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Room acoustical measures for open plan spaces

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In a Nordic cooperation project the acoustical conditions in five open-plan offices (OPO) was investigated. A measurement program was established were the room acoustical parameters, the measurement procedure and the equipment was described. The staffs' opinion about the working environment was investigated by a questionnaire. The results from the inquiry are not reported in this paper. The room acoustical parameters measured are EDT, T_{20}, D_{50} according to ISO 3382:1, STI and SII according to IEC 60268-16, ANSI S3.5-1997, respectively, DL_2 and DL_f according to ISO 14257:2001. Both directional and omni-directional sound sources were used in the measurements. In this paper some of the results will be presented. It is emphasized that the acoustical environment in open-plan spaces requires an evaluation procedure that differs from ordinary rooms. A fundamental purpose of the acoustical design in OPO is to secure that different working groups not disturb each other. In that respect measures related to the decrease of sound pressure level with distance is useful.

1 Introduction

The open-plan offices (OPO) has become a common working place for many people in today's society. A purpose of OPO is to create an environment for both concentration and communication. Sometimes these demands are contradictory and difficult to fulfill. The main source of disturbance in an OPO is people communicating by speech or by talking on telephone [1, 2, 3]. To overhear speech could be of benefit for people in the same working group but a disturbance if it is irrelevant information from neighboring work places. To create an acoustical environment both for concentration and communication without disturbance between different working groups is the main task for the acoustical design process. For this process it is of course important to know which room acoustical quality aspect to focus on and the acoustical parameter rendering this quality. In ordinary rooms it is common to use room acoustical parameters, like reverberation time, as an overall descriptor of the acoustical conditions. In OPOs many of the ordinary room acoustical parameters varies with the distance from the sound source and for that reason are difficult to use as representative for the acoustical conditions.

Measurements have been performed in five OPO. In order to coordinate the measurement a measurement specification was established were the parameters, performance of measurements and how to report was specified. The staff at the OPOs has also to fill in a questionnaire, however the results from the inquiry will not be discussed here. In this paper some of the results from the measurements will be presented.

2 Method

The measured room acoustical parameters are listed in Table 1. Measurement positions were chosen along lines in the offices as illustrated in figure 1. The speech intelligibility parameters STI and SII was measured both with a directional and omni-directional loudspeaker. The directional loudspeaker fulfills the requirements in ASTM E 1179-87. Other parameters were measured with the omni-directional loudspeaker.

The background noise levels was, if possible, measured for the cases

1. Normal activity
2. Without staff but with ventilation noise on
3. Without staff and with ventilation noise off

The frequency region, where appropriate, was 50 to 5000 Hz in third octave band. The parameters were measured according to relevant standard. For the sound propagation measures DL_2 and DL_f an omni-directional loudspeaker was used as a sound source. The loudspeaker emits a pink noise signal at a constant sound power level. The sound propagation values DL_2 and DL_f was evaluated for the octave band 125 to 4000 Hz and for the dB(A) values.

Parameter	Designation	Unit	Explanation	Standard
Early Decay Time	EDT	s	Speed at which sound disappears	ISO 3382-1/2
Reverberation time	T20	s	see above	see above
Clarity of speech	D_{50}	%	Measures the effect of the early reflections	see above
Speech Transmission Index	STI	-	Quality of speech transfer from speaker to listener	IEC 60268-16
Speech Intelligibility Index	SII	-	see above	ANSI S3.5-1997
Rate of spatial decay of sound level per distance doubling	DL_2	dB	Measure sound decreases with distance from sound source	ISO 14257
Excess of sound level rel. free field	DL_f	dB	Measure of room's contribution to the sound level at different distances	see above

Table 1 Room acoustic parameters

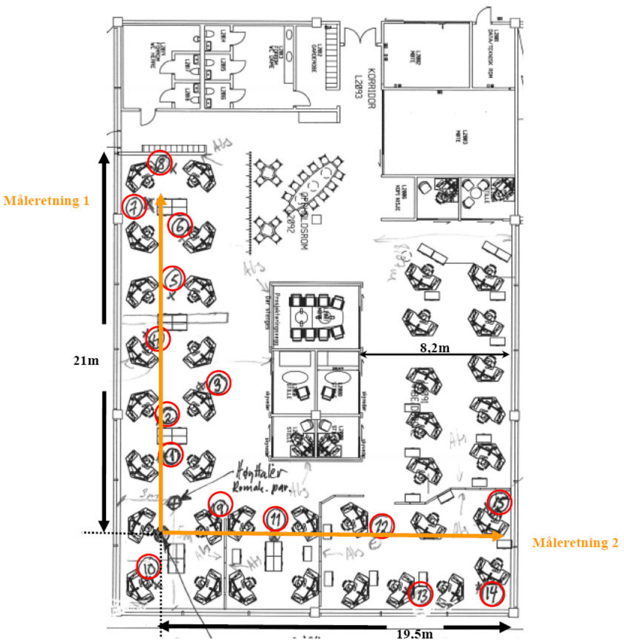

Figure 1. Example of plan drawing in OPO 1 with measurements positions and directions marked.

The measurements have been performed in furnished rooms. The loudspeaker and microphone was located at working positions, at the height 1.2 m (so simulating a person seated). The distance between the loudspeaker or microphone and any screen or wall was not less than 1 m.

3 Results

Representative values for the different parameters will be presented here. Where appropriate the parameters are averaged over the octave band frequencies 500 and 1000 Hz. The parameters are also averaged over all microphone and source positions. However, the behaviour of the parameters as a function of distance from the source is illustrated for some of the parameters. The offices are numbered 1 to 5 and simplified plan drawings with measurement positions are shown in paragraph 4.

3.1 Background noise levels

In table 2 the background noise levels in dB(A) and dB(C) are shown. Background noise levels has been measured both during normal activity with ventilation system on and without activity but with the ventilation system on.

OPO	$L_{A,eq}$ (dB)		$L_{C,eq}$ (dB)	
	activity	no activity	activity	no activity
1	51	33	58	50
2	48	29	56	46
3	-	28	-	44
4	53	27	60	49
5	52	42	56	51

Table 2 Background noise levels

3.2 Reverberation times

The reverberation times EDT and T_{20} are given in table 3. The values correspond to the average for the octave band frequencies 500 and 1000 Hz.

OPO	EDT (s)	T_{20} (s)
1	0.47	0.48
2	0.47	0.47
3	0.49	0.48
4	0.49	0.51
5	0.64	0.57

Table 3 Reverberation times

The variation of T_{20} as a function of the distance from the sound source is shown in figure 2 for OPO 2.

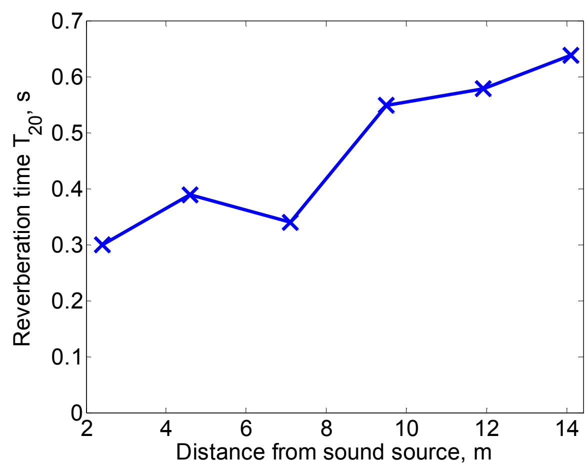

Figure 2 T_{20} as a function of distance from source

3.3 Speech intelligibility

The speech intelligibility has been quantified by the measures STI, SII and D_{50}. When measuring STI and SII both a directional and an omni-directional loudspeaker was used. The D_{50} values correspond to the average for 500 and 1000 Hz octave band. The parameters were measured with no activity in the room but with the background noise from the ventilation system present. The results are given in table 4.

OPO	Omni	Directional	Omni	Directional	D_{50} (%)
	STI	STI	SII	SII	
1	0.47	0.60	0.78	0.71	76
2	0.51	0.47	0.86	0.80	74
3	0.65	0.64	0.85	0.82	74
4	0.67	0.74	0.90	0.90	76
5	0.41	0.35	0.59	0.46	61

Table 4 Speech intelligibility

The variation of STI as function of distance from the sound source is shown in figure 3 for OPO 2.

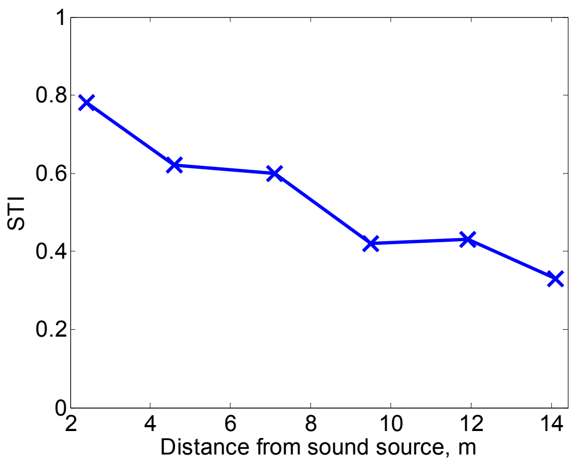

Figure 3 STI as a function of distance from source

3.4 Sound propagation

The sound propagation is characterized by the parameters DL_2 and DL_f. DL_2 correspond to the decrease in sound pressure level per distance doubling. DL_f measure the excess of the sound pressure level compared to the sound pressure level in a free field at the same distance. An omni-directional loudspeaker with constant sound power, emitting a pink noise signal, was used as a sound source. In each office the decrease of the sound pressure level was measured along two lines. The parameters are estimated for the range 3 to 10 meters along these lines. The results presented in table 5 constitute the average for the two measurement path.

OPO	DL_2 (dB)	DL_f (dB)
1	3.3	6.7
2	4.5	7.8
3	6.6	5.8
4	4.5	7.5
5	5	5

Table 5 Decrease in sound pressure level as quantified in the measures DL_2 and DL_f.

4 Plan drawing of offices

Figure 4 to 6 shows the measuring path in OPOs 1 to 3.

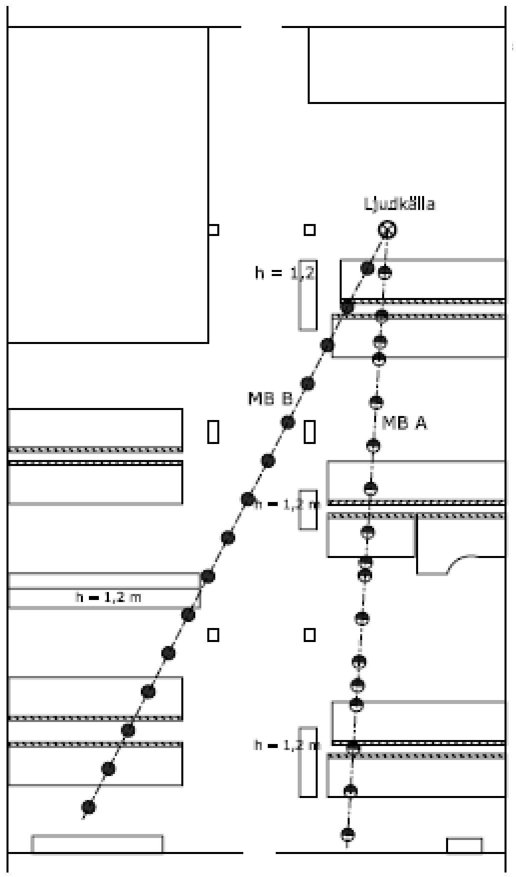

Figure 4 OPO 1.

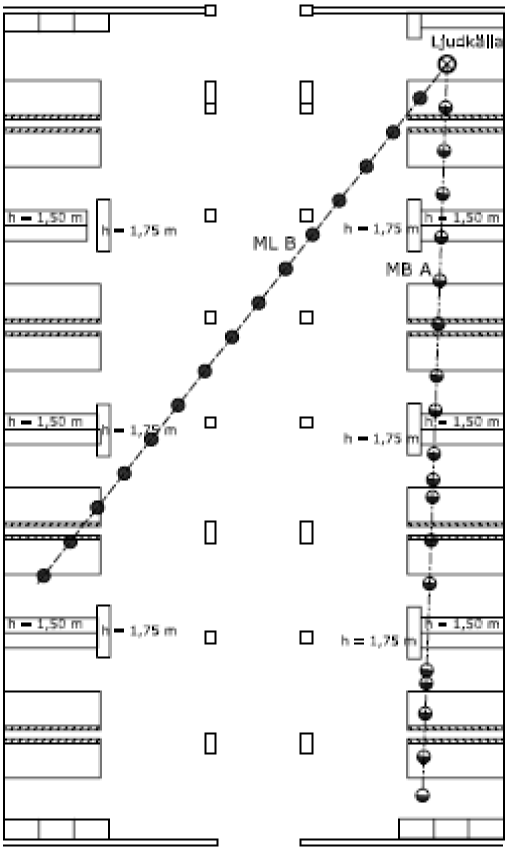

Figure 5 OPO 2.

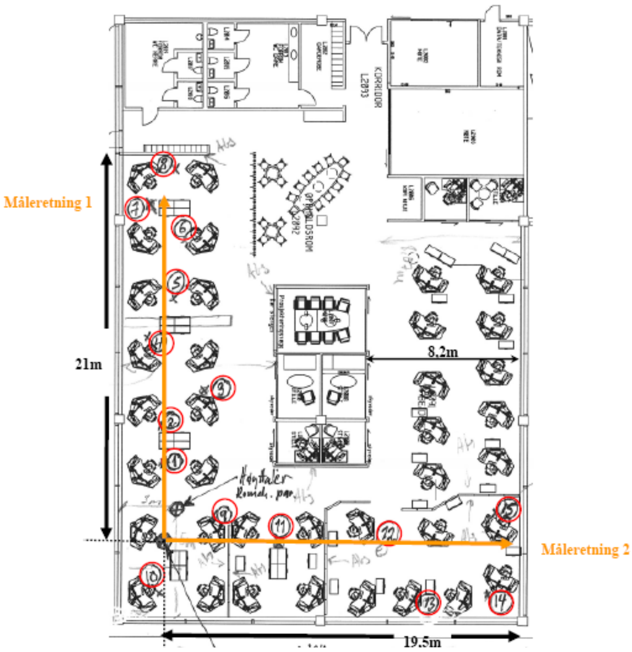

Figure 6 OPO 3.

5 Comments

The main acoustic source of disturbance in an open plan office is usually speech. It is therefore important that people who need to communicate sit near each other while, at the same time, different work groups must be sufficiently separated acoustically not to disturb each other. A central question is how the acoustic planning will affect the propagation of the sound. In order to achieve acceptable acoustic conditions in an open-plan office at all, a sound absorbing ceiling is a necessity. The ceiling must have a high absorption factor and be installed at as low level as possible to have the best possible acoustic effect. An absorbent ceiling reduces the sound level and increase the rate at which the sound level decrease over distance. This also means that the distance required between work stations in order to achieve an acceptable level i.e. a speech level that does not disturb or distract, will be shorter. The descriptors DL_2 and DL_f are related to the gradient of the sound propagation curve and the decrease in the sound pressure level, respectively. By increasing DL_2 or by decreasing DL_f the distance to the place where the sound level (speech level) is no longer disturbing will have decreased. Thus, both measures have to be considered.

6 Conclusion

There is a need for complementary parameters for the evaluation of OPOs. Ordinary room acoustic parameters like reverberation time, which normally is used as an overall acoustic descriptor in ordinary room, typically varies with distance in OPOs. Measures related to sound propagation like DL_2 and DL_f seems more applicable for the conditions in OPOs.

Acknowledgments

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