Acoustical simulation of open-plan offices according to ISO 3382-3

Jens Holger Rindel and Claus Lynge Christensen
Odeon A/S, Scion-DTU, Diplomvej 381, DK-2800 Kgs. Lyngby, Denmark.

Summary

In the new international standard ISO 3382-3 the measurement procedure for open-plan offices is described and a number of new room acoustical parameters for the objective evaluation are defined. Among the new parameters are the privacy distance and the distraction distance, both derived from the STI (speech transmission index). With room acoustic simulation software these measurements can be simulated, thus providing a tool for the acoustical design of open-plan offices. The paper presents an example office with a range of alternative acoustical solutions that include different amount of absorption, screens of different height, and different levels of background noise. Also the influence of dynamic background noise from people talking can be taken into account, leading to a significantly reduced privacy distance. The computer simulations provide a background for evaluating the efficiency of various acoustical measures in open-plan office design.

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1. Introduction

In open plan offices the acoustical conditions can be influenced by different measures including the amount of sound absorption, the introduction of screens and the level of background noise. Thus, it is quite obvious that the reverberation time, being the classical room acoustical parameter, cannot be a good measure to characterize the acoustics of this kind of space. Further more open plan offices tend to be large and flat rooms with uneven distribution of the absorption on the surfaces, which means the at the sound field is far from diffuse, and the reverberation time is not well defined. Thus the working group dealing with room acoustical measurements, ISO/TC 43/SC 2/WG 19, decided to suggest new room acoustical parameters specifically for open plan offices, and the result is laid down in the new standard ISO 3382-3 [1]. Although this is a measurement method, the same procedure can be simulated in room acoustic prediction software, which may provide an efficient tool for the design of open plan offices. This paper gives examples of how the new standard can be applied for predicting the efficiency of various acoustical measures in open plan office design.

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2. Speech spectrum for room acoustical measurements and calculations

In room acoustics a sound source is best described by the radiated sound power, and thus the spectrum of the source should be given as sound power levels, e.g. in octave bands. In an open plan office the main source of disturbance is speech, and thus the measurements laid down in ISO 3382-3 are based on a source emitting sound with a typical speech spectrum. A good reference for an average speech spectrum is ANSI 3.5 [2], which gives the average spectrum of male and female speech for various levels of vocal effort. The normal vocal effort is used here, and the octave band SPL (Sound Pressure Level) in a distance of 1 m in from of the mouth is as given in Table 1, except for the 125 Hz value, which has been estimated since it is not included in ANSI 3.5. In order to convert these data to the preferred sound power levels, it is necessary to know the directional directivity in each octave band for a human speaker. Fortunately, such directivity data are available [3] and have been applied to derive the octave band sound power levels given in Table I.

Table I. Speech spectrum in octave bands for normal speech, SPL in a distance of 1 m on axis for directional source and sound power levels as applied in ISO 3382-3 [1].

Frequency, Hz	125	250	500	1000	2000	4000	8000	A-weighted
$L_{p,S,1\,m}$ dB re 20 µPa	51,2	57,2	59,8	53,5	48,8	43,8	38,6	59,5
$L_{W,S}$ dB re 1 pW	60,9	65,3	69,0	63,0	55,8	49,8	44,5	68,4

In ISO 3382-3 it is stated that an omnidirectional source shall be applied, and for several good reasons. One reason is that the orientation of people speaking in an open plan office may not be well defined; actually it could be considered to take an average of all directions in a horizontal plane. Secondly, it would be technically complicated to make realistic and sufficiently accurate specifications for the directivity of a directive sound source, whereas the omnidirectional sound source is well established in room acoustical measurements.

3. Acoustical parameters for open plan offices

3.1. Source and receiver positions

It is essential that calculations are made in a furnished office, so the workstations can be identified. Source and receiver positions are in workstations in a height of 1.2 m above the floor. The calculations are made from a source position to a number of receiver positions in different distances, and as far as possible located along a line, although this is not mandatory. The parameters can be divided into two groups, three parameters based on the A-weighted SPL (Sound Pressure Level) and three other parameters based on STI (Speech Transmission Index).

3.2. Parameters based on A-weighted SPL

When the source is radiating a noise signal with speech spectrum the A-weighted SPL is determined in a number of positions with increasing distance from the source. Thus the spatial distribution of the A-weighted SPL can be displayed as a function of the distance using a logarithmic axis for the distance. The spatial decay rate of speech is then determined from the slope of a linear regression line, and expressed in dB per distance doubling, see Figure 2 below. The same regression line is also used to determine the A-weighted SPL of speech at a distance of 4 m. The latter is a parameter that tells how much the source level is influenced by nearby reflecting surfaces, whereas the spatial decay rate is a measure of the efficiency of sound absorbing materials and screens. In addition to these two parameters the average A-weighted SPL of the background noise is also measured/reported. In Annex A of ISO 3382-3 is suggested that a spatial decay rate of speech less than 5 dB is typical for poor acoustical conditions, whereas a value ≥ 7 dB is suggested as a target value for good acoustical conditions.

3.3. Parameters based on STI

The STI is determined in the same positions as the other measurements, i.e. from each source position along a line of receiver positions, all placed in relevant workstations. The impulse response method is preferred because it allows freedom in the choice of background noise, and in case the background noise is not the same in all positions the average over all positions must be used for the determination of STI. For each line the spatial distribution of the STI is displayed using a linear axis for the distance. A linear regression line is calculated and the crossing of the STI values 0.50 and 0.20 are used to define the 'distraction distance' and the 'privacy distance', respectively. See examples in Figure 3 below. In addition to these two distances, the STI in nearest workstation is reported.

In some cases with little or moderate attenuation the privacy distance can only be determined by extrapolation, and it may be greater than the longest dimension on the office, and thus the distraction distance is the more relevant parameter. However, in other cases, typically with good attenuation and high background noise, the distraction distance cannot be determined (extrapolation will give a negative distance) and instead the privacy distance is the more relevant parameter.

The interesting feature of these new distance parameters is that they depend on a combined effect of absorption, screens and background noise. In Annex A of ISO 3382-3 is suggested that a distraction distance greater than 10 m is typical for poor acoustical conditions,

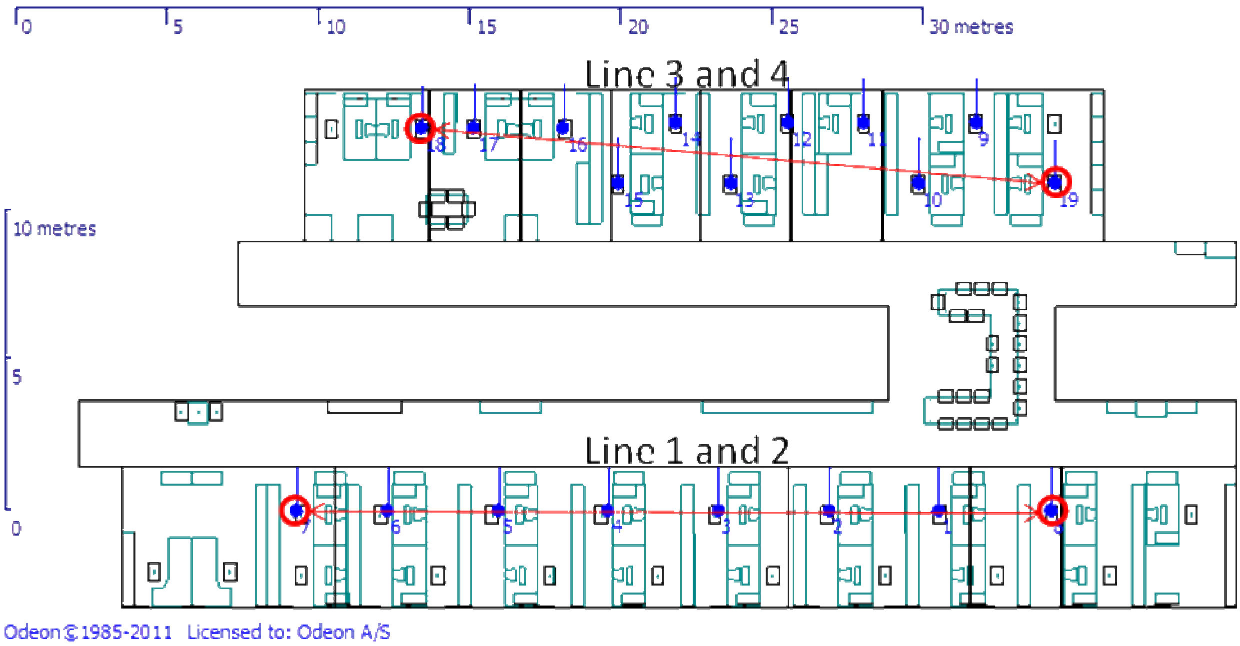

Figure 1. Plan of office with source and receiver positions. Four measurement lines are used, each associated with a point source.

whereas a value ≤ 5 m is suggested as a target value for good acoustical conditions.

4. Open plan office example

The purpose of this paper is to show how the measurements in ISO 3382-3 can be simulated with room acoustical modeling software. ODEON ver. 12.0β was used for the simulations, in which version the new parameters have been included and the regression lines and derived parameters are calculated. The example office is the same as originally measured and simulated by Pop & Rindel [4]. A view of the room model is seen in Figure 1. The office consists of two parallel wings with an open connection. The total length of the longest wing is 36.8 m.

In the longer wing two measurement lines have as shown in Figure 1 have been used, each with a source and seven receiver positions. So, the same line of receivers is used but in opposite direction for the two series of simulations, and similarly for line 3 and four in the other wing.

The average result is calculated for all parameters as shown in the example Table II. The background noise is 38 dB A-weighted with a spectrum decreasing approximately by 3 dB per octave.

Table II. Example of results from the four different measurement lines as shown in Figure 1; here in office 3.

	Line 1	Line 2	Line 3	Line 4	Average
STI in nearest workstation	0,64	0,67	0,75	0,64	0,68
Distraction distance, r_D, in m	8,20	10,14	10,53	7,09	9,0
Privacy distance, r_P, in m	22,38	24,08	21,70	19,13	21,8
Spatial decay rate of A-weighted SPL of speech, $D_{2,S}$, in dB	6,05	6,11	6,74	5,12	6,0
A-weighted SPL of speech at 4 metres, $L_{p,A,S,4\,m}$, in dB	48,5	50,2	50,9	46,0	48,9
Average A-weighted background noise, $L_{p,A,B}$, in dB	38	38	38	38	38

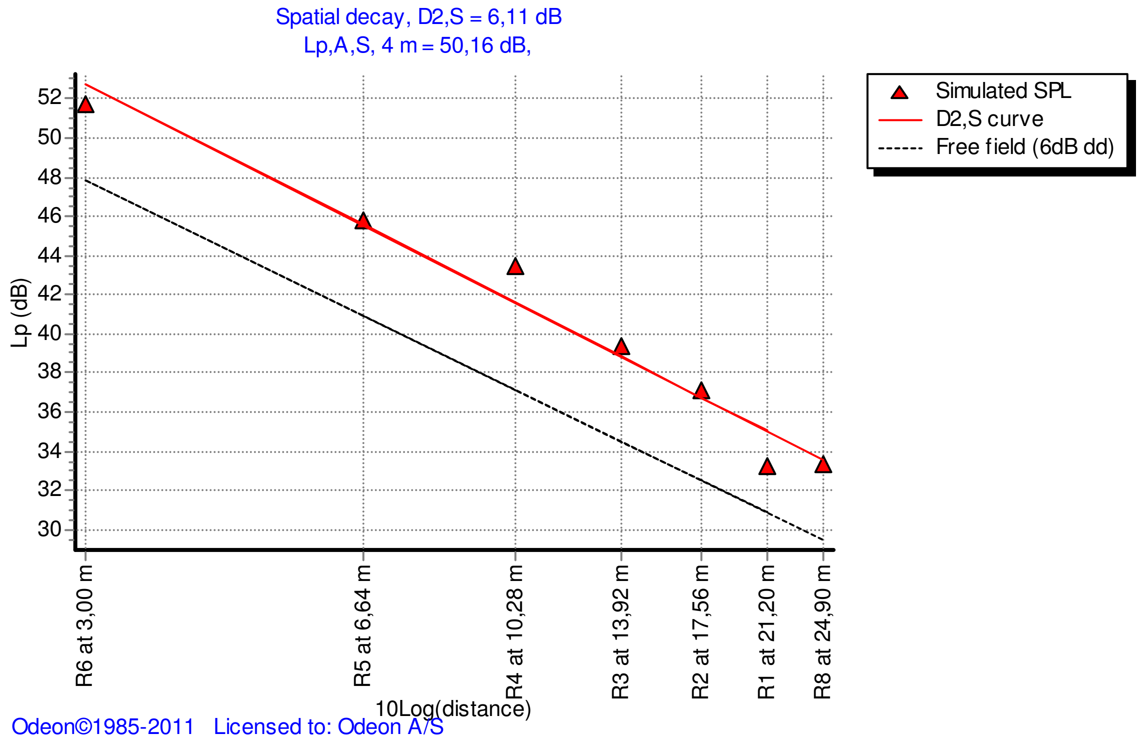

Figure 2. Spatial decay of A-weighted SPL in office 3, measurement line 2. Note the logarithmic distance scale.

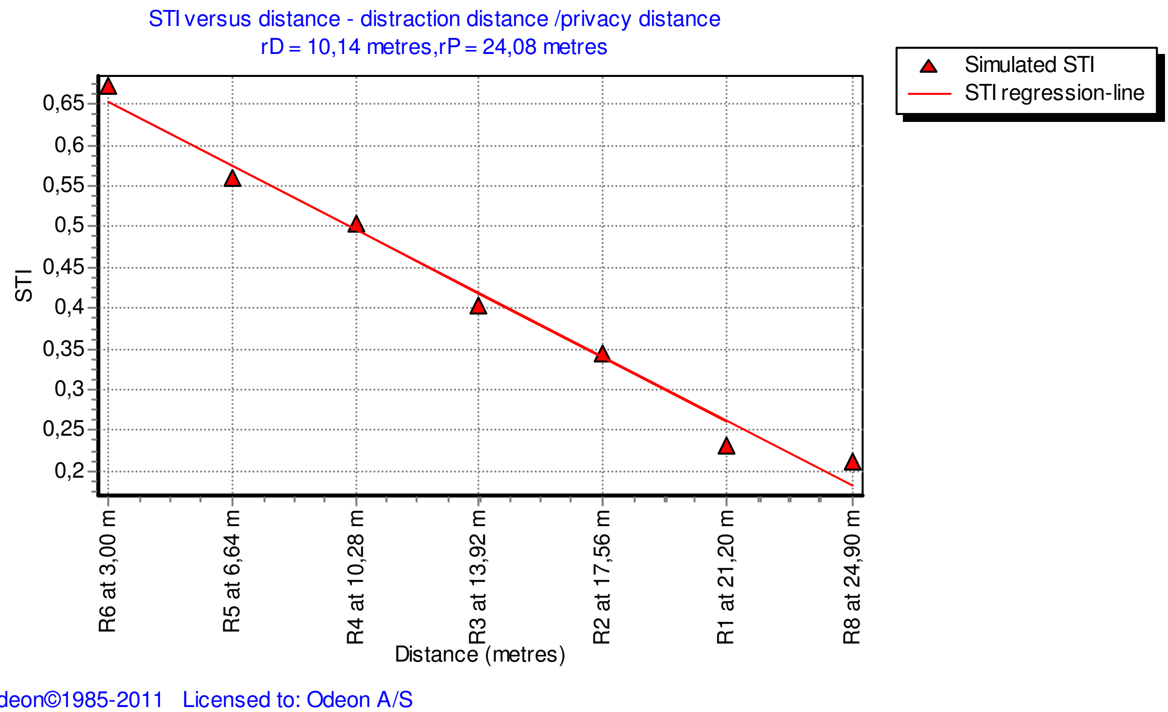

Figure 3. Spatial distribution of STI in office 3, measurement line 2. The crossing of the regression line with STI values 0.50 and 0.20 defines the distraction distance and the privacy distance, respectively.

5. Results

5.1. Influence of absorption

The original office as measured [4] has a sound absorbing ceiling but no screens; this is office 1 in Table III. Two modified versions of the office have also been simulated. Office 2 is much more reverberant because the ceiling is made highly reflecting concrete. Office 3 is more damped than office 1, having additional sound absorbing baffles under the acoustical ceiling, and 1.25 m high screens between the work stations. The results of the computer simulations are shown in Table III.

As expected the variation of the absorption has an influence on the spatial decay rate of A-weighted speech, being more flat in office 2 with the longer reverberation time and steeper in office 3 with the short reverberation time and screens. The A-weighted SPL at 4 m is significantly higher in office 2, but only a little lower in office 3. The spatial decay curves for one of the lines in office 3 is shown in Figure 2.

The variation of the distraction distance is interesting, because it is reduced from about 14 m in office 1 to about 10 m in office 2 and 9 m in office 3. So, this parameter indicates improvements in both cases, either with less absorption or with increased attenuation. With the longer reverberation time in office 2 compared to office 1 the STI goes down, at least in the positions close to the sound source, which is a known behavior of STI. However, in remote positions STI does not change much because the background noise is more important for the STI in positions with a low sound level. So, the distraction distance in office 2 is short because the speech intelligibility is low in a reverberant room, even if the sound level is much higher. In office 3 the distraction distance is also short, but for another reason; when the sound level is reduced by screens and baffles the background noise becomes more important for STI except in the nearest positions, and the slope of the spatial distribution of STI becomes steeper.

Table III. Results from the simulations of three office versions.

	Office 1	Office 2	Office 3
T_{20} (500 - 1000 Hz) in s	0,5	1,1	0,3
STI in nearest workstation	0,71	0,61	0,68
Distraction distance, r_D, in m	13,8	10,1	9,0
Privacy distance, r_P, in m	33,3	37,8	21,8
Spatial decay rate of A-weighted SPL of speech, $D_{2,S}$, in dB	4,4	3,8	6,0
A-weighted SPL of speech at 4 metres, $L_{p,A,S,4\,m}$, in dB	51,0	56,5	48,9
Average A-weighted background noise, $L_{p,A,B}$, in dB	38	38	38

5.2. Influence of screens

Different screen heights have been simulated in office 3; see the results in Table IV. Mainly the spatial decay rate of A-weighted SPL is influenced by the screen height. The distraction and privacy distances decrease with increased screen height,

Table IV. Results from the simulations with different screen height in office 3.

Office 3, Screen height	1,25 m	1,50 m	1,75 m
STI in nearest workstation	0,68	0,67	0,67
Distraction distance, r_D, in m	9,0	8,4	8,0
Privacy distance, r_P, in m	21,8	19,8	18,7
Spatial decay rate of A-weighted SPL of speech, $D_{2,S}$, in dB	6,0	6,6	7,1
A-weighted SPL of speech at 4 metres, $L_{p,A,S,4\,m}$, in dB	48,9	48,6	48,4
Average A-weighted background noise, $L_{p,A,B}$, in dB	38	38	38

Table V. Results from the simulations with different level of background noise in office 3.

Average A-weighted background noise, $L_{p,A,B}$, in dB	40	45	50
STI in nearest workstation	0,64	0,54	0,40
Distraction distance, r_D, in m	7,1	2,5	-
Privacy distance, r_P, in m	19,1	14,0	8,6

but not very much. Other parameters remain unaffected.

5.3. Influence of background noise

Different levels of background noise have been simulated in office 3 (with screen height 1.25 m), see the results in Table V. The spectrum of the background noise has not been changed. Only the STI parameters are shown, since the other parameters are not affected. Increasing the background noise from 40 to 45 dB has a beneficial influence on distraction distance and privacy distance.

In a similar way the dynamic background noise from human activities can be applied in order to calculate the room acoustical parameters in that condition, e.g. a noise level of 50 dB as shown in Table V. However, when the background noise exceeds approximately 45 dB the distraction distance is no longer a meaningful parameter, because it must be extrapolated from the spatial distribution of STI and it can easily take a negative value. Instead the privacy distance may be a useful parameter when the background noise from human activities is applied.

6. Conclusion

The new room acoustical parameters in ISO 3382-3 behave differently when the room acoustical conditions are changed by absorption, screens or background noise. None of the parameters can stand alone, but a combination of parameters is necessary for a sufficient characterization of the acoustical conditions. More research is needed in order to give guidelines for the interpretation of these parameters.

For instance, if looking only at the distraction distance it may be concluded that the more reverberant the better; but this would lead to very noisy conditions. On the other hand, if looking only at the spatial decay rate of A-weighted SPL it may be concluded that the reverberation time should be as short as possible; but this could easily lead to very high intelligibility even for remote sources, and thus a higher risk of distraction during work.

The three office cases studied here have also been used for laboratory experiments in order to study the effect of different acoustical conditions on work performance and human perception and comfort [5]. An obvious continuation of this work will be to examine possible correlations between the new objective parameters and the findings from such investigations on perception, comfort and office work performance.

References

[1] ISO 3382-3 (2012). Acoustics - Measurement of room acoustic parameters — Part 3: Open-plan offices.

[2] ANSI S3.5 (1997). American National Standard – Methods for Calculation of the Speech Intelligibility Index.

[3] W.T. Chu, and A.C.C. Warnock, Detailed Directivity of Sound Fields Around Human Talkers, IRC-RR 104, 2002, National Research Council, Canada.

[4] C.B. Pop and J.H. Rindel. Perceived Speech Privacy in Computer Simulated Open-plan Offices. Proceedings of Inter-noise 2005. Rio de Janeiro, Brazil.

[5] I. Balazova, G. Clausen, J.H. Rindel, T. Poulsen, and D.P. Wyon. Open-plan office environments: A laboratory experiment to examine the effect of office noise on human perception, comfort and office work performance. Proceedings of Indoor Air 2008, Paper ID 703. Copenhagen, Denmark.