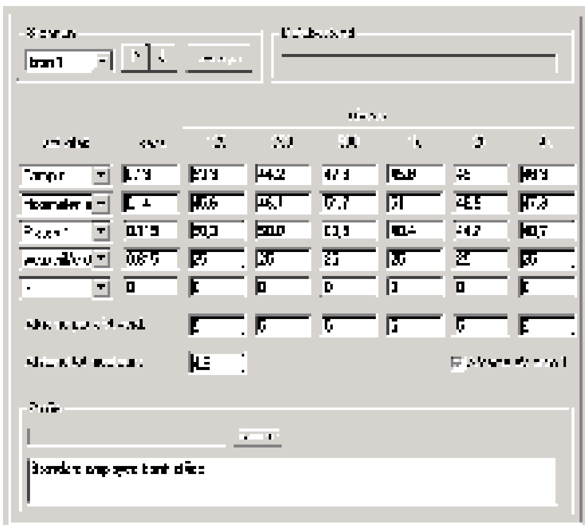

Figure 2. Application to organise input.

The input for the calculation are these sources with specific time distribution of activities and sound production corresponding with the activity.
Standard activities are conversations between colleagues, laptop/PC work, paperwork and writing. All sources together lead to a distribution of sound pressure levels at the calculation point. A statistical analysis of these sound pressure levels leads to L95 values. A Visual Basic application was made to organize the input, do the calculations and to give a graphic output of the results (figure 2).

3. Distribution of activities

Every organisation that works in an open office is rather unique as for the distribution of activities of the people. Where e.g. the open office of a telecom provider is generally a very communicative environment, the office of an ICT consultant can be rather quiet. The background noise levels can then be very different, as will be the speech privacy.

For this research, the distribution of activities for two offices was measured in practice: a regional bank office and a national telecom provider office. Both are standard offices and do not include a customer support center (call center). The telecom provider office is however a more communicative environment than the bank office. The activities of the people are registered per minute and allocated to five different categories as shown in table 1.

Every activity has a corresponding source level. This level depends on the activity but also varies during the activity. It is necessary to differentiate in ‘active’ and ‘non-active’ levels during an activity. For example the total time a person is having a telephone conversation can be divided in the active time that the person is actually talking and the non-active time when the other person (not audible in the room) is talking. For a telephone conversation this is generally a 50%/50% distribution, assuming that only one of the two is talking at the same time. Based on the performed time analysis of the activities in the two offices, the 50%/50% distribution shows to be valid for the other activities as well. This leads to the active time in table 1. The time a person is absent or non-active is the total passive time.

The distributions cannot be used as standard and should be determined for every organisation separately. For at least the larger organisations a study of activities and required number of workplaces is sometimes performed by a facility consultant. The acoustician can use this information from the consultant to set up the distribution as in table 1. At least a good comparison to a similar organisation of which work processes are studied should be performed.

Table I. Time distribution of standard activities.

	Bank office		*Telecom office*	
Activity	*Total*	*Active*	*Total*	*Active*
PC/laptop	26%	13%	18%	9%
Paperwork	28%	14%	4%	2%
Talking	23%	11,5%	64%	32%
Writing	0%	0%	8%	4%
Passive	23%	61,5%	6%	53%

Not every employee has the same time distribution of activities and not every workplace has the same time distribution of activities as well. Workplaces close to the pantry and elevators are usually the more communicative places and further from this dynamic zone more individually orientated workplaces are positioned. In the model different activity distributions can be used for different workplaces.

4. Sound sources

For every activity the sound pressure level at 1 m from the source is determined by measurements. These measurements are performed in the Peutz office on our own employees. Table II presents the A-weighted sound pressure levels during 'active' time. For the active time the L10% level is used based on the statistical analysis of the total activity time.

For the calculation in the prediction model, the octave band values are used.

Table II. A-weighted sound pressure level L10% on 1m for different office activities

Activity	*Lp,1m*
PC/laptop	53 dB
Paperwork	56 dB
Talking	58 dB
Writing	36 dB
Passive	34 dB

The level for speech corresponds to the values in the ISO 3382-3:2012 [3] of 57,4 dB as A-weighted sound pressure level at 1 m ($L_{p,S,1m}$).

5. Sound reduction

Now that information on the sources in the office has been gathered, the sound reduction from each source to the receiver position needs to be determined. The calculation uses the spatial decay of the sound pressure level per distance doubling ($a_{n,f}$) and the distance as input. The sound level can be determined by:

$$L_{cp,n,f} = L_{n,f} - a_{n,f} \cdot {}^{2}log(s_{n,f}) \qquad (1)$$

With $L_{cp,n,f}$ being the sound level in frequency band f at the calculation point caused by source n. $L_{n,f}$ is the sound level in frequency band f at 1 m from source n. The $a_{n,f}$ is the spatial decay of the sound pressure level per distance doubling.

For a larger open floor plan with a high quality acoustic ceiling ($\alpha_w \geq 0,9$) and carpet on the floor, a value $a_{n,f}$ of 5 dB can be achieved. Higher values require barriers between workplaces. In that case, the sound reduction for single screen barriers can be calculated e.g. as presented by Wang and Bradley [4]. If the actual sound reduction from each individual source to the receiver point is known from measurements these values can be used in the background prediction model.

In specific situations also sound reduction values obtained from room acoustical calculation models could be used, however it should be noted that ray tracing is inaccurate in case of shielding the direct line of sight between source and receiver.

6. Statistical Calculation

Every source leads to a time distribution of sound levels $L_{cp,n,f}$ at the calculation point. All sources together lead to a total time distribution of sound levels $L_{cp,tot}$ at the calculation point.

$$L_{cp,tot} = 10 \cdot {}^{10}log\left(\sum_n 10^{\frac{L_{cp,n,f}}{10}}\right) \quad (2)$$

Because $L_{cp,n,f}$ depends on the activity of source n this results in different $L_{cp,tot}$ at the calculation point for every combination of activities over all n sources. An example: a theoretical case of two sources with two modes (50% talking/50% passive) at different distances will lead to four different levels $L_{cp,tot}$ at the reference point, each occurring 25% of the time.

Having n sources with m different activities will lead to m^n different combinations at the calculation point. So for 10 sources with 5 activities this will lead to circa 10 million combinations and corresponding sound levels at the calculation point.

This gives us a distribution op $L_{cp,tot}$ levels and percentage of time they occur at the calculation point. This statistical distribution is used to determine the level that is exceeded 95% of the time (L95). This is the L95 and can be considered as being the relevant background level in an open office due to human activities.

7. Validation

For the two offices, the bank office and telecom office, the model was verified for two different measurement points in each office. The distribution of activities was determined (table I) for all workplaces and the $a_{n,f}$ was measured per frequency band.

Figures 3 and 4 show the results for the bank office and the telecom office at two measurement points. The figures show that the calculation of the L95 value is rather accurate. The shape of the calculated curve also corresponds to the measured curve. The measurement for the bank office is based on the floor plan as shown in figure 1.

8. Conclusion

The background noise caused by people is often not included in the calculation of speech privacy because it is not known and not easy to predict. This generally underestimates the level of speech privacy.

A prediction model based on an activity distribution of the people has been developed and has shown to be a rather accurate way to predict background noise levels (L95). The model makes it possible to calculate background noise level for every position in the office floor.

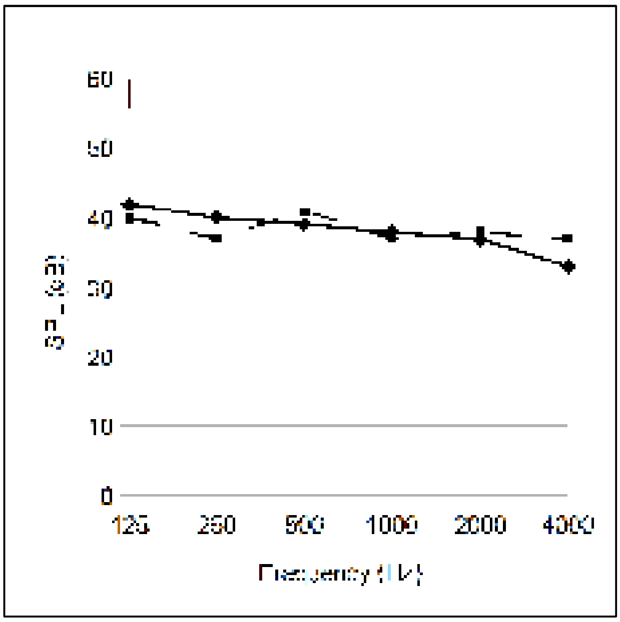

Figure 3. Bank office: Calculated values of L95 as dotted line (44 dB) and measured value of L95 (45 dB) as solid line.

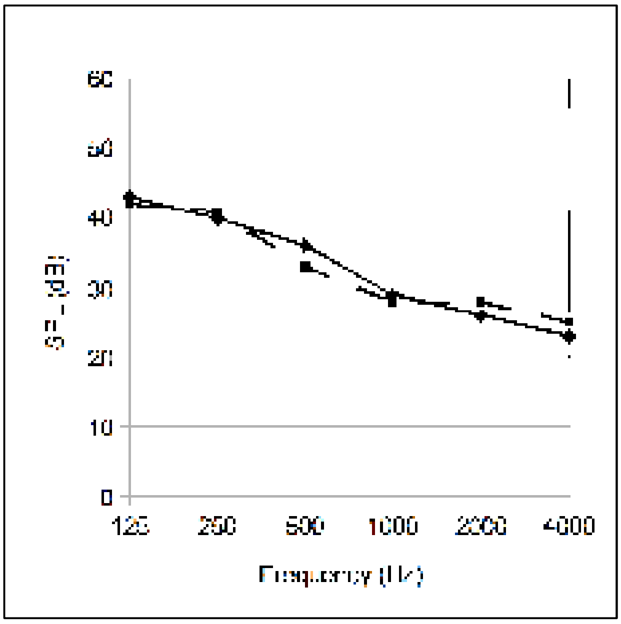

Figure 4. Telecom office: Calculated values of L95 as dotted line (37 dB) and measured value of L95 as solid line (39 dB).

Because every floor plan, but also every organization, is unique, the strength of the prediction model lies in the fact that it allows a bespoke organization specific input. The output is the background noise level (L95) for a specific organization profile in a specific office layout.

The prediction model can assist in making the right design choices for the layout of floor plans and other design choices in an early stage of the project.

References

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