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Acoustic assessment of an open-plan office environment against the newly published ISO 22955 acoustic parameters

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ABSTRACT

This paper aims to assess the acoustic performance of an existing open-plan office environment with suspended sound absorbers below a hard reflective ceiling and low workstation dividers against the newly published ISO 22955 acoustic parameters. Room acoustic variables, such as sound absorption, screens between workstations, speech masking sounds and room dimensions all interact in a complex way affecting the values of single-number quantities presented in the ISO 22955 standard. In order to determine the in-situ performance, acoustic measurements were carried out on site. Odeon room acoustic prediction software was utilized to assess the efficiency of various acoustical remedies such as free hanging sound absorbers, wall to wall sound absorbing ceilings, dividers between work areas and increased height of dividers between workstations. The results from the in-situ room acoustic measurements demonstrate that the required value as described in the ISO 22955 standard is not easily achievable in the open-plan office environment without dividers with sufficient height between workstations and modest room acoustic features. The acoustic modeling results confirmed that the required level for the open-plan office, in terms of the ISO 22955 standard, is only attainable with a combination of room acoustic variables that go against modern interior designs.

1. INTRODUCTION

There is an increasing trend worldwide to change from enclosed offices to open-plan office environments. Reasons include reduced cost associated with smaller building footprints and the belief that they promote better collaborative working spaces, social relations, communication and knowledge-sharing between employees. Architects and landowners prefer open-plan offices because of the spaciousness and the space planning flexibility [1].

The conventional open-plan office design, incorporating stand-alone screens and furniture, is usually replaced by either modular workstations, cubicles or linear workstations. The modern trend with which to experiment with the apparent innovative designs such as ‘activity-based workplaces’ and other variations where partial height screens between office workstations are absent or much reduced in size, is in conflict with acoustic solutions used to control speech propagation between workstations [2] and employee preference for screens between workstations for privacy [3].

Since the publication of the ISO 3382-3 [4] standard, a few countries have developed guidelines to describe classes of performance for various office settings due to the interpretation of the ISO 3382-3 single number quantities which does not provide a clear description of the target values for different office settings such as individual or collaborative work settings.

The newly published ISO 22955 [5] standard, provides more comprehensive, technical details and recommendations for what constitutes good acoustic quality in various open-plan office settings and defining the most important principles of room acoustic design compared to ISO 3382-3 standard. However, room acoustic variables, such as sound absorption, screens between workstations, speech masking sounds and room dimensions all interact in a complex way, affecting the values of single-number quantities presented in the ISO 22955 standard. Good open-plan office acoustics is only attainable with the use of screens between workstations or work areas and highly sound-absorbing ceilings for individual or collaborative settings. This is in direct conflict with the modern trend where open-plan offices have no screens or very low screens between workstations to provide easy communication between employees.

2. ISO 22955: ACOUSTIC QUALITY OF OPEN OFFICES

The ISO 22955 details some general recommendations for room layout and room acoustics features along with a methodology on workflow and analysis of spaces. The standard also provides guidelines for a number of typical office work activities. It describes their acoustic characteristics, challenges, and specifies acoustic indicators and values to accommodate them individually. The activity types described are:

- Space type 1: Vacant floor – activity still unknown
- Space type 2: Tele- and video communication – mainly focusing on external communication
- Space type 3: Primarily collaborative work – verbal communication with nearby colleagues
- Space type 4: Sporadic collaborative work – verbal communication with nearby colleagues
- Space type 5: Welcoming areas – receiving the public
- Space type 6: Mixed spaces – combining two or more activities in the same space

This paper only focuses on two work type settings namely, primarily collaborative work and sporadic collaborative work. The acoustic indicators and values are presented in Tables 1 and 2.

Table 1: Space type 3- Acoustic indicators and values — Activity mainly based on collaboration between people at the nearest workstation

Interaction	Acoustic challenges	Description, criterion	Target values	Required values
At workstation	Ability to communicate without raising voice	Good to excellent intelligibility at workstation when speaking normally	$L_{\mathrm{Aeq},T} \leq 52$ dB [a]	
Between workstations	Communicating between team members Satisfactory intelligibility within team when speaking normally	Moderate attenuation between same team workstations		Attenuation $D_{\mathrm{A,S}} \leq 4$ dB
On floor plate	Reducing disturbance between teams	Attenuating amplification inherent to room as much as possible by reducing reverberation Reducing noise in room by doubling distance		$T_r \leq 0{,}5$ s [b] $T_r \leq 0{,}8$ s at 125 Hz $D_{2,\mathrm{S}} \geq 8$ dB $L_{p,\mathrm{A,S,4\,m}} \leq 48$ dB

a	During activity
b	Arithmetic mean of times for octave bands centred on 250 Hz to 4 000 Hz.

Table 2: Space type 4- Acoustic indicators and values — Activity mainly based on a small amount of collaborative work

Interaction	Acoustic challenges	Description, criterion	Target values	Required values
Workstation	High level of intelligibility at workstation	Low ambient noise intelligibility good to excellent when speaking at normal level	$L_{Aeq,T} \leq 48$ dB [a]	
Between workstations	Need for discretion among workstations Average intelligibility among workstations	High level of attenuation		Attenuation $D_{A,S} \geq 6$ dB
On floor plate	Reducing disturbance from conversations in other services	Attenuating amplification inherent to room as much as possible by reducing reverberation Reducing noise in room by doubling distance		$T_r \leq 0{,}5$ s [b] $T_r \leq 0{,}8$ s at 125 Hz $D_{2,S} \geq 7$ dB $L_{p,A,S,4m} \leq 47$ dB
a	During activity			
b	Arithmetic mean of times for octave bands centred on 250 Hz to 4 000 Hz.			

The most noticeable parameter in the ISO 22955 standard is the in situ attenuation of speech between workstations, DA,S. The inclusion of in-situ attenuation of speech between workstations, the DA,S parameter is based on research by J. Harvie-Clark, the Apex method [6]. The Apex method can be used to identify acoustic conflicts between different types of use or activity and assist the workplace designer to identify where enhanced in situ attenuation can improve the acoustic conditions for workers, or where less acoustic protection may be adequate. The parameter DA,S is described as an in situ attenuation of speech and is measured between the positions of a seated speaker and seated listener, with source and microphone positions 1.2 m above floor level.
The distraction distance rD in the ISO 3382-3 is not presented under acoustic indicators and values of the ISO 22955 standard. However, the standard mentions that distraction distance must be limited to below 5 meters in recommended usage situations (target values) with the aim of achieving this reduction without the use of sound masking systems.

3. METHODOLOGY

3.1 SITE DESCRIPTION

The open-plan office used in this case study is based on modern industrial interior architecture with hard floor- and ceiling finishes. The open-plan office has complex room geometry with two workstation clusters separated by a printing station. It is used for individual work that is sporadic collaborative. The table-mounted screens have a total height of 650mm (the opaque screen is 300mm and the clear screen 350mm). Sound-absorbing baffles (200mm depth) are suspended 600mm below the concrete soffit and spaced 200mm apart. The walls are largely covered by glass surfaces, brick walls and timber cladding. The case study site has a sound masking system. Site photos can be seen in figure 1.

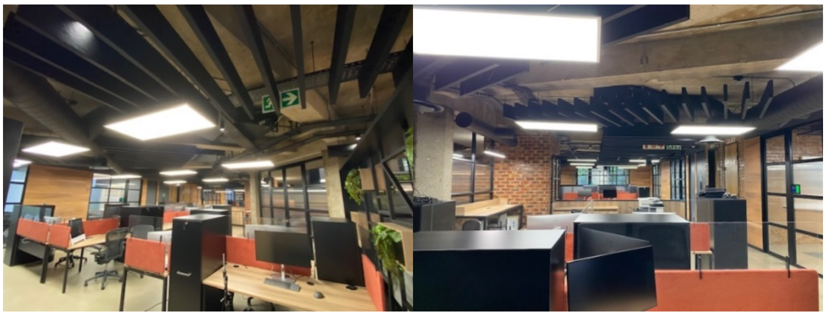

Figure 1: Case study site photos

3.2 TEST AND MODELLING METHOD APPLIED IN THIS STUDY

For this study, in situ acoustic measurements were taken to obtain data from an existing open-plan office to determine the real life acoustic performance of the open-plan office environment. Odeon room acoustic simulation software version 17 was used in this study to evaluate the efficiency of various acoustical modifications. Furthermore, the in situ acoustic measurement results were used to calibrate the Odeon model with Odeon's optimization tool that allows one to refine the materials in a model to match simulation results against the measured results. The acoustic measurements were conducted according to the following standards:

- ISO 3382-3: Spatial decay rate of A-weighted SPL of speech, D2,S, in dB
- ISO 3382-3: A-weighted SPL of speech at 4 meters, Lp,A,S,4 m, in dB
- ISO 22955: In situ attenuation of speech between workstations, $D_{A,s}$
- ISO 22955: Workstation noise level, LAeq,T
- ISO 3382-2: Reverberation time
- ISO 3382-3: Distraction distance, rD, in m

Six measurement lines were used in this study to evaluate the in situ acoustic performance parameters of spatial decay, A-weighted SPL of speech at 4 meters and distraction distance. The in situ attenuation of speech between workstations was measured between the nearest workstations on each measurement line.
The Workstation noise level, LAeq,T was measured at two locations with a time period of 4 hours each and then averaged in order to present a single number value. It is noteworthy that the office was only partially occupied at the time of the measurement and the measured noise levels consisted primarily of noise generated by the HVAC and sound masking system.
The measurement lines/ positions can be seen in Figure 2.

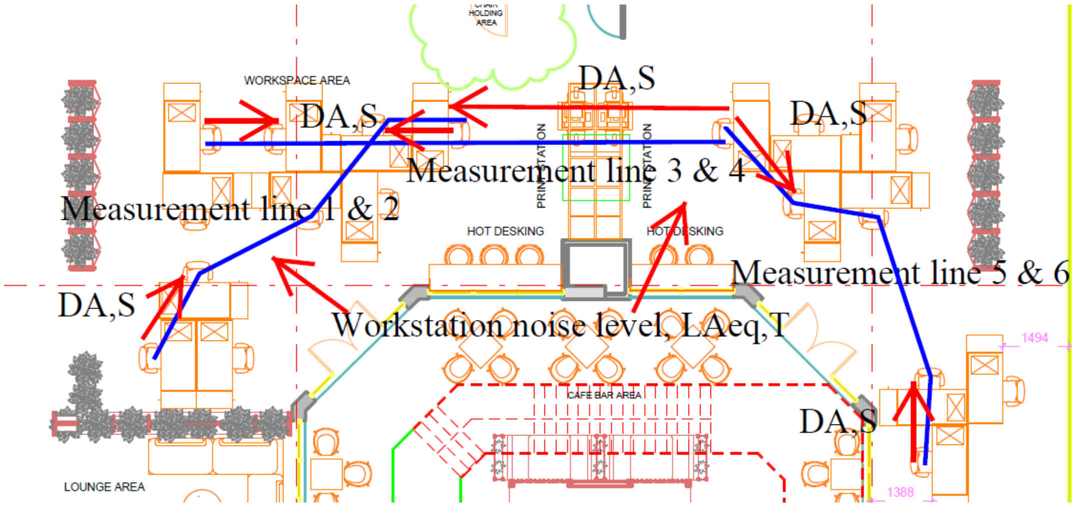

Figure 2: In situ acoustic measurement positions

The following acoustic modifications were made to the open-plan office to determine the influence each type of acoustical solution would have on the room acoustics:

- Solution 1: Apply sound absorbing table-mounted screens with a height of 650mm
- Solution 2: Remove suspended baffles and apply a wall to wall ceiling with a sound absorption coefficient of 0.95 (Class A) and sound absorbing table mounted screens with a height of 650mm
- Solution 3: Remove suspended baffles and apply a wall to wall ceiling with a sound absorption coefficient of 0.95 (Class A) and reduce the table mounted sound absorbing screen height to 300mm

4. RESULTS DISCUSSION

4.1 CASE STUDY MEASUREMENT RESULTS

The in situ acoustic measurement results indicate that acoustic indicators for the open-plan office case study do not fully comply with the target values for either Space type 3 or 4 if all acoustic indicators under the target values are to be achieved. The recommended target values for in situ attenuation of speech between workstations, DA,S is only achieved for ML 1, 2 and 4 for Space type 4. The in situ attenuation of speech between workstations, DA,S is only achieved for ML 1, 2, 4 and 6 for space type 3. In situations where there are no screens or appropriate distance between workstations such as ML 3 and Ml 5, the target value of DA,S will not be achieved without incorporating a screen between the two workstations. The speech level at 4 meters, Lp,A,S,4m, is only achieved for measurement line 1 that complies with space type 3. Distraction distance target value <5 meters is easily obtained with the high background noise level of 51.8dBA generated by an electronic noise-masking system, HVAC and sporadic office noise. The in-situ and calibrated Odeon simulation results are shown in table 3.

Table 3: In situ and calibrated Odeon model results

In-situ acoustic measurement and calibrated Odeon model results

Parameters	ML 1	ML 2	ML 3	ML 4	ML 5	ML 6
(D2,S), dB in situ	2.73	2.96	4.85	6.97	3.24	2.56
	4.45[a]	1.31[a]	4.16[a]	6.53[a]	2.23[a]	2.30[a]
(Lp,A,S,4 m), dB In-situ	47.8	48.7	51.2	53.0	50.6	49.4
	49.2[a]	49.8[a]	52.8[a]	56.4[a]	54.1[a]	53.3[a]
(DA,S), dB in situ	8	6.4	-1	8.1	3.9	5.8
	5.4[a]	3.8[a]	-2.6[a]	4.1[a]	1.1[a]	2.1[a]
Reverberation in situ (at 125Hz)	1.09 0.94[a] (1.04) (0.88 [a])					
Workstation noise level (LAeq,T), dB (average)	51.8					
Distraction distance (metres) rD	*.**	*.**	1.14	*.**	*.**	*.**
	0.13[a]	*.**[a]	2.82[a]	2.07 [a]	0.35 [a]	*.**[a]
(a) Calibrated Odeon simulation results (*.**) negative value						

There is noticeable difference between the in situ measurements and the calibrated Odeon model which may be due to the actual positing of the suspended baffles, sound absorption coefficient of the room materials and objects in the real room which are not factored into the model.
The most surprising difference is the large deviation of the in situ attenuation of speech between workstations (DA, s) and modeling results. This would suggest that Odeon underestimates the attenuation between workstations when compared to in situ field measurement results that produced higher attenuation values.

4.2 SOLUTION 1

The simulation results indicate that the acoustic performance improvement is very small. It is not beneficial to use sound-absorbing table-mounted screens with a height of 650mm with the current ceiling design. Therefore, modification 1 cannot be considered a suitable solution for either space type 3 or 4 in terms of the target values. The simulation results for solution 1 are shown in Table 4.

Table 4: Solution 1

Modification 1: Apply sound absorbing table-mounted screens with a height of 650mm						
Parameters	ML 1	ML 2	ML 3	ML 4	ML 5	ML 6
D2,S	2.91	1.36	4.36	6.81	2.29	2.40
Lp,A,S,4 m	48.6	49.1	51.3	55.2	53.4	52.1
DA,S	6.2	4.5	-0.9	5.5	1.7	3.0
Reverberation (at 125Hz)	0.87 (0.93)					
rD	*.**	*.**	1.99	1.45	0.29	*.**
(*.**) negative value						

4.3 SOLUTION 2

The simulation results indicate that the acoustic performance improvement is significant. This suggests that a wall to wall ceiling with a sound absorption coefficient of 0.95 (Class A) and sound-absorbing table-mounted screens with a height of 650mm are required to achieve the target values for attenuation (Lp,A,S,4m) over the floor plate for ML 1, 2, 3, 5 and 6 that would comply with space types 3 and 4.
The D2,S result for ML 2 is significantly lower compared to the other measurement lines despite the low Lp,A,S,4m parameter. This suggests that the D2,S parameter, which is determined by the slope of a regression line of line-of-sight decay over distance, is significantly affected by the screening and the line of receivers chosen and must be determined with Lp,A,S,4m. The only measurement line that achieved the D2,S target value is ML 4, but the Lp,A,S,4m does not meet the target value. In this situation, DA,S may be more suitable to determine attenuation between workstation clusters when attenuation is high as ML 4.
In terms of attenuation between workstations (DA,S) only ML 1, 2, 4 and 6 meet the requirement for space type 4, but ML 5 will meet the requirement for space type 3.
Solution 2 can be considered suitable in terms of the acoustic indicators under the target values for both space type 3 and 4. However, the table mounted screens with a height of 650mm will make collaborative communication difficult due to the height of the screens. The simulation results for solution 2 are shown in Table 5.

Table 5: Solution 2

Modification 2: Remove suspended baffles and apply a wall to wall ceiling with a sound absorption coefficient of 0.95 (Class A) and sound absorbing table mounted screens with a height of 650mm						
Parameters	ML 1	ML 2	ML 3	ML 4	ML 5	ML 6
D2,S	5.75	1.65	5.27	8.99	4.54	5.07
Lp,A,S,4 m	46.6	42.9	46.3	52.6	47.0	45.1
DA,S	7.0	9.0	0.4	8.8	4.4	6.8
Reverberation (at 125Hz)	0.52 (0.53)					
rD	*.**	*.**	1.11	0.27	*.**	*.**
(*.**) negative value						

4.4 SOLUTION 3

The simulation results indicate that the acoustic performance of solution 3 will affect the acoustic performance of the space negatively by reducing the height of the sound-absorbing table-mounted screens to 300mm. Low desk-mounted screens have a significant effect on the acoustic parameter that describes attenuation over the floor plate and attenuation between workstations. The target values will not be achieved with low screens unless considerable distance is placed between workstations to achieve the DA,S target value.
Upon further analysis, reverberation time target values were achieved for both solutions 2 and 3.

Solution 3 cannot be considered a suitable solution in terms of the acoustic indicators under the target values for both space type 3 and 4. However, the table-mounted screens with a height of 300mm will make collaborative communication easier.
The simulation results for Solution 3 are shown in Table 6.

Table 6: Solution 3

Modification 3: Remove suspended baffles and apply a wall to wall ceiling with a sound absorption coefficient of 0.95 (Class A) and reduce the table mounted sound absorbing screen height to 300mm						
Parameters	ML 1	ML 2	ML 3	ML 4	ML 5	ML 6
D2,S	5.68	5.98	6.08	5.84	4.84	5.61
Lp,A,S,4 m	49.7	49.9	50.4	51.8	50.7	49.1
DA,S	2.8	4.1	0.2	8.8	2.9	2.7
Reverberation (at 125Hz)	0.51 (0.54)					
rD	1.73	1.38	2.36	*.**	2.37	1.65
(*.**) negative value						

5. CONCLUSIONS

The ISO 22955 holds a lot of potential for acousticians when prescribing acoustic design interventions for open offices. However, the only viable design option to achieve the acoustic target values for space types 3 and 4 is screens with appropriate height between workstations and a highly sound-absorbing ceiling. This may be in conflict with aesthetic aspirations of interior designers or the client's requirements which may have a direct impact on employees' workplace satisfaction where low screens between workstations are preferred by many for easy communication.
The acoustic modeling results confirmed that the required level for the open-plan office in terms of the ISO 22955 standard is only attainable with a combination of room acoustic variables that go against modern interior designs.

6. ACKNOWLEDGEMENTS

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