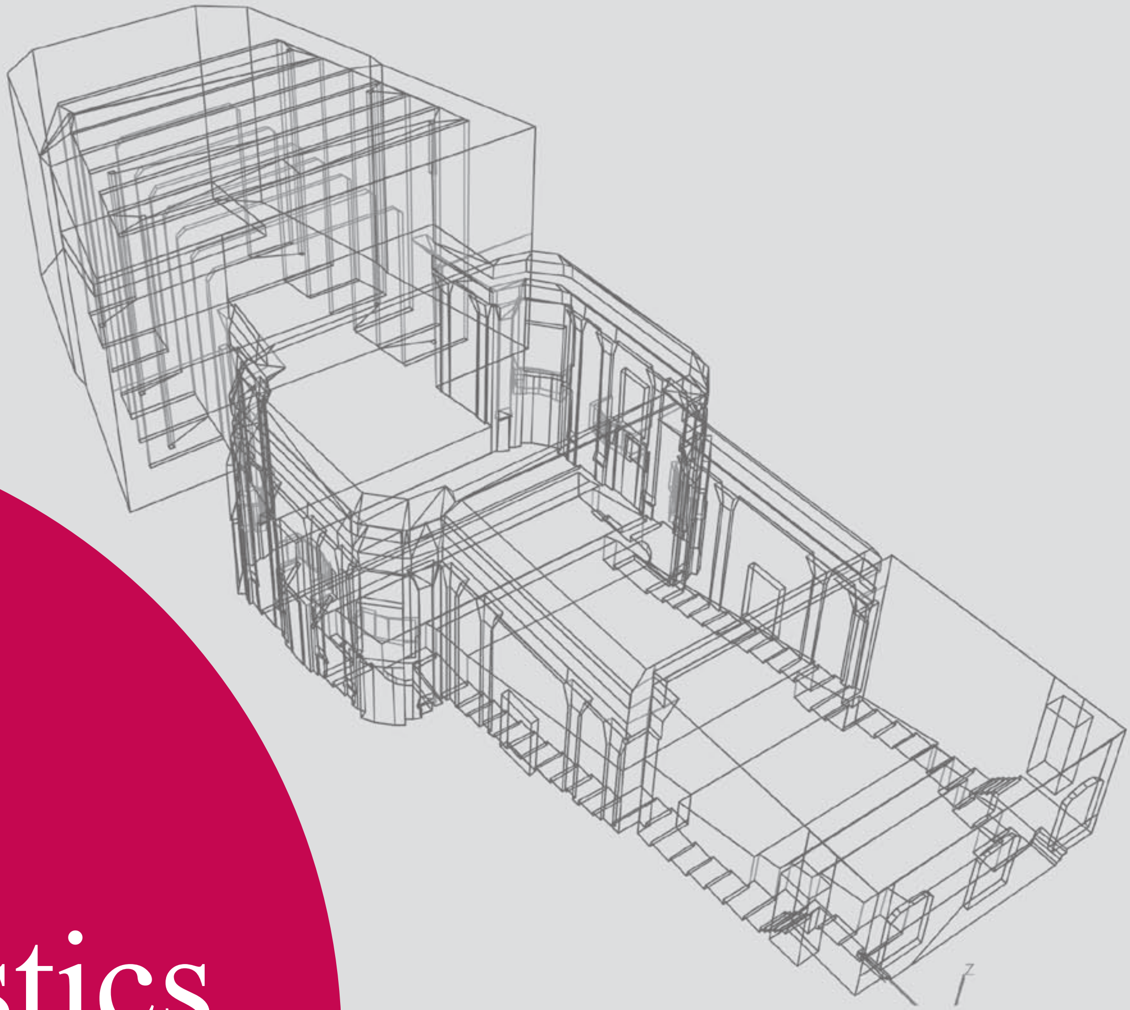

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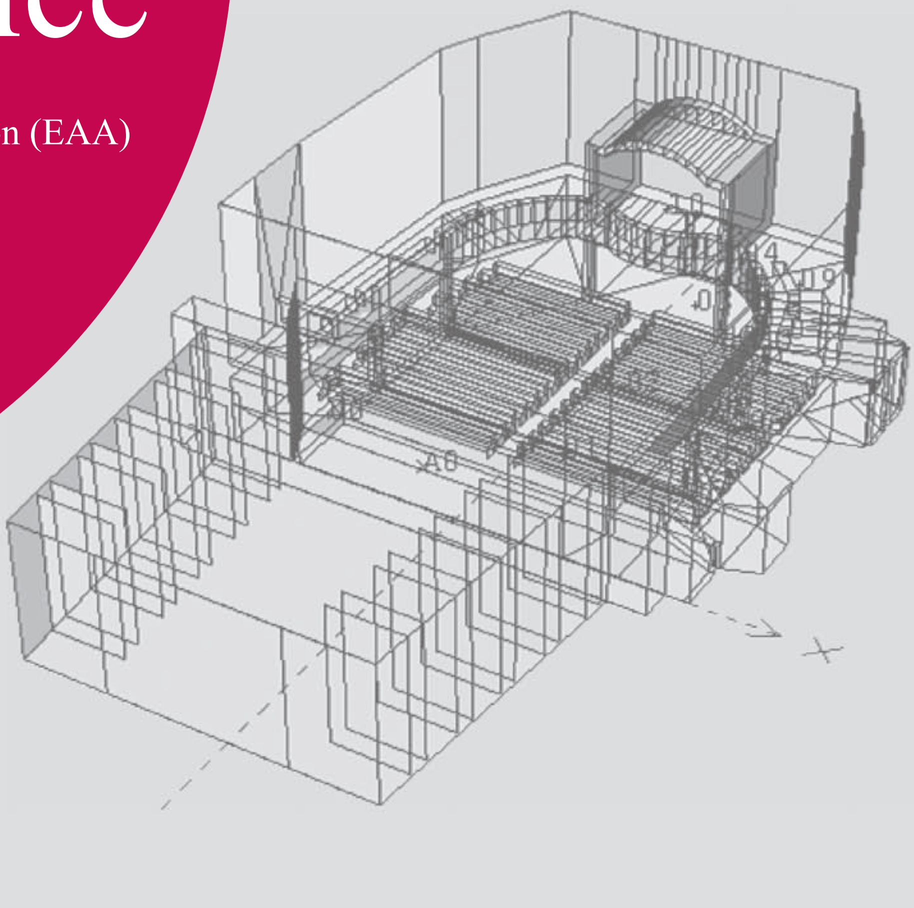

Defining the Acoustic Environment of (semi-)open Plan Offices

Acoustic Measurements leading to Activity Based Design for retrofit Buildings

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ABSTRACT

Before creating a new activity-based design in retrofit buildings projects the existing acoustic environment is carefully measured. Not only the acoustical qualities of the existing building and facilities are measured (according to NEN 5077 for sound insulation, ISO 3382 for room acoustics and ISO 3382-3:2012 for room acoustics in open plan offices), but also the actual behaviour of people is measured as well as this is a very important input for defining the acoustic environment. During a representative week of working hours, the sound levels are monitored at different locations in the open plan office. 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 provides a good starting point for redesigning a diversity of office environments. Often the new design leads to activity-based office plans, where the different activities are carefully projected in a (semi-) open plan office. Practical measurement data of office noise levels are presented and analysed.

1. INTRODUCTION

Working in an office environment includes many different activities. Communication on the phone, social interaction and meetings produce not only sound, but are also require good speech intelligibility and therefore need good room acoustics. Difficult performance tasks require different acoustic conditions. Areas with a quieter environment are needed so the level of distraction from surrounding activities is minimised. In the same office environment there is also a need for areas with a high level of interaction for the purpose of teamwork. Because the different activities ask for specific acoustic conditions, the existing acoustic environment is first mapped before creating a new office environment in an existing retrofit building.

2. NORMS AND RESEARCH

The ISO 3382-3 [1] norm provides guidelines for measuring building characteristics for open plan offices. An important statement is that concentration and privacy start to improve rapidly where the speech transmission index falls below 0,50. This statement is reinforced by Jahncke, Hongisto and Virjonen [2] where the effects of speech intelligibility have been studied for different office tasks. This work demonstrates that attempts to minimize speech intelligibility will yield increases in cognitive performance with a varying degree, depending on the type of focus task.

The corresponding distance for an STI below 0,50 is defined as the *distraction distance* r_D. This is the distance between the receiver and the speaker. The distraction distance is defined based on STI measurements combining the receiver levels of speech $L_{p,A,S}$ and the levels of background noise levels $L_{p,A,B}$. The built environment of the office without the existing background noise levels can be defined by the spatial decay rate of A-weighted SPL of speech $D_{2,S}$. The room acoustics can be defined by measurements as well as by predictions using computer modelling [3], [4]. Keränen and Hongisto [5] present a regression model for predicting the spatial decay. Their research has shown an acceptable prediction accuracy for most practical purposes.

However, the actual behaviour of people and how many people are talking at the same time is often not taken into account in defining the acoustic environment. The effects of unattended speech on

Figure 1. Open plan office (source www.bbc.com/news/magazine-23502251 "The decline of privacy in open-plan offices").

performance and subjective distraction have recently been studied by the Finnish Institute of Occupational Health and the University of Turku [6]. The speech conditions differed in terms of the degree of absorption, screen height, desk isolation and the level of masking sound. The actual sound level of the unattended speech is not taken in account as such, but can be regarded as varied in the distance to the receiver (2 to 6 metres). For all situations the distraction was rated higher for the nearby speech as opposed to the speech heard from a further distance. However, this result has to be seen as a combination of a level increase and an increase of intelligibility and cannot be used as an evaluation of purely the effect of the sound levels. In 2005 Chigot presented an overview of 11 abstracts on the topic of effects of sound in offices - subjective experience versus objective assessment [7]. Besides parameters as 'satisfaction with privacy' the sound level is often mentioned in relation to an increase of subjective workload [8] and a decrease of cognitive performance in memory tasks [9]. As an important comment on the research of Tang [10], Chigot mentions that $L_{A,eq,\ 5\ min}$ correlates the best with human auditory sensation.

3. OFFICE NOISE LEVELS

In 1978, some interesting information was published about office noise levels in the Acoustical Designing in Architecture [12]. A comprehensive survey of the noise in several thousand locations was conducted by the Bell Telephone Laboratories in order to determine typical noise conditions indoors and outdoors. The noise levels are a combination of three broad classifications: people, machinery and outdoor sources. For 45 per cent of the business locations people were the predominant source of noise, followed by machinery in 25 per cent of the locations and outdoor sources in 30 per cent of the locations.

We have collected a lot of data of noise levels in our measurements in open plan offices floors. During a representative week of working hours, the noise levels have been measured in different buildings with different types of workplaces. All measurements were conducted in open plan offices (> 10 desks).Measured data are presented in Figure 2 that show a comparison of office sound levels through history We conclude that the noise levels of modern day offices are substantially lower compared with those in the seventies of the twentieth century. The old fashioned loud typewriters and hard acoustic environments will probably have been a cause of this.

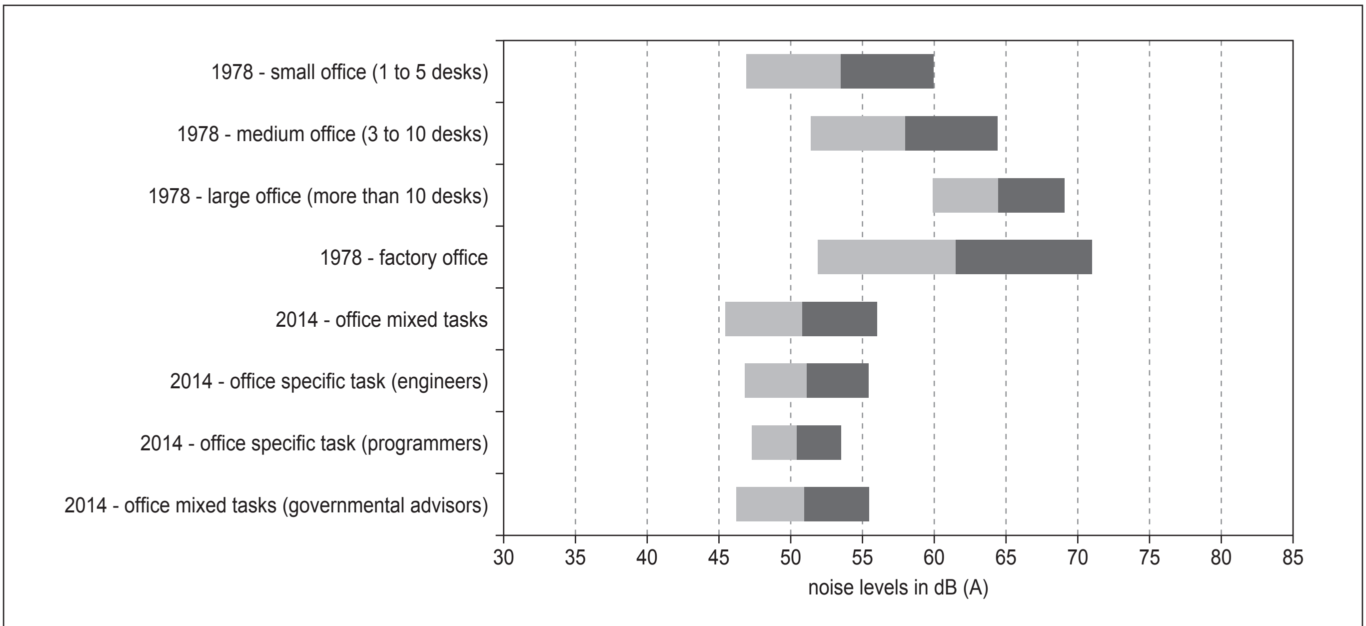

Figure 2. Noise level data (mean value -/+ standard deviation), comparison data 1978, United States of America, D.F. Seacord [1] and data 2014, The Netherlands, M+P.

4. STATISTICS OF MODERN DAY NOISE LEVELS

In Figure 3 the noise levels in modern day offices in The Netherlands measured by M+P are presented in a histogram. The data for offices with mixed tasks were collected for one working week from 9 to 5 for 8 offices with 2 or 3 monitoring positions per office. The curve of the histogram shows the curve of a normal distribution. The remaining data in the histogram were collected from 1 or 2 buildings for the specific office tasks (engineering, programming, governmental advisors). The main characteristic is that all measurements have a mean value of 50 to 51 dB(A). The difference is especially noticed in the standard deviation. Specific office tasks like computer programming and engineering tasks show a smaller standard deviation (3-4 dB) compared with the mixed tasks (5 dB) as shown in figure 2 and 3 for modern day offices.

4. OFFICES TYPES AND DIMENSIONS AND PERFORMANCE

Modern day offices do not conform to a standard format with fixed workplaces in cellular offices. Because of new ways of working, based on more flexibility, new office environments are being realised in existing buildings as retrofit projects. These days it is seldom found that new offices are being built, so new office environments can seldom be created from scratch. In The Netherlands a lot of the existing office buildings are made ready for refurbishment within the retrofit building project. The pattern of the office lay-out and the use of workspaces is no longer set as a regular pattern with fixed working spaces within cellular offices.

De Croon, Sluiter, Kuijer and Frings-Dresen state in [13] that conventional and innovative office concepts can be described using three parameters: 1. the office location (e.g. telework office versus conventional office), 2. the office lay-out (e.g. open lay-out versus cellular office), 3. the office use (e.g. fixed versus shared workplaces). A systematic review of literature between 1972 and 2004 provides strong evidence that working in open workplaces reduces privacy and job satisfaction. Limited evidence is available that working in open workplaces intensifies cognitive workload and worsens interpersonal relations. Close distances between workstations intensifies cognitive workload and reduces privacy and desk-sharing improves communication.

In 2009 the Finnish Institute of Occupational Health and the University of Turku in Finland performed a longitudinal study during relocation on the effects of the acoustic environment on work in private office rooms and open plan offices [13]. The aim was to determine how the perceived work environment –especially acoustic environment– and its effects differed in private office rooms as opposed to open-plan offices. Room descriptors showed a significant reduction in speech privacy after relocation. The noise level averaged over the whole working day did not change, but the variability of noise levels reduced significantly. Negative effects of the acoustic environment increased significantly, including increased distraction, reduced privacy, increased concentration difficulties and increased use of coping strategies. Self-rated loss of work performance because of noise doubled and cognitively demanding work and phone conversations were most distracted by noise. The article states that the results suggest that the open plan office is not recommended for professional workers.

5. (SEMI-)OPEN PLAN OFFICES AND ACTIVITY BASED DESIGN

It is important to define the existing office environment before starting a new office floor design. The variation can be found in office design, building acoustics and the activities of the workers. In Table 1 variations with

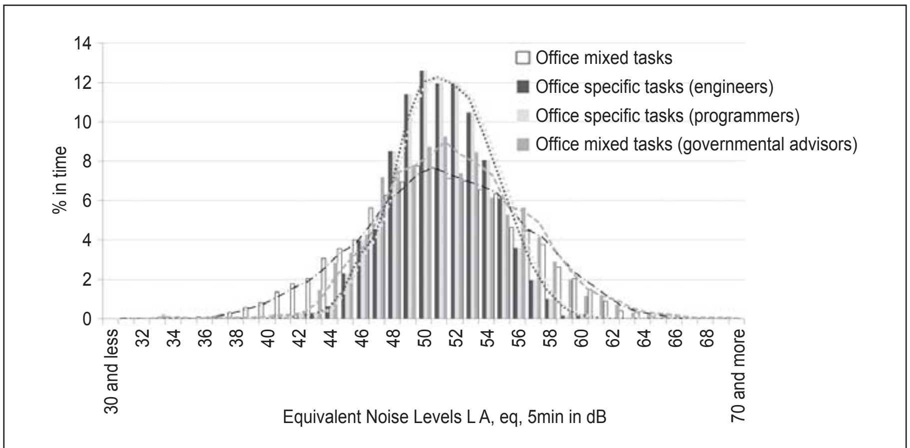

Figure 3. Histogram noise level in modern day offices measurement data M+P.

Table 1. *Defining the variations with associated parameters for defining the (acoustical) environment*

	Variation	Choices	Acoustical parameters
Office design	LAY-OUT	open / semi-open / closed	–
	USE	permanent versus flexible (desk-sharing)	–
	TYPE	mixed or activity based	–
Measurements building acoustics	ABSORPTION/ AVOID REFLECTIONS	ceilings, wall panels, furniture, interior elements	reverberation time T spatial decay $D_{2,S}$ STI
	ROOM INSULATION	walls, ceilings, floors, facades, doors, windows	sound insulation $D_{nT,A}$
	SCREENS	screens, walls, rooms, cabinets	spatial decay $D_{2,S}$ STI
	INSTALLATIONS	ventilation principles, masking systems	background noise $L_{p,A,B}$ STI/SNR
Measurement behavioural Acoustics	–	–	sound level ($L_{max,}$ L_{eq}) recording wave-files (defining sound source, type of sound)

associated parameters and choices are stated for defining the (acoustic) environment.

Based on the measured noise levels in modern day office buildings, the required distances have been calculated for the design of new office environments. The assumptions are a background noise level of 40 dB(A), a signal to noise ratio for speech of 3 dB and a spatial decay of 8 dB. These values are set as quite representative for modern Dutch office design as seen as in Figure 4.

6. RECOMMENDATIONS

For open plan office environments we recommend a semi-open structure which provides some screening

Figure 4. *Modern modern day office in The Netherlands (semi-open, activity based).*

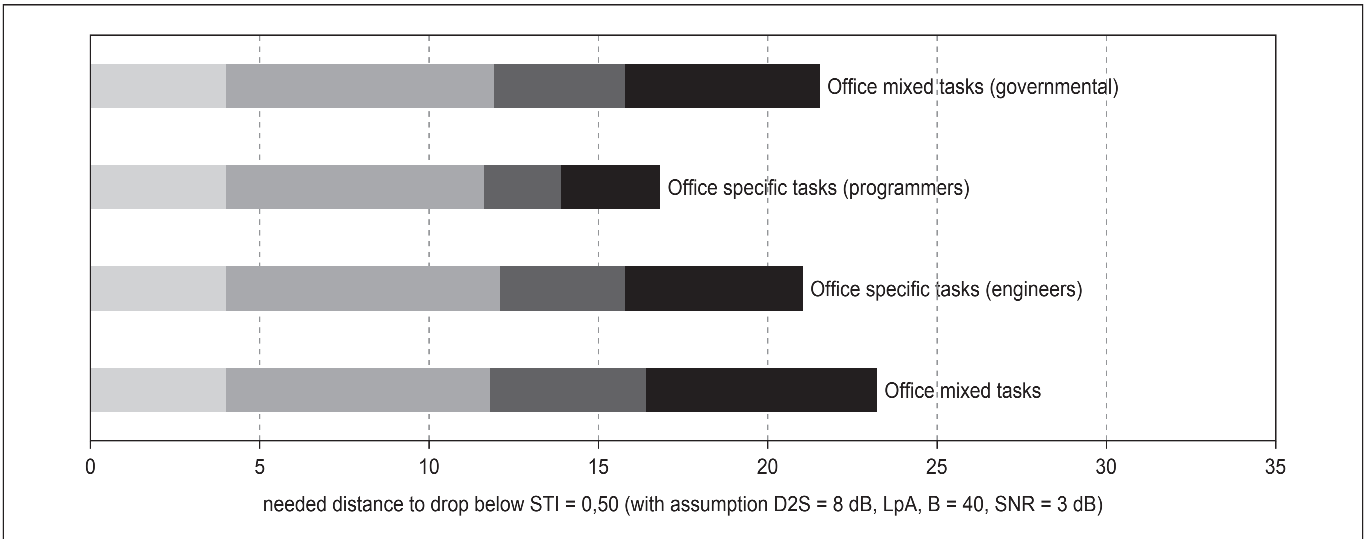

Figure 5. *Required distance for STI to drop below 0,50 (distraction distance r_D) for different design criteria (98% of time corresponding to mean value+2*st.dev.. 85% of time corresponding to mean value+1*st.dev. or 50% of time corresponding to the mean value of measured noise levels).*

and divides different areas in the working space. This results in a corresponding spatial decay of about 8 dB assuming that acoustic absorption is provided in ceiling and/or wall absorption. Another possibility is to create zones varying from silent to more interactive. Activity-based work provides the possibility of reducing the design distance between work departments (working groups) as seen in Figure 5. The bars corresponding to specific office tasks show a smaller standard deviation. Because of this a much smaller design distance is required. To achieve a distraction distance r_D (STI < 0.50 for 98% in time, a design distance is needed of about 23 metres in a mixed tasks office. In a specific task office this distance decreases to about 17 metres.

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