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Acoustic measurements in retrofit buildings lead to a sustainable design of a (semi-) open plan office

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Abstract

Working in an office environment entails various activities. Communication on the phone, social interaction and meetings produce not only sound, but are also in need of a good speech intelligibility and therefore in need of good room acoustics. Difficult performance tasks are in need of different acoustic conditions. Areas with a more silent environment are needed with a minimised level of distraction from surrounding activities. Areas with a high level of interaction provide workspace for the purpose of teamwork. Different activities require unique acoustic conditions.

Before creating a new activity based design in retrofit buildings, the existing acoustic environment is carefully measured. The acoustic qualities of the existing facilities as well as the actual behaviour of the existing population of the building are both measured. The sound insulation of the existing walls is defined as A-weighted standardized level difference $D_{nT,A}$, measured according to the Dutch norm NEN 5077 (similar to ISO 140-4). The room acoustic parameters are defined by the reverberation time T, measured according to ISO 3382, and the spatial decay rate of A-weighted SPL of speech $D_{2,\mathrm{S}}$ measured according to the norm ISO 3382-3 for room acoustics in open plan offices. The level of speech privacy is interpreted out of the combination of A-weighted sound pressure levels of speech $L_{p,\mathrm{A,S}}$ and the average A-weighted background noise level $L_{p,\mathrm{A,B}}$ per position. During a representative week of working hours the sound levels are being measured on different locations in the open plan office. The sound levels are measured in equivalent sound levels $L_{\mathrm{eq,\ 5min}}$ and maximum sound levels $L_{\mathrm{max,\ 5min}}$. To gather information about the character of the sound, sound fragments are also recorded based on a trigger level.

Defining the acoustic environment of (semi-)open plan offices based on building measurements and noise level measurements produces a solid foundation for designing a more sustainable office environment. Often the new design leads to activity based office plans where diverse activities are projected in a (semi-) open plan office. This is illustrated with a practical example of an engineering project.

Keywords: open plan offices; acoustic; retrofit buildings; activity based working

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1. Introduction

A sustainable design seeks to reduce negative impacts on the environment and aims to increase the health and comfort of building occupants. Acoustic comfort in the workplace is very important for a productive and satisfactory environment. The Leesman review of September 2014 [1] showed a high rate of dissatisfaction because of noise levels in the working environment. Out of about 55.000 employee, 47% of those surveyed found the noise level to be dissatisfying for an effective working space. Next to the feature ‘temperature control’, the sound related features for ‘noise levels’ and ‘quiet rooms for working alone or in pairs’ show the highest levels of dissatisfaction and the lowest of satisfaction. Defining the acoustic environment is an important part of the design process. Four questions should be asked:

- The first question is: ‘What is the acoustic comfort in the existing situation?’,
- the second question is: ‘What is the ideal acoustic comfort aimed for in a new environment?’
- and the third question is: ‘What is the best achievable level of acoustic comfort in the retrofit building?’.
- The final question is: ‘What level of acoustic comfort is present after refurbishment with activity based design?’.

To find out about the best achievable level of acoustic comfort ‘baseline measurements’ are made and these results translated into reasonable target values for an optimal acoustic comfort in the situation of the retrofit building. In that way, a sustainable office environment is created to host a flexible, activity based working environment.

After the process of re-designing, renovation and refurbishment the actual level of achieved acoustic comfort can be evaluated by measurements again. The results of these ‘control measurements’ show in what degree the target values are being met in practice. Control measurements also enable a comparison between the ‘before’ and ‘after’ situation , evaluate the targets and to pair these to the comfort of the workplaces.

2. Investigation approach

Before creating a new activity based design in retrofit buildings the existing acoustic environment is carefully measured using several acoustic parameters. Measurements taken previously as baseline measurements show the level of acoustic comfort in the existing situation. The acoustic qualities of the existing facilities as well as the actual behaviour of the existing population of the building are both measured. General target values are set according to the Dutch Handbook Quality in Building Physics for Offices [2]. Specific target values are based on the experience of M+P. For setting specific target values the current situation of the existing building and special needs of an organization are taken into account.

2.1. Acoustical parameters building and room acoustics

The sound insulations of the existing walls are measured, the reverberation times are measured including present ceilings and furnishing and the spatial decay is being defined over several lines of decay in the open plan parts of the office. The noise produced by the existing HVAC system is determined by measuring the background noise level. The position of ventilation ducts is considered regarding the sound transmission over the ceilings.

The sound insulation of the existing walls is defined as A-weighted standardized level difference $D_{\mathrm{nT,A}}$ (measured according to the Dutch norm NEN 5077 [3] similar to ISO 140-4 [4]). For meeting rooms with a high level of discretion a $D_{\mathrm{nT,A}}$ of 42 or 45 dB is set as a target value and 33 dB including a wall with a door. For a closed office with a normal level of discretion a $D_{\mathrm{nT,A}}$ of 39 dB is set as a target value and 27 dB including a wall with a door.

The room acoustic parameters are defined by the reverberation time T (measured according to ISO 3382 [5]). For a furnished open plan office a target value is set as a maximum of 0,5 s as a mean value of octave band 250 Hz to 2.000 Hz. For furnished closed cell offices the target value is adjusted to 0,6 s.

The spatial decay rate of A-weighted sound pressure level of speech $D_{2,\mathrm{S}}$ is measured according to the norm ISO 3382-3 [6] for room acoustics in open plan offices. The level of speech privacy is interpreted from the combination of A-weighted sound pressure levels of speech $L_{\mathrm{p,A,S}}$ and the average A-weighted background noise level $L_{\mathrm{p,A,B}}$ per position. The Dutch handbook sets a target value of 5 dB within a cluster of working spots with the same activities and 11 dB between clusters of working spots with different activities. When the signal to noise SNR drops under 3 dB the sound intelligibility rapidly decreases, assuming the speech level as the signal and the background noise level interferes as noise. With a background level of about 40 dB a $D_{2,S}$ of about 8 dB is needed for an open plan office with mixed activities according to the experience of M+P (see also [7]). Figure 1a shows a picture of measuring the spatial decay in an open plan office.

a b c

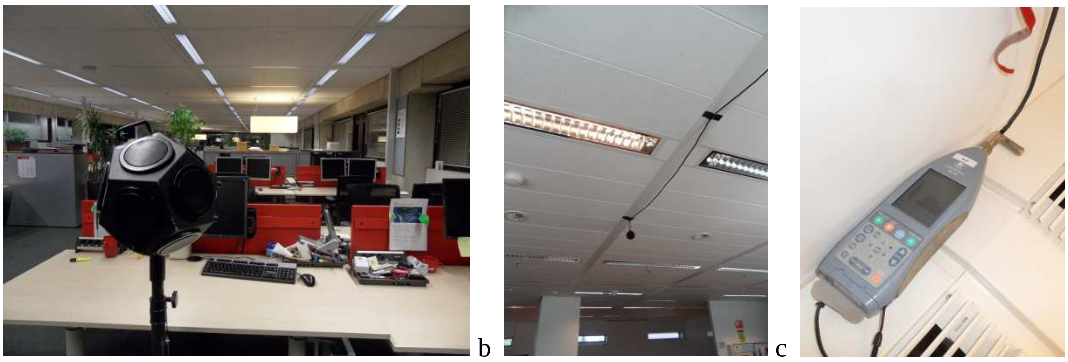

Fig. 1. Photos measurements of (a) spatial decay and (b, c) activity noise levels

2.2. Noise activity levels and interpretation

During a representative week of working hours the sound levels are measured on different locations in the open plan office. To gather information about the character of the sound, sound fragments are recorded based on a trigger level. The activity levels are measured in blocks of five minutes equivalent and maximum sound levels. The number of recorded sound fragments give insight into the sound character and how many times the trigger level of 70 dB(A) is being exceeded. In analysing the equivalent sound levels one has to consider possible side effects like sneezing or coughing during winter time period or hay fever season. The sound levels are measured over periods of 5 minutes in equivalent sound levels $L_{eq,\,5min}$ and maximum sound levels $L_{max,\,5min}$. The Dutch practical guideline NPR 3438 [8] sets a target value of 45 dB(A) for equivalent sound levels to be able to perform office tasks with computer screens, classified as a task with reasonable concentration. An equivalent sound level of 55 dB(A) is considered the maximum level for performing these tasks. Figure 1b shows a picture of a noise activity level measurement.

The sound levels measured because of human activities on the open plan office floor are used as an indicator of activity. Whether or not a high noise level or a low noise levels is acceptable has a lot to do with the kind of firm and the necessary activities that go with that. For a company with a high need for interaction like a sales floor or an operating design team, high noise levels might be very well acceptable. For an engineering company with a lot of mixed activities high noise levels might be disruptive and distracting for tasks requiring high concentration. In the first situation high noise levels might lead to an office environment with several room dividers, dividing the open plan office into smaller acoustic compartments to lower the noise levels a little but do enable the necessary interaction. For the second situation, it is recommended to separate the different activities into different zones and rooms, like meeting rooms, an interactive zone for telephone calls and small meetings and a quiet zone for activities in need of a high level of concentration according to the principle of an activity based office design.

3. Example of an office building project

3.1. Baseline measurement results

In figure 2 the existing office plan is presented as an example of an office project. In table 1 are the full results presented of the baseline measurements for building and room acoustics.

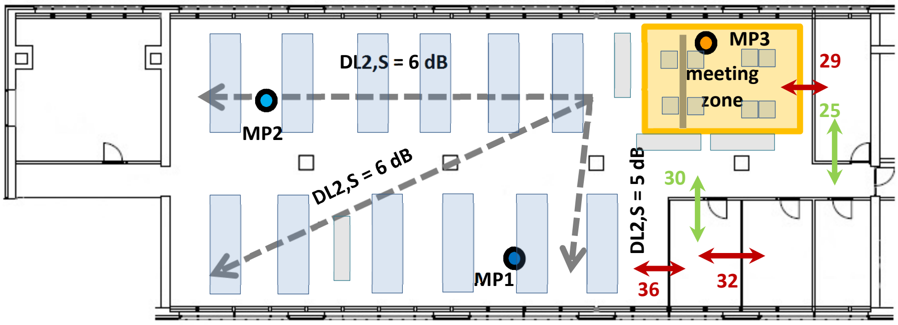

Fig. 2. existing office plan with measurement positions and results.

Table 1. Results baseline measurements for building and room acoustic.

Acoustic parameter	results	
Sound insulation closed walls $D_{nT,A}$ [dB]	29-36	(green notation in fig. 1)
Sound insulation walls with doors $D_{nT,A}$ [dB]	25-30	(red notation in fig. 1)
Reverberation time open plan office $T_{250\text{-}2k}$ [s]	0,5	
Reverberation time meeting zone $T_{250\text{-}2k}$ [s]	0,3	
Reverberation time office cells $T_{250\text{-}2k}$ [s]	0,4-0,5	
Spatial decay rate $D_{L2,S}$ [dB]	5-6	
Background noise level $L_{p,A,B}$ [dB]	37-44	

The sound insulations of the existing walls are 29 and 36 dB, which values are in shortage of the needed speech privacy compared to the target values of 39 dB for normal speech privacy between rooms and 42 to 45 dB for high speech privacy. One of the explanations for a lack of insulation is the flanking sound transmission through the fancoil units attached to the interior façade as can be seen in fig 1c. For the new design it is highly recommended to avoid positioning closed rooms like meeting rooms and concentration rooms against the interior façade. The sound insulation towards the circulation area is varying from 25 to 30 dB. The choice of doors and door detailing should be reconsidered in the new design in order to achieve a normal or high speech privacy as wished for. In the open plan office the reverberation time complies with the target value of 0,5 s. In the meeting zone the reverberation is a bit too low with the measured 0,3 s because of the extra used interior screens of highly absorbing material. The ceiling consists of a ceiling system with a good acoustic absorption. Computer screens placed on the desks shield a little bit of the sound resulting in a spatial decay of 6 dB in the longitudinal direction of the desks. In the transverse direction function a little lower value is measured of 5 dB. The background noise levels caused by technical services vary from 37 to 44 dB, where the highest levels are measured close to the fancoil units at the façade.

The activity noise levels are measured at three positions as pointed out in fig 2. The monitoring positions in the open plan office show a high percentage in time of exceeding the maximum level of 55 dB(A). On monitoring position 1 the maximum level is exceeded for 68% in time and for monitoring position 2 a percentage of 61% is measured. The measurement results of monitoring position 3 show only little activity with a percentage of only 26% exceeding the level of 55 dB(A), which does not correspond with an intense use of the meeting zone. The conclusion can be made that in this situation any conversations or discussions are probably made at the normal office desks with a high chance of disturbing neighbouring colleagues.

3.2. Engineering the new design

The results of the baseline measurements are communicated to the organization. Bringing together the constraints of the existing building and the pattern of necessary activities for running the organization, a new floor lay-out is designed based on an activity based office lay-out. Activities with a high need of concentration or speech privacy are placed in closed rooms. In the open plan office the level of noise is orchestrated by creating a noisier zone entering the office with a quieter zone at the back of the open plan office. The more noisy zone includes a pantry, short stay working spots and long stay working spots. At the back the same kind of working spots are located with short and long stay working spots, but in a more quiet atmosphere showing in higher desk screens in a different color. Higher desk screens help to increase the spatial decay of the open plan office. Visuals like color or a different heights in screens serve another purpose as a practical emphasis on the difference in activity zones.

Fig 3 show the engineering using a ray-tracing computer model in the Catt program to research the effect of separating elements made of glass including absorption panels. The model with a glass wall between the activity zones (fig 3b) shows a relevant increase of the spatial decay rate up to 10 dB in the longitudinal direction and the diagonal direction. Noted is that this effect was also measured in real time situation later on. Fig 4 shows the final design of the new office plan with the different zones of activities highlighted in yellow and blue separated by glass walls of a meeting room or an individual glass wall. Absorption panels are located on the glass walls to avoid bothersome effects like flutter echoes between parallel walls and sound reflections ‘around the corner’ and deep into the open plan office.

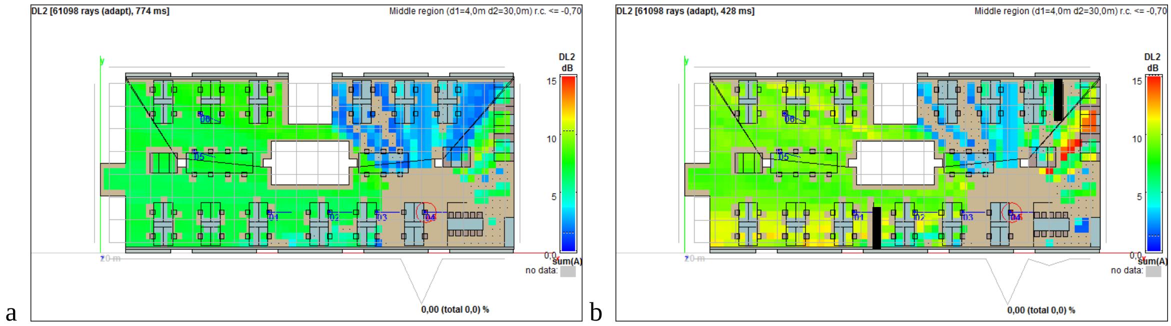

Fig. 3. modeling results of spatial decay rate $D_{L2,S}$ [dB]
(a) without separating glass wall including absorption panels
(b) with separating glass wall including absorption panels (black lines)

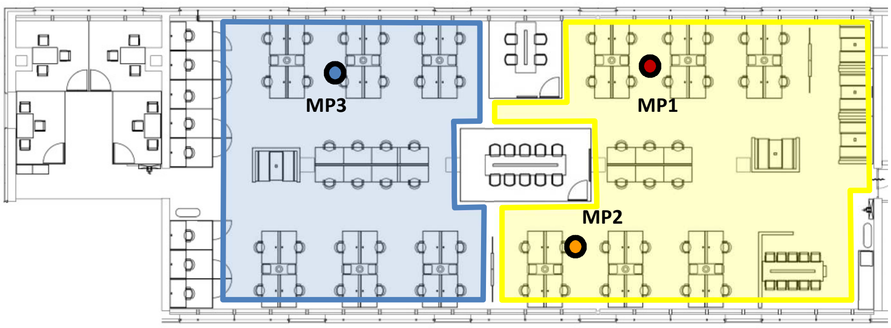

Fig. 4. new design office plan with activity based working:
- open plan office divided in zones (yellow zone more interactive, blue zone: quiet less interactive)
- closed office cells for specific tasks (meeting rooms, concentration cells, conference calls).

3.3. Control measurements and conclusions

The results of the control measurements for building and room acoustics made sure the aimed values were met for speech discretion and acoustic comfort in general. The activity noise levels were measured before and after as seen in fig 5. The percentage of exceeding the maximum level of 55 dB(A) for office activities has significantly lowered in the ‘after’ situation.

The conclusion can be drawn that the separation of activities provides a more clear division between noisy activities and quiet activities. Activities with a high level of noise activity are set apart from the open plan office by locating them in closed meeting rooms and closed conference call rooms. The more quiet office activities can be performed in closed concentration cells or in the quiet zone of the open plan office.

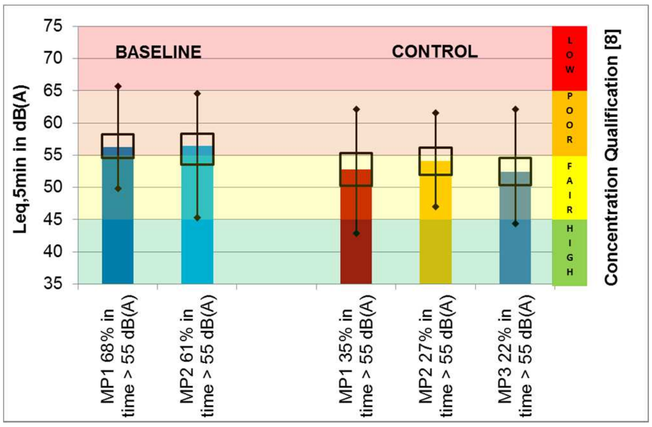

Fig. 5. results activity noise levels comparison baseline and control measurements (monitoring positions are given in fig 2 and 3).

The interactive process between the organization and the acoustic experts has led to a satisfying design of the (semi-) open plan office following the principle of an activity based working environment. The acoustic measurements gave a valuable contribution in creating a sustainable office environment with good acoustics within the restrictions of the retrofit building.

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